Commonwealth Government

REHABILITATION OF FORMER NUCLEAR TEST SITES AT EMU AND MARALINGA (AUSTRALIA) 2003

REPORT BY THE MARALINGA REHABILITATION TECHNICAL ADVISORY COMMITTEE

DEPARTMENT OF EDUCATION, SCIENCE AND TRAINING

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MARALINGA REHABILITATION TECHNICAL ADVISORY COMMITTEE

MARTAC

Secretariat,
P.O. Box 9880,
Canberra City,
ACT 2601

March 2003

The Hon. Peter McGauran, MP
Minister for Science
House of Representatives
Parliament House
CANBERRA ACT 2600

Dear Minister,

We have the honour to submit to you the report of the Maralinga Rehabilitation Technical Advisory Committee on rehabilitation of the former nuclear test sites at Maralinga and Emu in South Australia.

Yours sincerely,

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FOREWORD

Following agreement in March 1991 between the three stakeholders for the Maralinga Lands—Maralinga Tjarutja, the South Australian Government and the Commonwealth Government—on the preferred approach for the partial rehabilitation of the Maralinga lands, Cabinet funding was conditionally approved on the proviso that the British Government made a significant contribution to the cost of the project.

Late in 1991, Australia's claims were put to the British Government both at the Ministerial and technical levels. In June 1993 a UK ex-gratis offer amounting to £UK 20 million for settlement of Australia's claims against the British nuclear program in Australia was accepted. Formal Cabinet approval and project funding followed. The Maralinga Rehabilitation Technical Advisory Committee (MARTAC) and the Maralinga Consultative Group (MCG), with members drawn from the various stakeholders for the Maralinga lands, were formed shortly after approval of funding (see p. vii).

MARTAC first met in September 1993 and its final meeting was held in June 2001. This MARTAC report is structured into three broad components.

- *Chapters 1* and *2* set the scene for the project detailing site characteristics and emphasising those aspects that significantly influenced the nature of the contamination (e.g. soil particle size, wind and dust storm statistics, rainfall history), the safety of the remedial measures (e.g. geology and groundwater hydrology) and permanency of solutions (e.g. land systems and associated vegetation). These parameters also dictate the nature of an Aboriginal outstation lifestyle for which the rehabilitated lands are to be suitable.

  Chapter 1 also shows the extent and nature of the contamination at the start of the program and the detail of the UK testing program that had left this legacy.

  The first component concludes with an outline of the financial, administrative and organisational arrangements that allowed the project to be implemented on behalf of the Commonwealth.

- *Chapters 3* to *5* describe the work that was planned, how it was done, and its outcomes and occupational and public health consequences. They contain detailed comparisons between the corrective measures applied and the scope of work outlined in the option chosen by the stakeholders (Option 6[c] of the TAG report). This emphasis is a consequence of MARTAC's charter:

  ... the definition of engineering tasks to be undertaken to achieve the objectives encompassed in Technical Assessment Group rehabilitation option 6(c).

It also details the outcome achieved for each element of the rehabilitation program with emphasis on the quality assurance aspects that were intended to provide the confidence the stakeholders could have in the acceptability of the rehabilitated lands for their lifestyle[1].

- The third component (*Chapter 6*) deals with the future. It includes discussion of land and environment management issues that the new owners and occupiers of the Maralinga Lands must address, and experiences to be drawn from the project.

  Other plutonium contaminated sites elsewhere in the world will be cleaned up. MARTAC hopes that Australia's conduct of a successful, large-scale rehabilitation project will be an experience of benefit to others.

The report is layered with respect to detail and is intended to appeal to a wide range of readers. Within each subdivision of the text, lengthy technical detail appears as an appendix on the accompanying CD-ROM. These appendices were written and reviewed within MARTAC and constitute part of MARTAC's report. This separation means that inevitable duplications occur between the main body of the report and its accompanying appendices.

Poor British records impeded MARTAC from its first meeting to its last. To avoid a similar situation in the future, MARTAC therefore decided to bring together within the one structure all the final reports that were prepared by various contractors to detail the work they performed for the Maralinga rehabilitation program.

Although MARTAC may have commented on the scope of these independent and separate reports, they are the responsibility of the authoring organisation. To make the distinction clear, these reports are referred to as attachments. Attachments from the regulator (ARPANSA), the project manager (GHD), the primary health physics provider, (CH2M Hill) and the primary earthworks contractor (Thiess)[2] are included as are many other attachments that provide basic information about Maralinga and its rehabilitation. These attachments are also presented on the CD-ROM.

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[1] In its report, the TAG had used the term 'semi-traditional', where this report uses the term 'outstation lifestyle' throughout. Outstations have few amenities—no water supply or permanent buildings and few if any permanent services (health, communication, schooling, supply stores). Community behaviour is governed through a mixture of European trappings and cultural requirements. For this report, the characteristics of an outstation lifestyle are taken as those of Oak Valley residents in 1986/87 and reported by Palmer and Brady in their report to TAG (see *Glossary*).

[2] In practice, the Theiss report was subsumed into the Project Manager's report.

In a project of this size and complexity a vast amount of quantitative data is generally to be found in the attachments. For convenience, a summary of the analytical data, including the various measurements which lead to estimates of the plutonium inventory, is provided at *Attachment 4.11*.

The in situ vitrification (ISV) contractor, Geosafe, was given a copy of the draft MARTAC report for comment. Its comments are included verbatim as an attachment to the Annex to the main text, where MARTAC's review of Geosafe's comments is also presented. MARTAC has made changes to this report where warranted.

The full range of operations in the removal and burial of contaminated soil and the ISV works carried out during the rehabilitation project is also covered by a series of four videos, each of approximately 30 minutes duration. These videos are not part of MARTAC'S report but MARTAC commends them to interested readers. They are available from Maralinga Tjarutja, PO Box 435, Ceduna, SA 5690, Australia.

MARALINGA REHABILITATION TECHNICAL ADVISORY COMMITTEE

TERMS OF REFERENCE

(a) Advise the Minister for Primary Industries and Energy on strategies for implementation of the Government's preferred option for rehabilitation of the former British nuclear test sites in South Australia. In particular the committee will advise the Minister on:

- (i) definition of engineering tasks to be undertaken to achieve the objectives encompassed in Technical Assessment Group rehabilitation Option 6(c);
- (ii) studies required to ensure that, in meeting the objective of removal of existing potential radiological hazards, proposed rehabilitation works will not present unacceptable hazard to future generations or cause additional environmental detriment;
- (iii) measures, including specific operating criteria, which should be taken to ensure the work force of the rehabilitation project is protected from radiological and physical hazards and appropriate means of documenting these measures in order to minimise the prospect of future claims for personal injury against the Commonwealth Government;
- (iv) tasks which might practicably be undertaken by the Maralinga Tjarutja Aboriginal community.

(b) Advise the Minister on progress with the project, with a particular emphasis on the adequacy of measures to ensure radiological protection of the rehabilitation workforce.

(c) The Technical Advisory Committee will convene as necessary to advise the Minister on the matters referred to in (a) and (b) above and on matters referred by the Minister, providing an initial report to the Minister by 30 November 1993.

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The in situ vitrification contractor, Geosafe, offered comment on the draft MARTAC report. The annex contains MARTAC's response to Geosafe's comments and Geosafe's comments verbatim.

The annex for this report is contained on the CD at the back of this report.

APPENDICES

Appendices for this report are contained on the CD at the back of this report.

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ATTACHMENTS

Attachments for this report are contained on the CD at the back of this report.

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- 1.3 Technical Assessment Group (TAG) 1990, *Rehabilitation of former nuclear test sites in Australia*, Department of Primary Industries and Energy, Canberra
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ABBREVIATIONS

AAEC	Australian Atomic Energy Commission
ACS	Australian Construction Services
AEAT	AEA Technology (the Health Physics Manager)
AHC	Australian Heritage Commission
AIRAC	Australian Ionising Radiation Advisory Council
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
ALI	annual limit of intake
ANFO	ammonium nitrate fuel oil
ANSTO	Australian Nuclear Science and Technology Organisation
APS	Australian Protective Services
ARL	Australian Radiation Laboratory
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand
ARPANS	Australian Radiation Protection and Nuclear Safety
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
AWRE	Atomic Weapons Research Establishment
AWTSC	Atomic Weapons Tests Safety Committee
BPT	best practicable technology
CBH	Ceduna Bulk Hauliers
CEO	Chief Executive Officer
CMP	Conservation Management Plan
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAC	derived action concentration

DC/RB	decontamination and radiobiology
DNDE	Department of National Development and Energy
DPIE	Department of Primary Industries and Energy
DQO	data quality objectives
DSTO	Defence Science & Technology Organisation
EPA	Environment Protection Agency
ESV	*ex-situ* vitrification
FP	fission products
FTE	full-time equivalent (e.g. the number of FTE workers is the total project hours reported divided by 2000 hr/yr)
GHD	Gutteridge, Haskins and Davey
GPS	global positioning system
GTL	Geophysical Technology Limited
HCM	high cyclone mesh (fence)
HDPE	high density polyethylene
HEPA	high efficiency particulate air
HPRT	Health Physics Review Team
ICRP	International Commission of Radiological Protection
ISR	Department of Industry, Science and Resources
ISV	in situ vitrification
ITPs	inspection and test plans
LWC	lost workday case (using US definition)
MARTAC	Maralinga Rehabilitation Technical Advisory Committee
MCG	Maralinga Consultative Group
MDA	minimum detectable activity
MOWS	method of work statement

NAA	National Archives or Australia
NHMRC	National Health and Medical Research Council
NOI	notice of intention
OAT	Operational Acceptance Test
OECD	Organization of Economic Co-operation and Development
OHS	occupational health and safety
OPC	outer protective clothing
PAS	personal air sampling devices
PPE	personal protection equipment
ppm	parts per million
PWC	Parliamentary Standing Committee on Public Works (Public Works Committee)
QA	quality assurance
RC	Royal Commission
RDP	remedial design plan
RO	reverse osmosis
RSJ	reinforcing steel joist
RWP	radiological work permits
S_f	resuspension factor
SRB	soil-removal boundary
TAG	Technical Assessment Group
TLD	thermoluminescent dosimeters
TNT	trinitro toluene
TNU	Thermo NUtech Laboratory
TRC	total recordable case (using US definition)
UK	United Kingdom

UKAEA	United Kingdom Atomic Energy Authority
UKMOD	United Kingdom Ministry of Defence
UMTRA	Uranium Mill Tailings Remedial Action
USA	United States of America
USDOE	United States Department of Energy
VB	*Vixen B*
veh w/pd	vehicle accident with property damage only
WHO	World Health Organization
WP	work procedures

METRIC PREFIXES

10^{15}	peta (P)
10^{12}	tera (T)
10^{9}	giga (G)
10^{6}	mega (M)
10^{3}	kilo (k)
10^{2}	hecto (h)
10^{1}	deka (da)
10^{-1}	deci (d)
10^{-2}	centi (c)
10^{-3}	milli (m)
10^{-6}	micro (μ)
10^{-9}	nano (n)
10^{-12}	pico (p)
10^{-15}	femto (f)

ELEMENTS

Ac	actinium
Am	americium
Be	beryllium
Ce	cerium
Co	cobalt
Cs	caesium
Eu	europium
Nb	niobium
Pb	lead
Po	polonium
Pu	plutonium
Ra	radium
Sc	scandium
Sr	strontium
Th	thorium
U	uranium
Zr	zirconium

UNITS

A	amps
Bq	becquerel
g	gram
hr	hour
kBq	kilobecquerel (1000 Bq)
keV	1000 electron volts
kg	kilogram
km	kilometre
km^2	square kilometres
kT	kiloton
L	litre
m	metre
m^2	square metres
m^3	cubic metres
mg	milligram
mSv	millisievert
MW	megawatt
µg	microgram
µSv	microsievert
°C	degrees centigrade
s	second
Sv	sievert
t	tonne
TBq	terabecquerel (10^{12} Bq)
wt%	percent of component when expressed on a weight basis
yr	year

EXECUTIVE SUMMARY

INTRODUCTION

Between 1956 and 1963 the Maralinga Lands were used by Britain for the testing and development of nuclear weapons. The British made three attempts to clean-up Maralinga but only the last was intended to leave the site in a state where no further security control would be necessary. All were unsuccessful and, save for an approximate two-year period from 1974 to 1976, the area has been regularly patrolled by representatives of the Australian Federal Police stationed in the area.

The rehabilitation program reported here is the only Australian attempt at a clean-up of a nuclear test site. We, the Maralinga Rehabilitation Technical Advisory Committee (MARTAC), expect that it will be the last.

The program was completed on schedule and within budget although it was hampered by the limited and frequently incorrect UK records, including those that were heavily classified at the time. These poor records cost the project money and time. Detailed safety procedures that were rigidly enforced and thoroughly audited were developed for each facet of the operation. Plant modifications were implemented that catered for circumstances much worse than turned out to be the case.

The occupational health and safety (OHS) record for the project is presented in detail in the report and detailed by the Health Physics Provider in an attachment. No exposure reached as high as the action levels that were generally set at one-tenth of the regulatory limit.

THE REHABILITATION PROGRAM

The Maralinga legacy from the British had two components that required intervention. These were contaminated surface soils at Taranaki, TM100, TM101 and Wewak; and formal waste disposal pits at Taranaki, TM101 and the airfield cemetery. In all cases the contamination of concern was plutonium—mainly the isotope 239, and americium-241 (Am^{241}) that grows through radioactive decay from the plutonium isotope 241.

This contamination arose from the so-called minor trials (i.e. the development work on nuclear weapons carried out at Maralinga that is broadly described in historical documents as the ‘experimental program’).

Plutonium (Pu) was almost entirely the contaminant that determined the scope of the program. It is acknowledged as a very radiotoxic element if taken into the body, particularly by inhalation. A large literature on the health effects of plutonium exists.

The Kuli site, relatively close to Maralinga village, contained substantial amounts of natural and depleted uranium (U), still visible on the ground surface. While this did not present a radiological hazard, it could be chemically toxic, in particular for small children, and therefore also required rehabilitation.

None of the contamination of concern arose from the so-called major trials—the testing of nuclear weapons by evoking a nuclear detonation. Without the minor trials at Maralinga, the rehabilitation program would have been short and simple and akin to that which preceded the handing back of the Monte Bello Islands to West Australia so that they and the surrounding waters could be incorporated into a marine national park.

SURFACE LAND CONTAMINATED WITH PLUTONIUM

The contamination of the lands consisted of fine particulate of plutonium and fragments of paraffin wax, lead, light alloys and plastic with plutonium plated on them. The Technical Advisory Group's (TAG) Option 6(c) envisaged that the soil in those areas severely contaminated with plutonium that had been ploughed during the unsuccessful UK clean-up program, *Operation Brumby*, (approximately 1.5 km^2 at Taranaki, 29 ha at Wewak, and 46 ha at TM100/TM10) would be removed and disposed of in a purpose designed burial trench under 5 m of uncontaminated rock and soil cover.

The plant used for this operation were specially modified standard machines. Modifications included:

- strengthening and sealing of cabins;
- fitting of 'submarine' doors;
- high strength glazing;
- high efficiency particulate air (HEPA) filtering cabin and engine inlets; and
- stripping plant of unnecessary fittings.

The cabins operated at a continuous over-pressure and had warning alarms that activated if the cabin over-pressure dropped. The modified plant allowed most fieldwork to be conducted in a clean environment free of any requirement for personal protective equipment. This had two advantages:

- personal protection that was superior to and more consistent than that provided by respirators; and
- minimal hindrance to operations.

Other plant modifications allowed easier servicing by field staff and thereby mimimised exposure of personnel to radiological hazards. The design of the modifications was primarily a nuclear engineering exercise and worked exceptionally well. The cost was approximately $130 000 per plant item.

Soil collection was done using open bowl scrapers pushed by a rubber-tyred bulldozer. Rubber-tyred plant was preferred to tracked vehicles, as the latter had been found in US experience to push contamination deeper in the soil profile. Ultrasound depth detectors fitted to the scrapers monitored depth of scrape by the plant.

When rock outcrops limited the effectiveness of the scraper for the removal of contaminated soil, a modified street cleaner was used to brush and vacuum clean the rock surfaces and crevices within them. This worked quite effectively. A total of 200 000 m^2 was cleared in this way (6% of the total area cleared.)

MARTAC reassessed the boundaries for the soil removal. The reassessment was based on criteria that considered both the inhalation hazard resulting from fine particulate matter and the wound contamination risk that could result from the fragments. Criteria for the wound contamination exposure route were more demanding at many locations than were the criteria related to the inhalation pathway.

MARTAC criteria were:

- the average level of surface radioactive contamination over a hectare would not exceed a stated level of Am^{241};
- no particle or fragment exceeding 100 kBq Am^{241} would be present; and
- particles of activity greater than 20 kBq Am^{241} would not exceed a surface density of 0.1 per square metre.

The ‘stated level’ of Am^{241} varied from site to site. These changes were a consequence of the varying Pu:Am ratios at each of the sites as well as varying soil and re-suspension characteristics.

An important reason for the major difference between the soil removal requirements at Taranaki and other sites is that on completion of the project, the cleared lands at Taranaki remain surrounded by land restricted to hunting and transit for future use. In contrast the lands at the TMs and Wewak are now unrestricted.

Under Option 6(c), use of the lands within the Taranaki plumes was restricted to traditional hunting and transit. This hypothetical boundary was set to be equivalent to an annual dose limit of 5 mSv/yr under ultra-conservative assumptions that involved permanent residency at the boundary and with all activities being conducted at the boundary limit of surface contamination. Further, in a formal sense, this level of risk is only reached if daily activities are those of a ten-year-old child.

The actual boundary was located conservatively using a monitoring vehicle (the OKA) developed especially for Maralinga. The boundary encloses approximately 412 km^2 (in contrast to approximately 120 km^2 envisaged under Option 6[c]) of which the plume area represents about 26% (108 km^2). The conservative boundary corresponds to a reduced dose arising from the contamination of the order of 1 mSv for an individual living an outstation Aboriginal life style while permanently located on the boundary.

The Technical Advisory Group (TAG) had recommended a continuous single stranded wire fence around the boundary. MARTAC observed that such a fence would inhibit the remaining unrestricted use for the enclosure (i.e. hunting and transit). Accordingly, MARTAC changed the specification to one involving boundary markers (posts), with each marker bearing a warning sign approved by the indigenous land owners.

The locations of the disposal trenches were chosen following geological investigations. The cap design is the same for all trenches and is shaped for geomorphologic stability and low probability of ponding. Periodic inspection and engineering maintenance of these caps is a requirement built into the Maralinga Land and Environment Management Plan.

PLUTONIUM AND OTHER WASTES BURIED IN THE FORMAL DISPOSAL PITS AT TARANAKI

The other major item of the UK legacy was the plutonium and other contaminated wastes buried in shallow pits at Taranaki, TM101 and in the airfield cemetery.

The British numbered these pits and their locations were formally recorded. Estimates for the contamination level of the waste in these pit was supplied historically in the so-called ‘Pearce Report’ (Pearce 1968) which provided the technical basis for the Australian Government in 1968 to release the UK from any further liability for the Maralinga lands.

The UK information grossly underestimated the volume of these disposal pits.

Under Option 6(c), the intention was to deal with all formal disposal pits in the same manner and treat them with the ISV process while noting that it was in an early stage of development and that investigations into its applicability to the Maralinga situation were required. This straightforward approach by TAG was aided by the stated unit cost of the ISV treatment which was lower than alternative technologies such as grouting or excavation and reburial. These estimates for ISV proved to be substantial underestimates[3].

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3 With hindsight MARTAC believes that the cost estimates for the ISV process supplied to TAG were unit costs that excluded all but the ongoing operational costs. They may have also excluded energy costs.

ISV is a process developed by the US Department of Energy being commercially applied by Geosafe Corporation. Geosafe reports that the process involves electric joule heating to melt contaminated soil and/or other materials, to destroy, remove and/or immobilise toxic and radioactive contaminants. Typical melt temperatures of 1400–2000°C were to be developed by passage of up to 4 MW of electrical power into the soil in a pit from a square array of four graphite electrodes. Off-gases were to be removed by a steel containment hood spanning the area being processed, for treatment by filtration. On ceasing application of electrical power at the completion of the melt, the molten mass was intended to solidify into a vitreous/ceramic monolith with outstanding physical, chemical and weathering properties, typically five to ten times stronger than un-reinforced concrete. Potential individual melts were up to 7 m deep, 15 m in diameter and 1000 tonne in mass. The largest melt which had previously been produced was about 700 tonne.

ISV was used to treat 11 of the 21 pits at Taranaki. During the last melt an explosion within the developing melt severely damaged the ISV plant. As a consequence of this and many other factors related to uncertainties in outcomes for any further application of ISV, excavation and reburial of the remaining pits replaced continued ISV work.

As part of its quality assurance requirements, MARTAC arranged excavation and inspection of four of the pits treated with the ISV process. Following these inspections it was decided to excavate all the ISV melts and re-bury the excavated material. Consequently the ISV work played no part in determining the residual risk of the rehabilitated site.

During the excavation of the remaining pits, MARTAC had focused on the chemical analytical results for the ISV product for each of the treated pits. With the assumption that UK records were correct, these data combined with the tally of material excavated from the outer pits allowed MARTAC to assess whether there was a substantial discrepancy in any of the waste components relative to that expected from the materials used in constructing the facilities for the Taranaki development trials. This comparison made it obvious that there was a shortfall in the amount of lead accounted for.

The shortfall difference did not lie in the amount of lead vapourised and exhaled from the melt during the ISV process since, in one case (pit 18), an analysis of the particulate in the filter to the ISV hood gas off-stream could account for only about 20% of the lead retained in the melt and this was only a small fraction of the total quantity of lead believed to be involved.

A metal detector showed that large amounts of lead—an estimated nine tonnes—had migrated downwards and outwards by between 1 and 2 m through cracks and interstices in the surrounding rock during the ISV process. Although not itself meaningfully contaminated, it may have served as a transport medium for plutonium on its surface, as some plutonium was also found immediately below the pit bases.

OTHER FORMAL DISPOSAL PITS

TM101

The burial pit at TM101 (Tietken's Plain Cemetery) was claimed to contain drums of bitumen that was heavily contaminated with plutonium. For this reason MARTAC questioned the applicability of the ISV technology to this pit. As the plutonium content of all pits in the TM101 area was expected to be less than 100 g, excavation and reburial under 5 m of clean fill (in contrast to the reliance on a concrete cap) was a safe and economic option.

AIRFIELD CEMETERY

Existing arrangements at the airfield cemetery were unacceptable when judged against current world practice.

- The depth of clean soil cover was inadequate. Here as elsewhere, concrete caps had been relied on to provide isolation (e.g. of the 25 highest level disposals, none had 5 m of cover and only four had more than 2 m of cover).
- The area contained waste of unstated quantity and nature that had originated from University of Adelaide.
- Within the low level category of wastes, three containers had burial records that were ambiguous with respect to the amount of plutonium they contained. Circumstantial evidence favoured the quantity being based on the stated activity (equivalent to 3 mg) rather than the stated mass (3 g) but this uncertainty required the offending containers to be excavated and relocated.

In the event, all the 'high' level and 'medium' level wastes and the low level waste pit containing the above drums were excavated and transported to the forward area and re-buried under 5 m of cover in the ISV trench.

THE DISPOSAL TRENCHES

Taranaki soil burial trench

The Taranaki soil burial trench is marked by a concrete plinth in the most southerly corner of the trench. The other three corners of the trench are marked with metal signposts. These burial-trench warning signs contain information about the contents of the trench and the time of burial, and warnings regarding digging in that area. The Taranaki soil burial trench was 206 m x 141 m (at grade level) and 15 m deep.

TM100/101 soil burial trench

This trench is marked by a plinth on the southerly corner of the trench and metal signposts at the other corners. Soil was removed at TM100/101 and placed at least 3 m below the surface in a burial trench 130 m x 87 m (at grade level) and 16 m deep. The soil was then covered by 5 m of clean fill. The waste exhumed from the three waste disposal pits at TM101 is also buried at the bottom of this trench.

Wewak soil burial trench

The Wewak trench contains the contaminated soil from the lots in the Wewak soil removal area as well as the contents of the concrete firing pads designated in British documents as pits 20 and 21. This contamination was placed at least 3 m below the ground's surface in a burial trench 113 m x 90 m (at grade level) that was 11 m deep and covered by 5 m of clean fill.

Pit debris burial trench

The pit debris burial trench is the trench established in 1999 for the disposal of the debris from Taranaki formal disposal pits and the vitrified pit melts. This trench contains the exhumed outer Taranaki pits and the melts of most of the inner Taranaki pits. Its dimensions and design are detailed in *Chapter 4*. The trench contents are covered with uncontaminated rock and soil cover of a minimum depth of 5 m. It is marked by a concrete plinth in the southerly corner of the trench and by three metal signposts at each of the other corners. Figure 6.13 shows the longitudinal cross section of this trench and where each class of waste was deposited. All excavated steel, debris and soil lies between 8 m and 14 m below grade. The un-melted steel masses from the ISV exhumations is at 6 m to 8 m below grade and the boulders of the ISV melt material are placed to serve as a stark indicator of a man-made environment. Similar warning devices are provided by the orange plastic sheeting that covers the full area of the trench just below ground level and black plastic sheet covering immediately above the blast walls and steelwork debris. The top waste item is the ISV melt material and is covered by a minimum of 5 m of clean fill.

ISV burial trench

During operations of the ISV plant, it was necessary to dispose of contaminated material that was generated during operations. These materials consisted of used electrodes, filters contaminated with hundreds of kilograms of lead oxide powder along with a milligram or so of plutonium, and other operational waste generated during the treatment of the Taranaki formal disposal pits. The ISV burial trench was in use from 1997 to 2000. It is marked similarly to the Taranaki soil burial trench with a concrete plinth in the southerly corner of the trench and with metal warning signs at each other corner. In practice, the trench was also used for other disposals, such as wastes from the airfield cemetery.

OTHER REMEDIAL MEASURES

Kuli

Kuli differed from all other sites in that the potential problem was not radiological but chemical. The contaminant was uranium (without its longer-lived daughter products such as radium). The uranium was present as surface contamination, generally as large fragments which were slowly corroding. The concern was that these corrosion products would be soluble in gut fluids and that their bright yellow colouring might be attractive to crawling infants.

The rehabilitation of Kuli involved:

- an intensive ‘seek and collect’ emu parade; then
- stripping and burying of surface soil where the fragment density was too great for a successful scavenging operation; and
- site classification for land use restrictions and placement of warning markers around the area.

The hand scavenging yielded approximately 50 kg of uranium fragments and a total of 1000 m^3 of surface soil was stripped from the most contaminated area. The boundary markers were placed on a contour equivalent to a surface uranium concentration of 5 kBq/m^2—a level about five times higher than natural background levels from typical soils from around Australia.

Informal disposal pits

Throughout the Maralinga lands the UK opened a large number of rubbish pits. No records were kept of their locations or contents. At the last count 74 of these informal pits had been found and their locations recorded. A random back-hoeing of part of the contents had revealed a few that contained low levels of radioactivity. This radioactivity was secondary in nature (e.g. an instrument dial face, a vacuum cleaner bag containing some plutonium contamination and a trailer, the bottom of which showed plutonium contamination).

MARTAC concluded that even deliberate intrusion of these pits would not carry a risk unacceptable for those circumstances and examined each of these pits in turn for an appropriate surface stabilisation and revegetation treatment after removal of any visible debris.

Periodic inspection of these informal pits is built into the *Maralinga Land and Environment Management Plan*.

PROJECT ORGANISATION

Early in 1994 a project manager was appointed to oversee the establishment of site infrastructure and to manage all rehabilitation activities apart from those of the ISV Contractor, who held a separate contract during the developmental phase of the ISV process. This changed in 1998, once the ISV program moved to the treatment of the formal pits at Taranaki and all site activities fell within the responsibility of the Project Manager (GHD). This covered:

- oversight of soil removal and disposal;
- treatment of formal and informal pits;
- control and management of radiation protection and general OHS;
- revegetation of disturbed areas;
- general remediation of hazards in the village; and
- final decommissioning at the end of the project.

During the period from Cabinet's final approval of the project and its budget (August 1993) to the submission for the Parliamentary Standing Committee on Public Works (PWC), the Department undertook the necessary procedural steps with the Commonwealth Environment Protection Agency (EPA) and with the Australian Heritage Commission.

The report includes initial budget estimates put to the PWC and a summary of actual expenditure. It should be noted that half the Taranaki pits were treated with ISV and that ultimately all Taranaki pits (i.e. treated and untreated) were excavated and re-buried under a minimum of 5 m of clean fill.

With so much of the rehabilitation program involving earthworks it was apparent that all stakeholders would have to be party to the final plan to manage the residual risks at the site, and that a formal long-term Maralinga land and environment management plan for the site would be required.

The MARTAC summary recommendations regarding the plan were to:

- perform a risk assessment of the final condition of the site;
- identify from the risk assessment the risks that require long-term management via a land and environment management plan;
- jointly prepare an agreement of roles and responsibilities for the execution of the plan;
- create an oversight group that would track the execution of the plan and, with an agreed mechanism, resolve issues that may arise subsequent to handover; and

- ensure that there is a mechanism to allow the Commonwealth Department responsible for management of radioactive wastes to request additional funds for unforeseen problems arising at the site.

The basic principles of the *Maralinga Land and Environment Management Plan* are to ensure through agreements among the stakeholders that appropriate systems are put in place to maintain the security of the buried radioactive materials and maintain the land-use restrictions at Maralinga for the ongoing protection of people and the environment.

MARTAC considered that the following objectives were essential portions of the *Maralinga Land and Environment Management Plan*:

- to ensure that no changes occur in the containment of the radioactive materials that would increase the level of risk to current and future generations above that existing at the time of completion of the rehabilitation;
- to ensure that any exposures or discoveries of potentially contaminated materials are reported to an appropriate authority for investigation and action;
- to ensure that the area is managed in a manner which is consistent with not disturbing the contained contaminants and that land use restrictions are adhered to;
- to ensure that the records on the final disposal of all contaminated materials are stored for long-term preservation and are readily retrievable; and
- to ensure that the historical record of events and structures of the testing period and subsequent rehabilitation programs are maintained indefinitely.

The plan developed by the stakeholders contains sub-plans that address:

- institutional management;
- records management;
- site monitoring;
- radiological safety standards;
- conservation management;
- revegetation;
- auditing; and
- contingency planning.

Risk assessments of the final condition of the site are to be found as attachments to *Chapter 6*. The *Maralinga Land and Environment Management Plan* is available from the Commonwealth or South Australian governments.

Under its terms of reference MARTAC's role on risk assessment was to put in place a scope of works, and to achieve outcomes that led to a degree of risk that fell comfortably within the risk limit for the stated lifestyle and assumed administrative control as was postulated in Option 6(c) and accepted by the stakeholders. MARTAC has done this and *Chapter 3* contains the outline of argument that led it to the conclusion that the rehabilitation program as implemented has achieved its objectives.

The rehabilitation program has been achieved within budget and on schedule.

REFERENCES

Pearce, N 1968, *Final report on residual radioactive contamination of the Maralinga Range and the Emu site*, AWRE Report No. 0-16/68, United Kingdom Atomic Energy Authority.

CHAPTER 1

BACKGROUND TO CLEAN-UP

1.1 INTRODUCTION TO THE TEST SITE AND THE BRITISH TESTING PROGRAM

1.1.1 LOCATION, OWNERSHIP AND GENERAL ENVIRONMENT OF THE FORMER TEST SITES

The following is a brief overview of the location, ownership and general environment of the former test sites. Further detail is given in *Appendix 1.1*.

1.1.1.1 Location

The former nuclear weapon test sites at Maralinga and Emu are located in the State of South Australia within the confines of the Great Victoria Desert—north of the Nullarbor Plain (see Figure 1.1). Maralinga is 300 km north-west of Ceduna. Emu is approximately 200 km north-east of Maralinga. The nearest Aboriginal settlement to Maralinga is the Oak Valley settlement, located approximately 140 km north-west of the Maralinga village. Oak Valley was established in 1984 (Cane 1992).

1.1.1.2 Ownership of lands

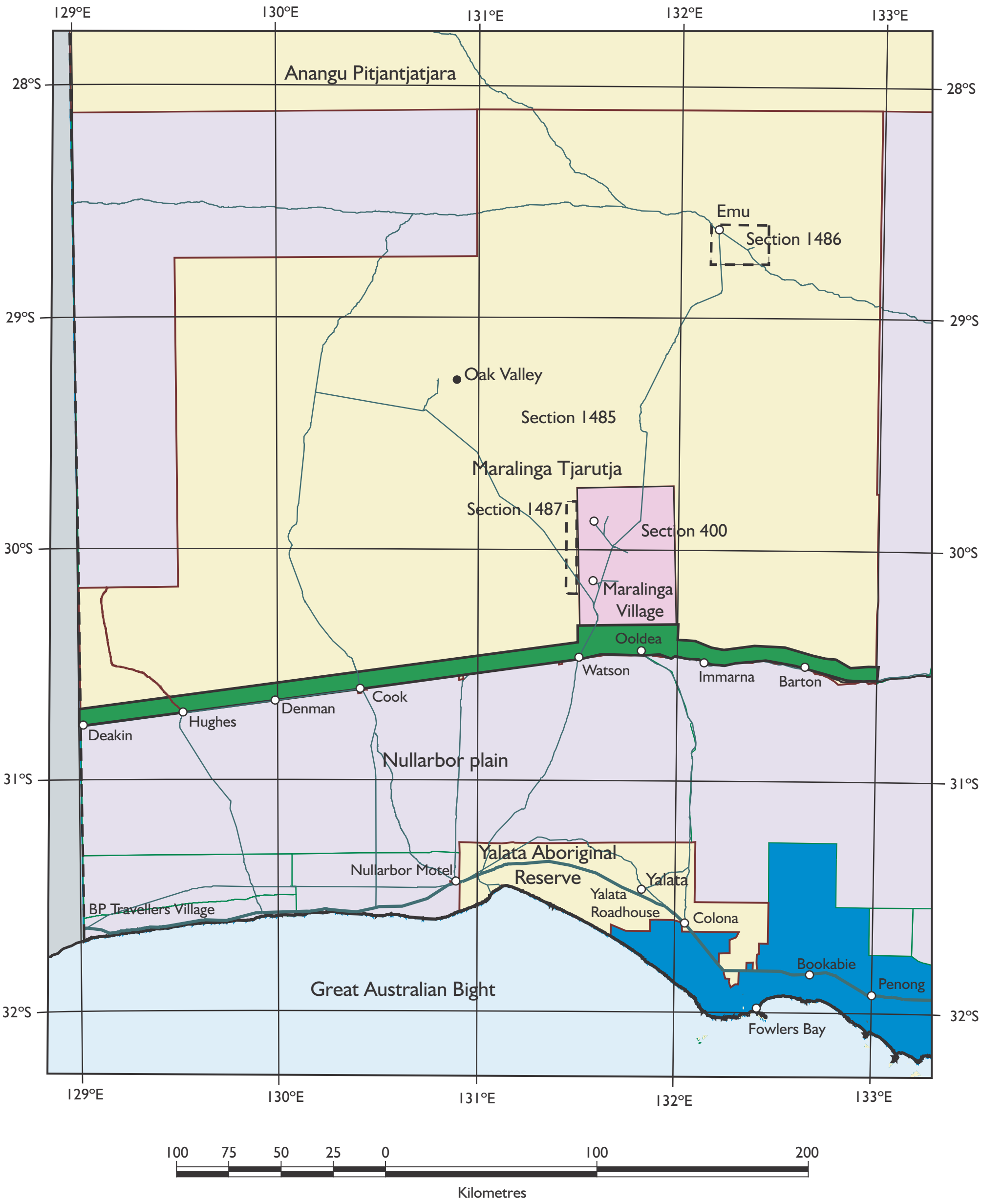
There are sites which provide evidence of the occupation and use of the Maralinga-Emu lands by indigenous Australians at times that probably predate the arrival of the ancestors to the current traditional owners.

Use of the lands by the traditional owners is well documented in papers published by ethnographers in the early 1940s and Palmer and Brady (1988) reproduce a series of maps from these earlier reports that shows migratory movements and the dreaming tracks along which ancestral figures are believed to have travelled and left their mark on the landscape.

The earliest contact with Europeans occurred during E Giles' first and second expeditions (1872–1874) but with some animosity in these encounters. WH Tietkens was an assistant to Giles during these expeditions (McLaren 1996). Tietkens later attempted, under commission, to establish a pastoral property on the Maralinga lands.

Regular contact between community members and Europeans developed with the construction of the transcontinental railway line from 1912. Daisy Bates established herself with missionary zeal at Ooldea in 1919 having been working with Aboriginals since 1905. Bates used her private moneys to supply flour and sugar to the community at Ooldea whose numbers had expanded greatly as a result of the severe 1914–1915 drought in central Australia. Daisy Bates' work was to an extent supplanted by the establishment of the Ooldea Mission from 1933 (Blackburn 1994).

Figure 1.1 Location map showing region (locality map).



Several of the current elders recall how they did a seven-day return trek to Ooldea for flour and sugar from their traditional homelands by following the kapi (water) route that included Piling Rockhole[4]. Photographs of Daisy Bates with the father of a current elder appear in her book *The Passing of the Aborigines*.

The mission at Ooldea closed in 1952. The closure was unrelated to the British nuclear weapon program although by this time (June) decisions had been taken to seek a test site in the northern region of South Australia. There are differences of opinion on how much choice the inhabitants of Ooldea were given on their future location after the closing of the mission (Royal Commission into British Nuclear Tests in Australia 1985) but the end result was their transportation to Yalata. The Royal Commission report sums up this result with the words:

> *The understandably confused people gave in to MacDougall's mixture of persuasion, cajolery and orders and allowed themselves to be transported to Colona and eventually Yalata.*

For the traditional owners, the Maralinga-Emu lands remained essentially forbidden country from 1952 to 1981.

In 1984, the State Government of South Australia made a grant of the lands surrounding Section 400, excluding Sections 1486 (approximately 510 km^2) and 1487 (approximately 200 km^2), to Maralinga Tjarutja[5]. The reason why these two sections were not handed back to Maralinga Tjarutja at the time was because of uncertainty about the potential radiological hazards that existed within them (see Figures 1.1 and 1.2).

In March 1998, after a program of minor works carried out at Sections 1486 and 1487 as part of the recently completed Maralinga Rehabilitation Project (see *Chapter 3* of this report), the State Government of South Australia transferred ownership of Sections 1486 and 1487 to Maralinga Tjarutja.

At the time of writing of this Maralinga Rehabilitation Technical Advisory Committee (MARTAC) report, Section 400 is Commonwealth land. It is MARTAC's understanding that ownership of Section 400 will be transferred to the South Australian Government, who will subsequently transfer ownership to Maralinga Tjarutja.

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[4] Piling Rockhole is sometimes referred to Paling Rockhole or Waterhole.

[5] The statutory land holding body created under Section 4 of the *Maralinga Lands Right Act 1984* (SA).

Figure 1.2 Location map showing land sections (2000).

1.1.1.3 Physiography

Maralinga

The most prominent features of the Great Victoria Desert in the Maralinga region are the sand dunes of the Ooldea Range that rises to 300 m altitude. Maralinga village lies on the crest of the range, and the minor trials sites at Kuli, TM50 and Dobo lie in sandhills of adjacent ranges, in open woodland vegetation.

Some 40 km to the north of Maralinga village, lies the sparsely vegetated, undulating, karstic limestone surface of Tietkens Plain, at an altitude of approximately 200 m.

The seven major nuclear weapons tests at the Maralinga Test Range (see Table 1.1 in *Section 1.1.2.1*) were conducted on Tietkens Plain, as were the minor trials at Taranaki, Wewak, and TM 100 and 101 (see Table 1.2 in *Section 1.1.2.2*).

Emu

The Emu test sites lay 200 km north-north-east of Maralinga village. Tests at Emu were comprised principally of the two *Totem* nuclear weapons tests in 1953. The region lies on a plain above which rise low mesas. The plain is overprinted by the widely separated sand dunes of the Great Victoria Desert. The vicinity of the Emu test sites is sparsely vegetated with low open woodland.

The major physiographic features are shown in Figure 1.3.

1.1.1.4 Climate

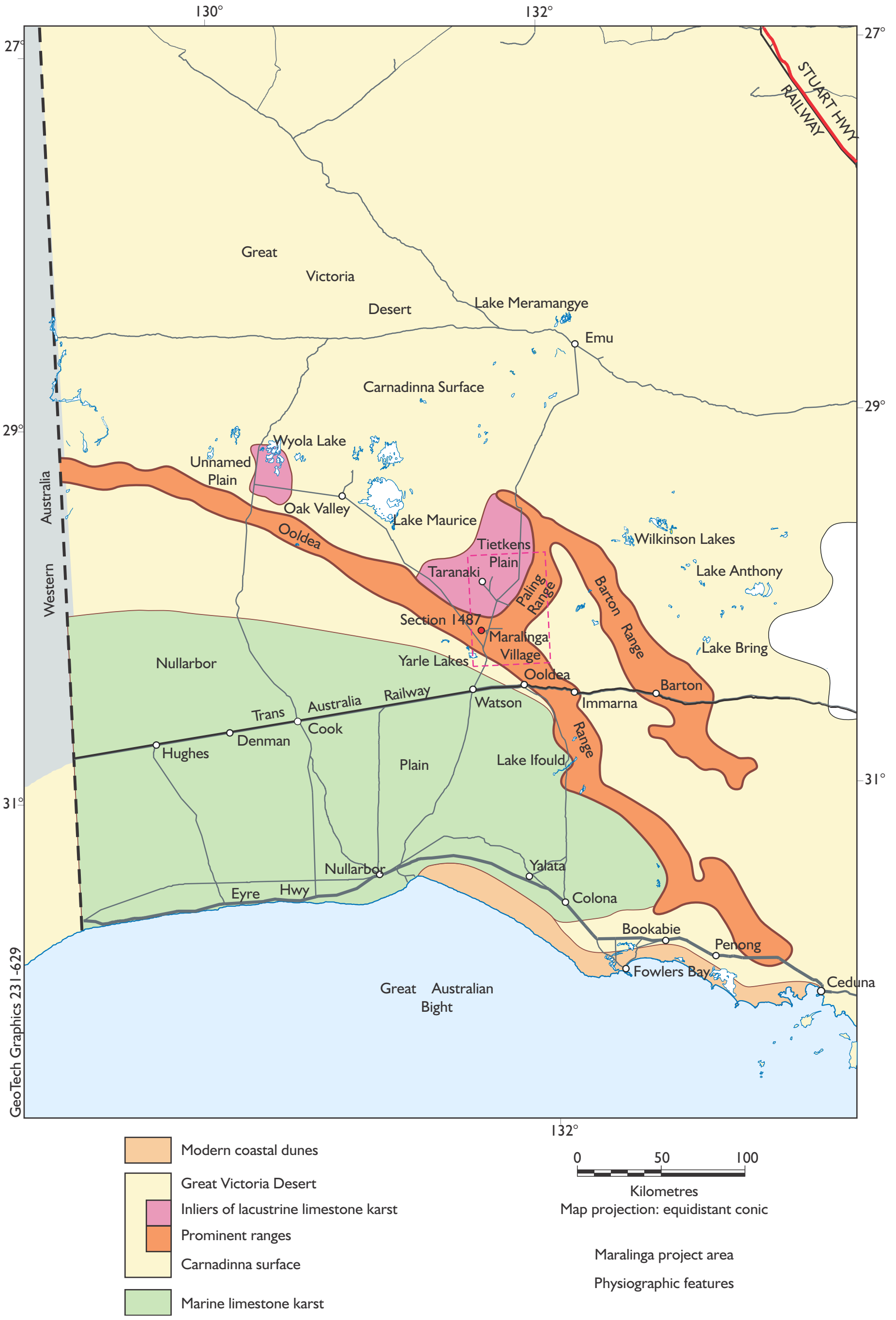
Maralinga is typical of semi-arid Australia, receiving on average, approximately 200 mm of rainfall per year, in a range of less than 100 mm to more than 400 mm.

The climate ranges from cool winters with overnight dews and frosts, to hot summers where day temperatures in excess of 40°C are common.

The annual total sunshine hours are approximately 3250 hours in the Maralinga area. Mean annual evaporation is extremely high, ranging from 3000 mm to 3600 mm.

Winds at Maralinga are generally light to moderate. In the period 1957 to 1966 the number of recorded days of ‘dust haze’, ‘local dust’ and ‘dust storm’ were respectively 18, 15 and 12 days. Wind gusts during the 12 days recording ‘dust storms’ ranged from 25 m/s to 35 m/s (90 km/h to 125 km/h).

Figure 1.3 Physiographic features of western South Australia.



1.1.2 OVERVIEW OF BRITISH TESTING PROGRAM

In mid-1951, the Australian Prime Minister accepted a British proposal to conduct nuclear weapons testing in Australia (Symonds 1985). The UK had experienced problems with determining a site for testing its newly developed devices. It wanted to carry out a test in 1952 but would have preferred to use the already developed sites in the US, since both equipment and infrastructure would have been available. However, the US remained evasive in providing a final answer and the British were forced to seek an alternative in Australia, should the US remain uncooperative. In the event, the US did remain negative and the Australian option as a test site for nuclear weapons testing came to the fore.

The first test, supported by British naval resources, was conducted at the Monte Bello Islands in 1952 but subsequent tests were transferred, mainly for logistical reasons, initially to Emu on the mainland, then briefly back to the Monte Bello Islands, and finally to Maralinga.

The tests which fall within the ambit of this report were those conducted at Maralinga and Emu. Figures 1.4 and 1.5 show the locations of the major and minor trials carried out.

Figure 1.4 Location map showing major and minor trial sites at Emu (based on information in Pearce 1968).

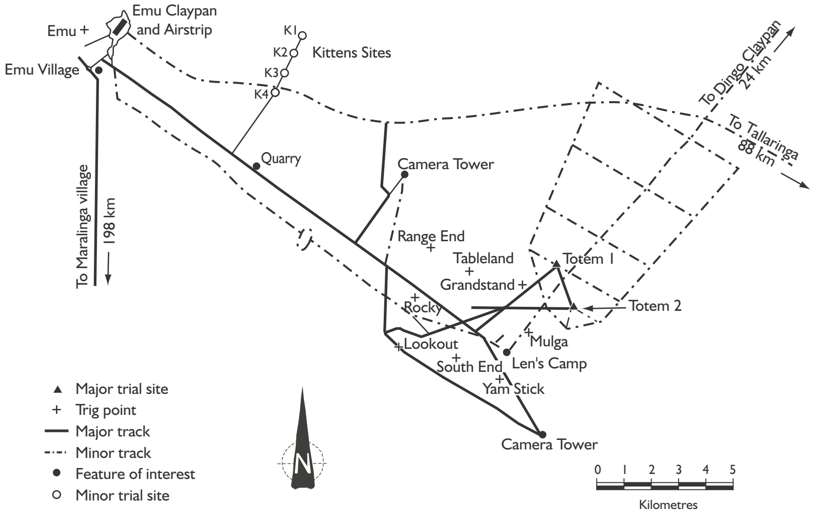
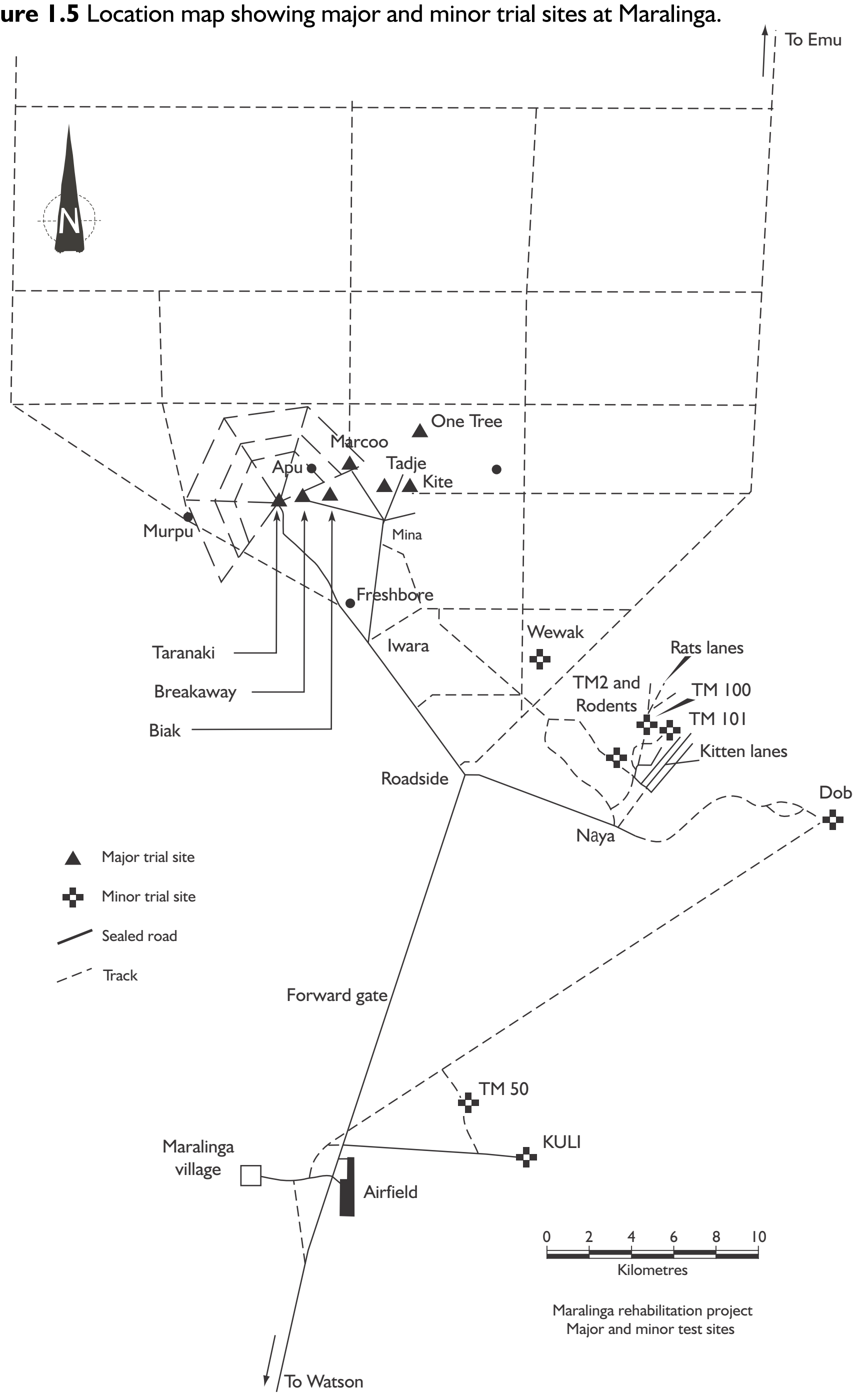


Figure 1.5 Location map showing major and minor trial sites at Maralinga.



1.1.2.1 Major trials

Between 1953 and 1957, the British conducted a program of nine nuclear weapon tests involving atomic explosions at Maralinga and Emu (Table 1.1).

In 1953, the first two tests (*Totems 1* and *2*) were carried out at Emu. The next series of trials took place at Maralinga in 1956, when four major trials, code named *One Tree, Marcoo, Kite* and *Breakaway*, were carried out in *Operation Buffalo*. In 1957, the final three major tests at Maralinga, code named *Tadje, Biak* and *Taranaki*, were carried out in *Operation Antler*.

The smallest of the trials were *Tadje* and *Marcoo* (each of approximately 1 kT yield), and the largest of the trials was *Taranaki* (approximately 27 kT yield). Most of the nuclear devices at Maralinga were exploded on 30 m towers, with the exception of *Marcoo* (at ground level), *Kite* (at an airdrop at 150 m) and *Taranaki* (balloon borne at 300 m).

1.1.2.2 Minor trials

In addition to the major trials, the British carried out minor trials at Emu in 1953 and at Maralinga between 1955 and 1963. Although the minor trials did not involve nuclear explosions, the *Vixen B* trials at Taranaki involved a limited number of fissions. The equivalent nuclear yields of these trials ranged from 0 to 300 g of TNT, with an average of approximately 3 g of TNT.

The minor trials were essentially developmental experiments designed to investigate the performance of various components of a nuclear device, both separately and in combination. Almost all involved radioactive materials in conjunction with conventional high explosives. In all, the British carried out five series of minor trials

Table 1.1 Summary of the major weapons tests at Emu and Maralinga (*Attachment 1.3*, Table 2).

Year	Code name of major trial series	Site of test	Yield (as kilotons of TNT)	Position
1953	Totem	Emu:		
		Totem 1	10	30 m steel tower
		Totem 2	8	30 m steel tower
1956	Buffalo	Maralinga:		
		One Tree	15	30 m aluminium tower at
		Marcoo	1.5	ground level
		Kite	3	150 m air burst (free fall)
		Breakaway	10	30 m aluminium tower
1957	Antler	Maralinga:		
		Tadje	1	30 m aluminium tower
		Biak	6	30 m aluminium tower
		Taranaki	27	300 m airburst (balloon)

at Emu and Maralinga. Table 1.2 summarises the five series of minor trials. The locations of the minor trial sites are shown on Figures 1.4 and 1.5.

The first series of minor trials involved the testing of initiating devices for nuclear weapons and was code-named *Kittens.* The first five tests in the series occurred at Emu in 1953 and produced substantial amounts of short-lived radioactive fallout in the surrounding bush. The *Kittens* trials were continued at Maralinga between 1955 and 1961 in an area called the Kittens Lanes.

The *Tims* series of tests investigated the flow and compression of materials and took place at Maralinga (at Kuli, TM2, TM50, TM100 and TM101) every year between 1957 and 1963 (with the exception of 1962).

The *Rats* weapons development trials were similar to *Tims* except that measurements were taken using sources within instead of outside the devices. The *Rats* tests took place between 1956 and 1960 on the Rats Lanes north of TM100 and at Dobo.

The *Kittens, Rats* and *Tims* trials caused radiologically significant contamination, but by short-lived materials only at *Kittens* and *Rats* sites. The *Vixen* trials (performed at Wewak and Taranaki) were potentially the most dangerous held at Maralinga because of the amount of high explosive detonated and the scattering of radioactive plutonium.

In particular, the *Vixen B* series of 12 trials dispersed 22 kg of plutonium explosively from Taranaki. The trials were described as a series of safety experiments that were undertaken to ensure that nuclear weapons could not be accidentally triggered to produce a nuclear explosion while in storage or in transit. There were also three

Table 1.2 Summary of the minor trials carried out at Maralinga and Emu (entries refer to the Maralinga site except where noted).

Code name of minor trials series	**Characteristics (see Symonds 1985)**
Kittens	Neutron initiator development trials carried out between 1955 and 1961. These experiments involved the use of polonium-210 (Po^{210}) and beryllium. A series of *Kitten* trials was conducted at Emu in 1953.
Tims	Fissile material compression tests (some plutonium but generally with natural or depleted uranium used in place of fissile material). Extensive multiple series spanning 1955–1961 and 1963, involving predominantly uranium and beryllium.
Rats	Fissile material compression tests. Involved uranium and intense gamma sources.
Vixen A	Burning trials on rods of plutonium, uranium and beryllium. Conducted during 1959—minimal combustion and dispersion (VK33). Four explosive dispersions involving plutonium in 1961 (VK60A and VK 60C).
Vixen B	Safety/development trials to determine the characteristics of nuclear warheads. Three series, in 1960, 1961 and 1963. Detonations with emphasis on measurement of nuclear characteristics.

calibration rounds fired in the *Vixen B* series but these did not involve the use of plutonium.

Table 1.3 shows the relationship between the locations and sub-locations of some of the Maralinga trial sites that are mentioned in the text. It should be noted that consecutive numbers were used neither to codify the TM and VK locations, nor their sequence of detonation.

Estimates of radioactive and toxic materials used at the minor trial sites are given in Table 1.4 (amounts are variously reported as either a mass in kilograms, or as an activity in becquerels). Where MARTAC understands amounts of particular radioisotopes to be insignificant, gaps are left in the table. Although not a radioactive element, beryllium is included in this table because it is known to be an inhalation hazard that can lead to the lung disease ‘berylliosis’.

A full list of radionuclides and their half-lives, mentioned in this report, is provided in *Appendix 1.2*. For a discussion of the contamination arising from the minor trials see *Section 1.1.4.2* and *Chapter 3*.

1.1.3 EARLY ATTEMPTS TO CLEAN UP THE SITE AND RESPONSIBILITIES HELD

At the end of experiments in 1963, the test sites were placed on a care and maintenance basis. By this time, the test sites were contaminated with a variety of radioactive and hazardous materials.

1.1.3.1 British attempts at cleaning up the sites

The British conducted several campaigns to clean up the radioactive contamination at Maralinga and Emu, the most recent and significant of which was *Operation Brumby* in mid-1967. Clean-ups included:

- *Operation Clean-up* (1963);
- *Operation Hercules* (1964); and
- *Operation Brumby* (1967).

Operations Clean-up and Hercules

The early clean-up programs of 1963 (*Operation Clean-up*) and 1964 (*Operation Hercules*) had the single objective of removing major hazards so that entry to the areas, within the sense of a military operation, could be made without direct health physics supervision.

Operation Brumby

Later, in 1966, a site survey (*Operation Radsur*) was carried out with the goal of better defining the prevailing levels of contamination and exposure rates. This led to a final program of clean-up works (*Operation Brumby* in mid-1967). The clean-up criteria

Table 1.3 Relationship between location and sub-location names at Maralinga.

Code name of minor trial series	Location	Sub-location
Kittens	Naya 2	Kitten Lanes
	Naya 3	Special Kitten
Tims	TM100	
	TM101	
	Kuli	TM11, TM16, TM4, TM12, TM5
	TM50	
Rats	Dobo	
	Naya 1	Rats Lanes
	Naya 3	Rodents
Vixen A (fire – burning trials)	Wewak	VK33
Vixen A (explosive – dispersion trials)		VK60A, VK60C
Vixen B (VB1 to *VB3)*	Taranaki	

Table 1.4 Rounded estimates of radioactive and toxic materials used in the minor trials.

Code name of minor trial series	Location				Material			
		Pu^{239}	U^{238} or natural	Po^{210}	Sc^{46}	Pb^{212}	Ac^{227}	Be
		(kg)	(kg)	(TBq)	(TBq)	(TBq)	(MBq)	(kg)
Kittens	Naya 2	–	120[C]	210[C]	–	–	–	0.75[C]
Tims	TM100/101	1.2[A]	172[C]	–	–	–	–	–
	Kuli	–	7400[A]	–	–	–	–	>28[A]
		–	7700[C]	–	–	–	–	70[C]
	TM50	–	90[A]	–	–	–	–	9[A]
		–	–	–	–	–	–	10[B]
Rats	Dobo	–	26[A]	–	3.7[C]	4.4[C]	–	–
		–	28[C]	–	–	–	–	–
	Naya 1	–	150[A]	15[A]	75[C]	–	–	–
		–	170[C]	–	–	–	–	–
Vixen A – fire	Wewak	0.41[A]	40[C] 4.8[D]	–	–	–	–	4.5[D]
Vixen A – explosion		0.57[A]	>17[C]	–	–	–	5[C]	3.5[C]
Vixen B	Taranaki	22[A]	22[C]	–	–	–	–	18[C]
		–	#[C]	–	–	–	–	–

\# 24 kilograms of enriched uranium also used.

A Schofield 1985.

B Carter 1985.

C Cornish 1986.

D Stewart 1960.

developed to guide *Operation Brumby* considered a scenario in which future pastoral land use at the sites was envisaged. Under this scenario, inhalation hazards to stockmen were considered. The chosen parameter values were ‘cautious best estimates’ and included an assumed occupancy factor.

Operation Brumby did not address plutonium contamination on fragments, and it assumed that ploughing and other soil mixing techniques would reduce all the radiological hazards. The program made no allowance for the subsidence of burial and debris pits, and it assumed rapid natural revegetation of the areas. It was assumed that within a matter of years, it would not be possible to identify areas impacted by the tests from those that were not. This has not proven to be the case. A description of the state of the sites after *Operation Brumby* is given in a 1968 British Atomic Weapons Research Establishment (Pearce) Report (report no. 016/68, Pearce 1968). This report is often referred to as the ‘Pearce Report’.

According to Pearce (1968), *Operation Brumby* included the:

- removal of general debris and glazing;
- ploughing of soil and grading around the areas of the major trial ground zeros;
- ploughing of soil to a depth of 100 mm in the minor trial areas of Taranaki, Wewak, TM100, and TM101 (dispersing the plutonium through the top few centimetres of surface soil);

Figure 1.6 A well near Taranaki, dug by Tietkens in 1879.

- covering of localised, more highly contaminated areas at Taranaki with 75 mm of clean soil;
- removal of highly contaminated soil from Wewak for subsequent burial in the *Marcoo* Crater; and
- capping of debris pits at Taranaki, TMs, and at the Tietkens Plain Cemetery (the name given to an area within the TM101 site; see *Section 3.5.2.1* for further explanation of the Tietkens Plain Cemetery).

1.1.3.2 Commonwealth Government Policy on Maralinga 1968–1984

From 1965 the Maralinga Range was progressively closed down until in December 1968, the Australian Minister for Defence was able to revoke the declaration under the *Defence (Special Undertakings) Act 1952* (Cwlth). However, the declaration under the Supply and Development Regulations was retained since the Australian Department of Supply was made responsible for control and safety in respect of the residual radioactivity and any other hazards in the area. After completion of the *Operation Brumby* clean-up and its acceptance by Australia, the UK was released, for the most part, from any future liability for the Maralinga test sites. The text of the memorandum of understanding reached on the matter between the British Government and the Australian Government is included as *Attachment 1.1*.

1.1.4 THE EXTENT OF WIDESPREAD CONTAMINATION REMAINING AT MARALINGA AND EMU FOLLOWING *OPERATION BRUMBY*

This section contains a brief overview of the contamination and hazards at the site in the lead up to the start of the Maralinga Rehabilitation Project (Project) to establish the radiological context within which decisions were being made.

1.1.4.1 Contamination at the start of the Maralinga Rehabilitation Project—major trial sites

At the instant of detonation of an atomic explosion, there is a burst of intense thermal, x-ray, gamma ray and neutron radiations, followed by the formation of a cloud containing highly radioactive material with short half-lives (e.g. fallout debris decays nominally at $t^{-0.5}$, where t = time). This cloud can rise to the troposphere and the radioactive material may be carried around the globe by the wind depositing fallout downwind along the way. Radioactive contamination on the ground close to the site of an atomic explosion results from the close-in fallout, and from neutron activation of the soil immediately below the detonation point (ground zero).

Some forty years after the tests, the principal neutron activation products that remain in the soil are cobalt-60 (Co^{60}) and europium-152 (Eu^{152}), and the principal fallout products (e.g. fission fragments) are strontium-90 (Sr^{90}), caesium-137 (Cs^{137}) and europium-155 (Eu^{155}). The short-lived radionuclides from the tests have now decayed.

At the start of the project, radiation levels that arose from the atomic tests (major trials) close to all nine ground zeros at Maralinga and Emu were considered by MARTAC to be of low, long-term concern (0–10 µSv/hr).

At *Tadje*, because of the nature of the warhead tested, there was an area of approximately 1 ha extending from ground zero for approximately 1 km in a north to north-east direction which was contaminated with plutonium (and associated americium) as well as some small pellets of Co^{60}. The Co^{60} was of sufficiently short half-life (5.3 years) for it to present little potential hazard to health in the long-term, but the half-life of plutonium-239 (Pu^{239}) is such (24 100 years) that this small area north of the *Tadje* ground zero implies restrictions on use. At the Maralinga and Emu sites of the six tower-mounted tests, glazing, or fused sand that formed at the time of the explosions, remains. The glazing, which contains trapped radioactive materials including plutonium, required further consideration (for a discussion of how views on this have changed, see *Section 3.8* of this report).

Airborne radiological survey

In 1987 the Technical Assessment Group (TAG) undertook an aerial radiological survey and other works to better define the nature and extent of the contamination remaining at Maralinga and Emu (for a description of these and other studies carried out by TAG, see *Section 1.2.5* and *Attachment 1.2* to this report). Figure 1.7 shows the areas flown over in the survey at Maralinga.

The contamination plumes from the major trials are shown in Figures 1.8 to 1.12 for Maralinga, and in Figures 1.13 and 1.14 for Emu.

Although the actual test sites were contained within Section 400 at Maralinga, the fallout was not. Low levels of plutonium contamination can be detected beyond Oak Valley (see Figure 1.15).

Of particular note to MARTAC, in its refinement of the areas of soil to be cleared during the current project, were a number of aerial radiological survey findings (TAG 1990, pp. 93–95).

A total inventory of Pu^{239} of approximately 1.5 kg was derived over a total area of 132 km^2 at Maralinga (excluding the firing sites at Taranaki and the central area surrounding them). This total inventory assumes the contamination to be distributed on the surface and based on measurement for Am^{241} (EG&G 1991) (see Table 1.5).

Areas 1 and 2 (Figures 1.7 and 1.8) included the major trials sites of Taranaki, *Breakaway*, *Biak*, *Marcoo*, *Tadje*, *Kite* and *One Tree* as well as the plumes from the minor trials at Taranaki. The aerial data showed the presence of Am^{241} (associated with Pu^{239}), Cs^{137}, Co^{60}, and Eu^{152}. No measurable uranium-235 (U^{235}) or uranium-238 (U^{238}) was detected.

Figure 1.7 Areas flown over in the survey at Maralinga and Emu.

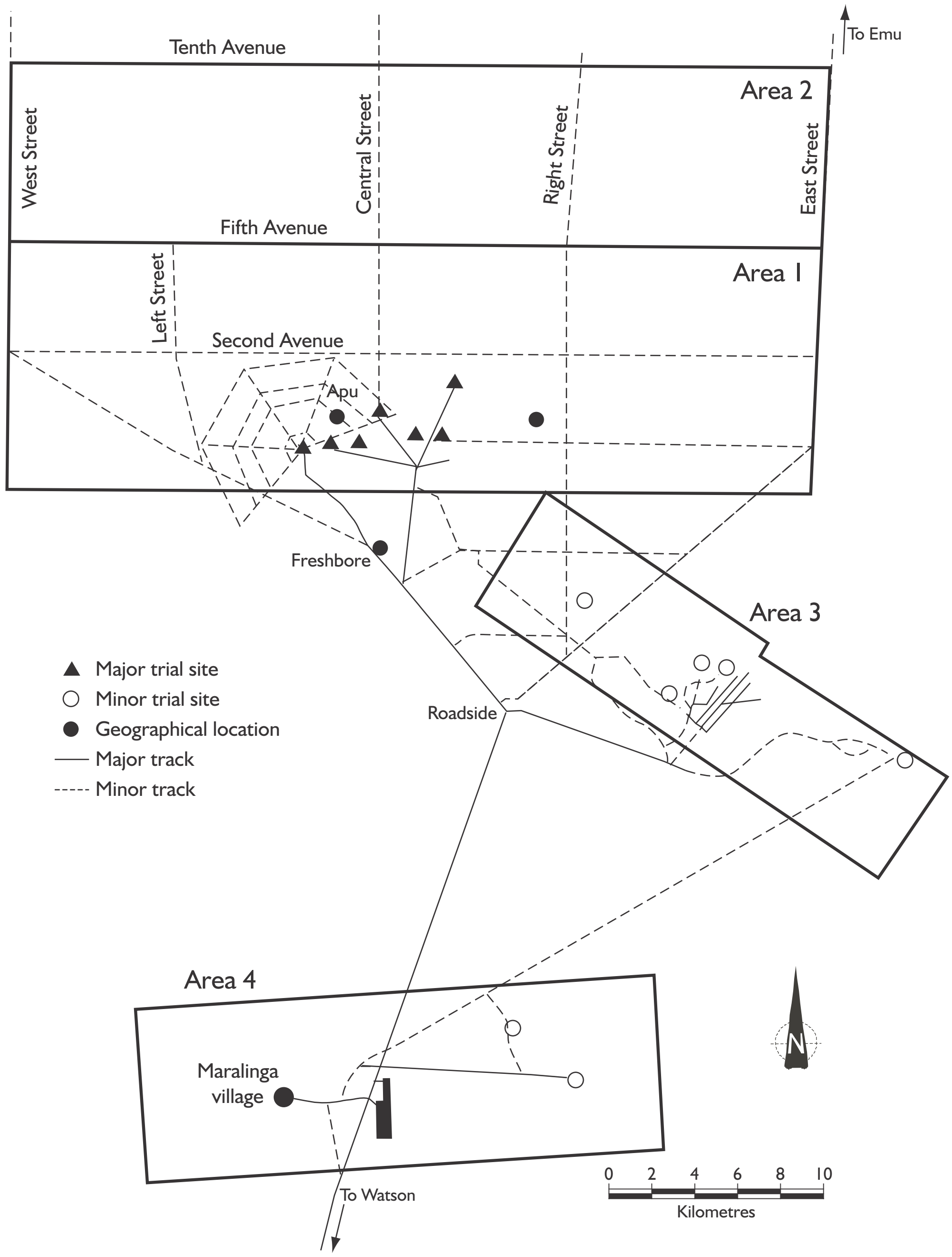


Figure 1.8 Results of aerial survey over Areas 1 and 2 processed for Am^{241} (Maralinga).

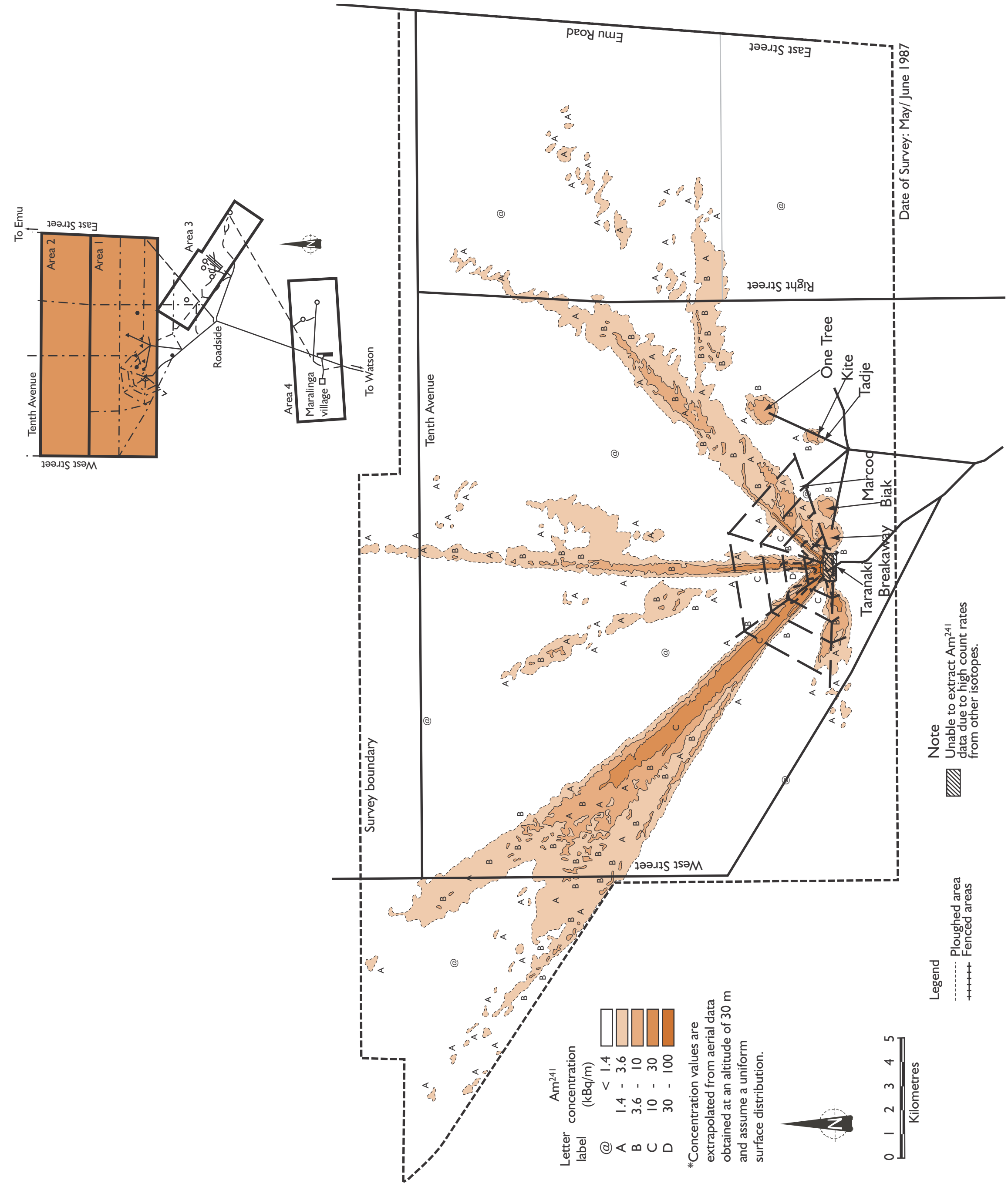
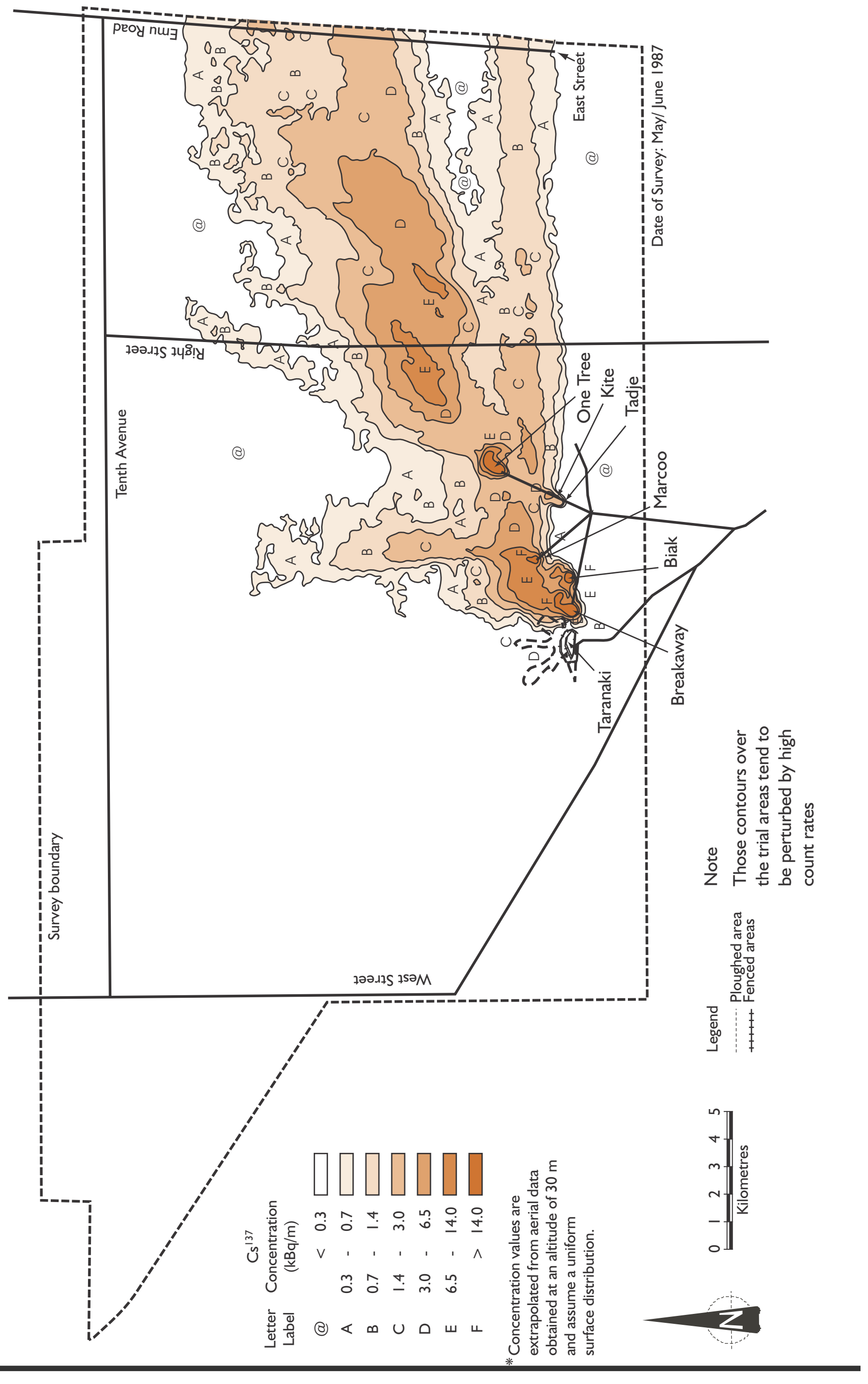


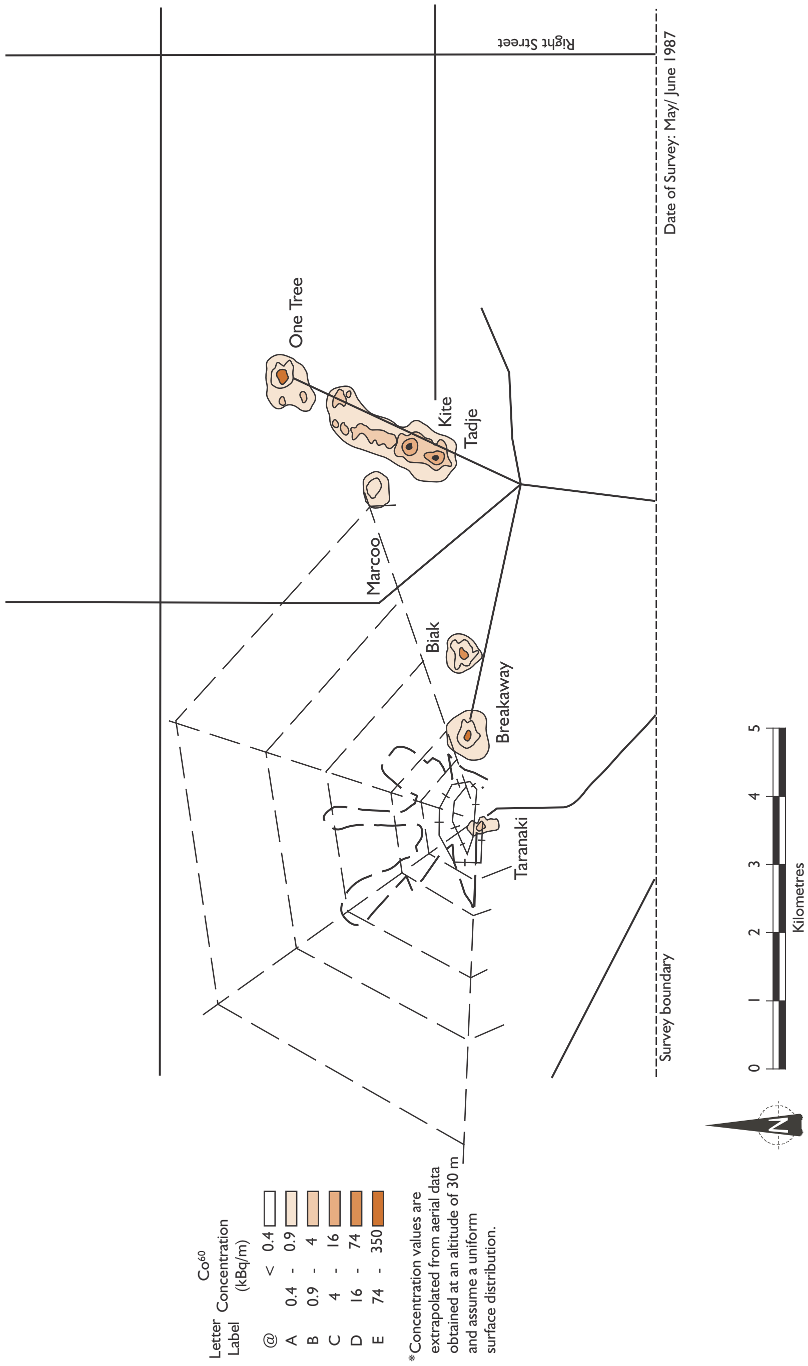
Figure 1.9 Results of aerial survey over Areas 1 and 2 processed for Cs^{137} (Maralinga).



* Concentration values are extrapolated from aerial data obtained at an altitude of 30 m and assume a uniform surface distribution.

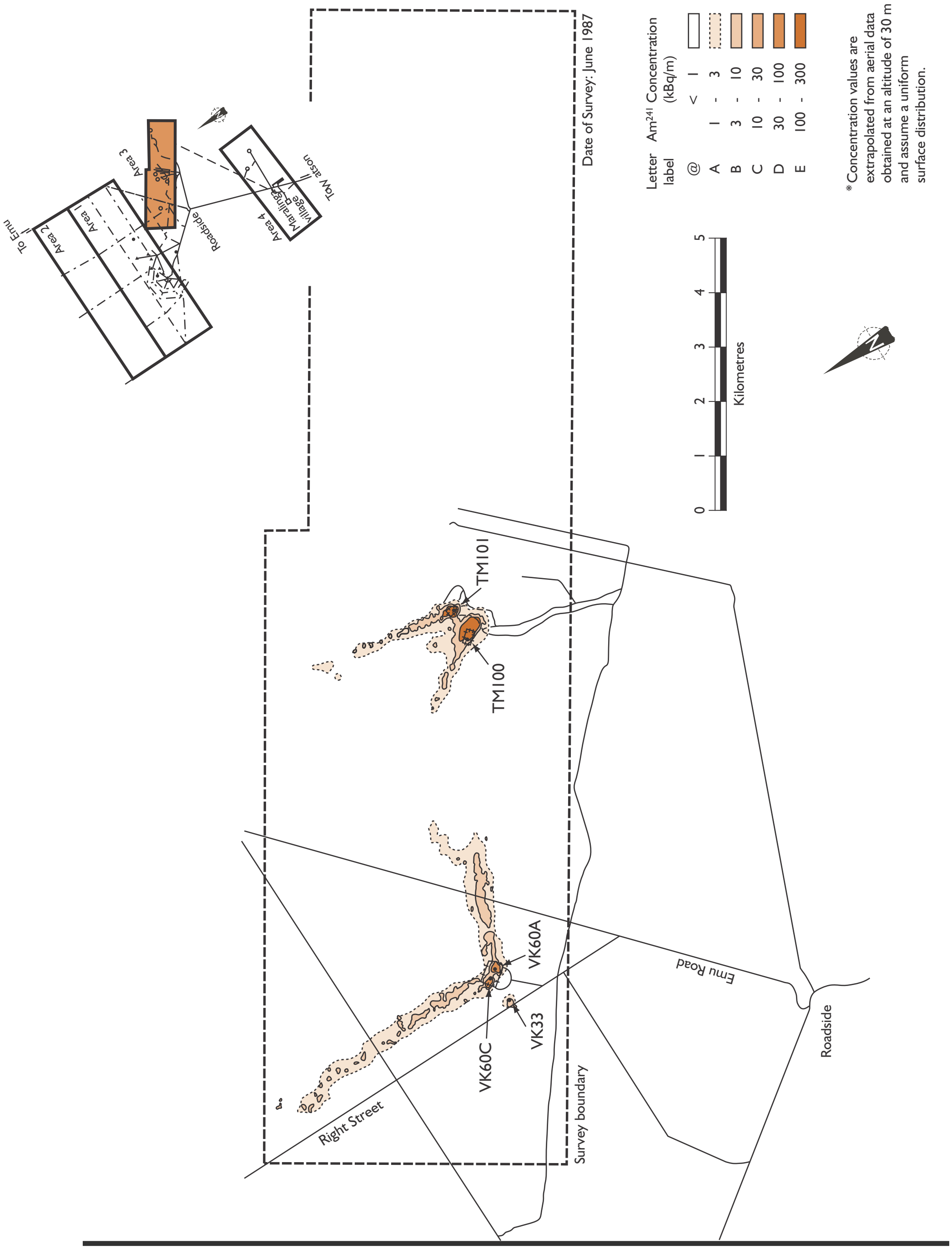
Note
Those contours over the trial areas tend to be perturbed by high count rates

Figure 1.10 Results of aerial survey over Areas 1 and 2 processed for Co^{60} (Maralinga).



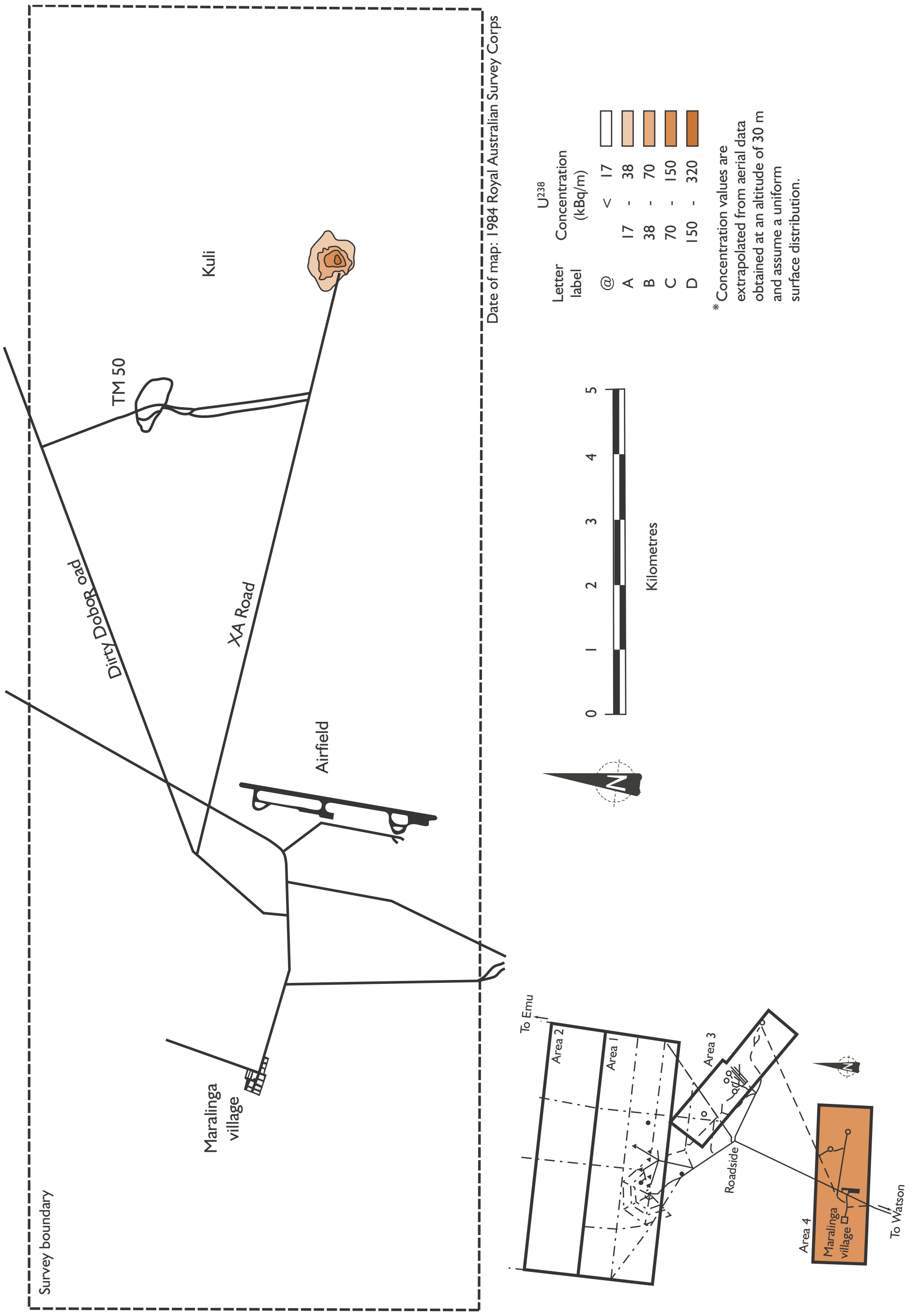
*Concentration values are extrapolated from aerial data obtained at an altitude of 30 m and assume a uniform surface distribution.

Figure 1.11 Results of aerial survey over Area 3 processed for Am^{241} (Maralinga).



* Concentration values are extrapolated from aerial data obtained at an altitude of 30 m and assume a uniform surface distribution.

Figure 1.12 Results of aerial survey over Area 4 processed for U^{238} (Maralinga).



* Concentration values are extrapolated from aerial data obtained at an altitude of 30 m and assume a uniform surface distribution.

Figure 1.13 Results of aerial survey over Area 5 processed for Cs^{137} (Emu).

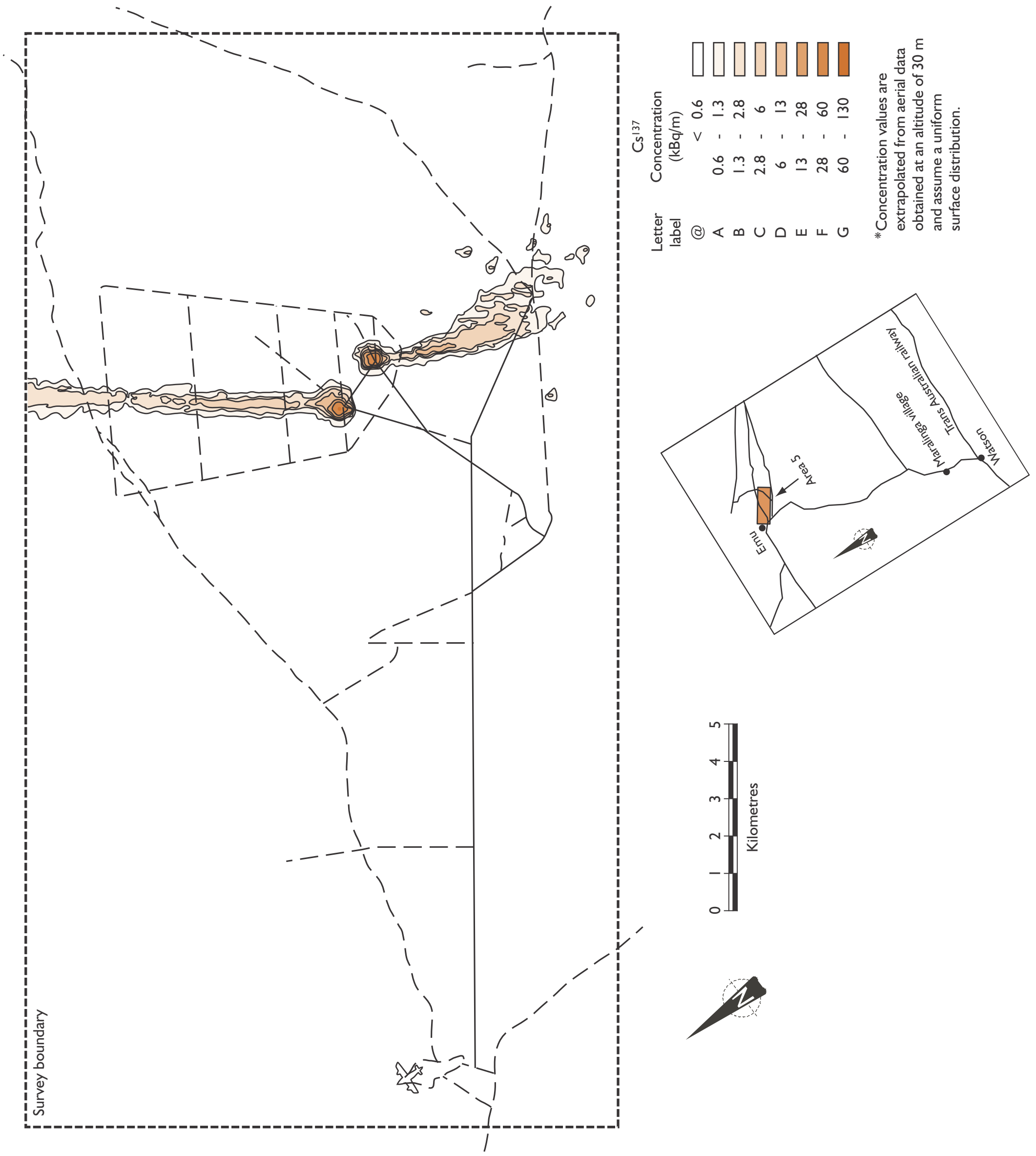


Figure 1.14 Results of aerial survey over Area 5 processed for Am^{241} (Emu).

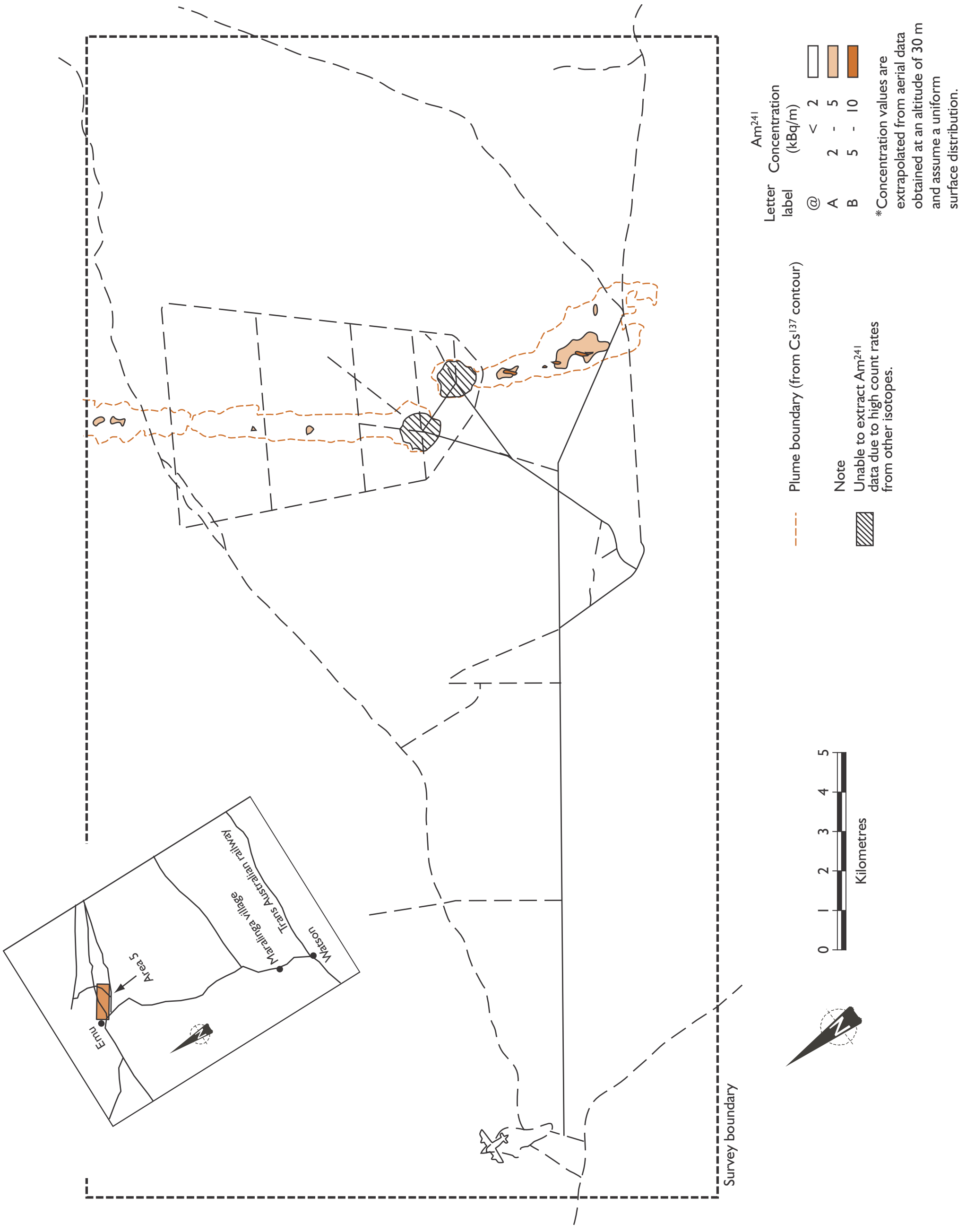
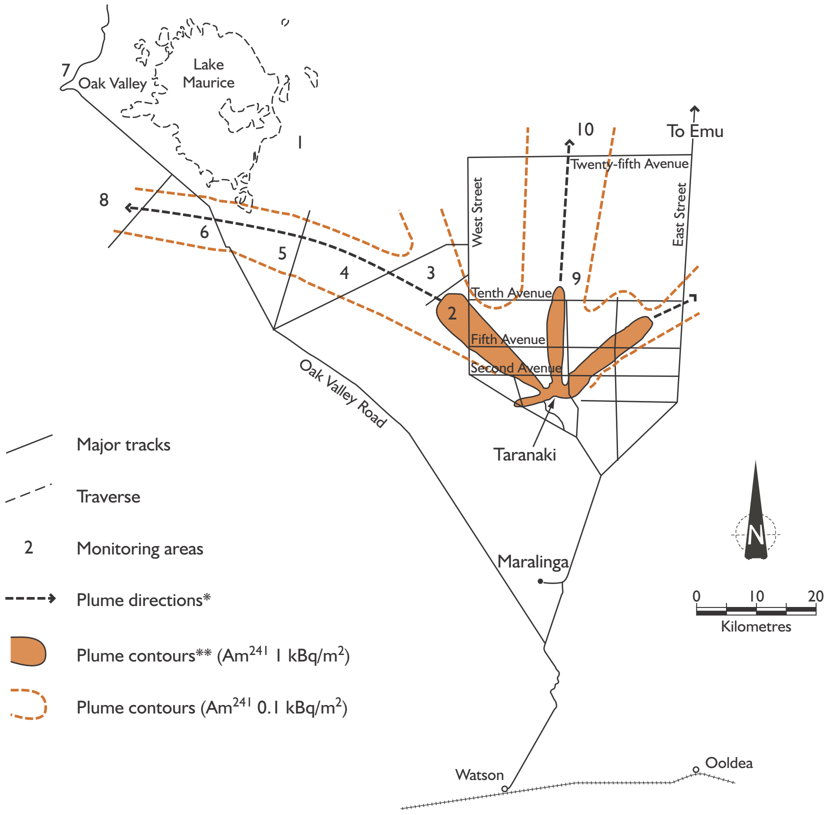


Figure 1.15 Further extent of plutonium contamination (Johnson et al. 1989).



Map of the Maralinga area showing major tracks and Oak Valley.

Measurement areas are identified (e.g. Area 1)

* Inferred directions of the major plumes are based on the present measurements, and are indicative only.

** Plume boundaries are based on this and previous ARL studies and are indicative only.

Four primary plume directions of Am^{241} in west, north-west, north and north-east directions (Figure 1.8) were detected from minor trials at Taranaki, together with several minor plumes to the north and north-east. The north-west plume was the longest, with activity being detected approximately 28 km from Taranaki.

Cs^{137} from the major trials (Figure 1.9) was detected in fallout patterns primarily to the east and north-east at a limit of detection of 0.3 kBq/m^2. Co^{60} (Figure 1.10) was detected at *Tadje* in a north-north-east plume and in a localised source approximately 1 km north-north-west from *Tadje*, and at *Taranaki*, *Breakaway*, *Biak* and *One Tree* ground zeros, with a limit of detection of 0.4 kBq/m^2 at the detection limit for the aerial survey.

Area 3 (see Figure 1.11) was included in the minor trial sites at Wewak, TM100 and 101 and Dobo. Three Am^{241} plumes at Wewak are associated with plutonium burning experiments at VK33 and explosive dispersal at VK60A and VK60C. Two plumes were detected from explosive dispersal trials at TMI00 and TM101. No Am^{241} was detected at Dobo.

Area 4 included the Maralinga village, the airstrip and adjacent burial ground, and the minor trial sites at TM50 and Kuli (Figure 1.12). The only contamination detected in the aerial survey was that of U^{238} at Kuli, resulting from explosive dispersal experiments. The limit of detection for U^{238} was 17 kBq/m^2. No Am^{241} was detected at TM50 or Kuli.

Table 1.5 Am^{241} inventory at Maralinga (excluding the firing sites at Taranaki and the central area surrounding them).

Location	**Total activity[1] (GBq)**	**Contaminated area[2] (km^2)**
Areas 1 and 2[3]		
West Plume	17	4.5
North-west Plume	266	58.1
North Plume	78	25.1
North-east Plume	97	39.8
Area 3		
Wewak (VK33, VK60A, VK60C)	6	2.7
TM100, TM101	9	1.5
Areas 4 and 5	nil	1.5

[1] Assuming the contamination is deposited on or within mm of ground surface.

[2] Within the sensitivity limits of the aerial system (1.4 kBq/m^2 in Areas 1 and 2, and 1.0 kBq/m^2 in Area 3).

[3] Does not include an estimate for the major trial areas because of high gamma background from soil activation products and glaze material, or, as at Taranaki, the high level of contamination relative to that of the plumes.

Area 5 covered the test sites at Emu, approximately 180 km north of Maralinga (Figures 1.13 and 1.14). No remaining contamination was observed from the minor trials at the *Kittens* sites at Emu.

1.1.4.2 Contamination at the start of the Project—minor trial sites

Surveys of the minor trial sites at Maralinga and Emu in the 1980s (Lokan 1985) have shown that in many cases, the minor trial sites have either been adequately cleaned up, or the radioactive materials have been of sufficiently short half-life as to be no longer detectable. Because of the relative short half-life of polonium-210 (Po^{210}) (138 days), scandium-46 (Sc^{46}) (84 days) and lead-212 (Pb^{212}) (10 hr), and the low radiotoxicity of uranium, the only 'minor trial' areas with a continuing radiological hazard were those associated with plutonium dispersed at Wewak, TM100/101, and with the *Vixen B* trials at Taranaki. Of these, the Taranaki site was the most significant. The following gives an overview of the sites with significant residual contamination at the start of the project.

Taranaki

Taranaki was the site most extensively contaminated with plutonium and, therefore, represented the greatest potential health hazard to workers and to Aboriginals living an outstation lifestyle. Although the balloon-borne major trial carried out there left little contamination at the test site, the minor trials carried out between 1960 and 1963 left it significantly contaminated.

The area just to the north of the Taranaki ground zero was used for 12 *Vixen B* trial live firings. Twenty-two kilograms of Pu^{239}, along with a similar amount of U^{235}, was explosively dispersed. The *Vixen B* trials involved a sufficient quantity of high explosive to sustain a large chemical explosion. Chemical explosions of this magnitude released sufficient energy to lift plutonium-contaminated debris high enough to be carried many kilometres downwind. Fallout from the firings formed long narrow plumes to the north-west, north and north-east.

An attempt was made at the time to measure ground deposition associated with one of the 1960 *Vixen B* detonations but the resulting plume apparently did not overlay the sampling array. The monitoring results obtained after the event contained systematic errors greater than a factor of ten as a result of the methods used. A comparison between the levels reported by the UK at the time (Pearce 1968) and the field results reported by Australian Radiation Laboratory (ARL) (Lokan 1985) demonstrates an underestimate of the plutonium contamination by about an order of magnitude. Further discussion of this is to be found at *Attachment 1.6*.

The hazard at Taranaki arose from plutonium plated out onto fragments of debris and in the form of finely divided contaminated dust. It was the experimental set-up of the *Vixen B* trials that made them the principal source of lasting environmental contamination. The tests involved massive, steel supporting structures known as ‘featherbeds’ which were intended to be recovered for re-use. The experimental set-up is described in *Chapter 3*. The other sites at Wewak and TM100/TM101 are very much smaller, though the local soil concentrations and fragment/particle densities are often comparable.

Close to the Taranaki minor trials test site, the surface soil was ploughed during *Operation Brumby*. Even after *Operation Brumby*, this area contained many thousands of contaminated fragments large enough to attract attention as souvenirs. The range of types of fragments included wire, steel cables, steel plate, lead, pieces of a low density grey metal, bitumen and a yellowed plastic material. Beyond the ploughed area, the plutonium contamination had remained mostly on the surface. Figure 1.8 shows the extent of the Am^{241} plumes from the *Vixen B* series of trials at Taranaki.

Kuli

Uranium and beryllium were dispersed explosively at Kuli. The nature of the experiments at Kuli would lead to the expectation that most of the 7000 kg of uranium used at Kuli was dispersed as fine fallout down range to the north-east and south-west. Some of the remaining fragments of uranium and beryllium were scavenged at the time of the trials. These are presumed to be buried in a large pit on the northern side of the Kuli site. However, pieces of uranium metal and uranium oxides were readily found close to the firing pad in the centre of the site and further to the east, for more than 300 m. Figure 1.12 shows the extent of the U^{238} contamination at Kuli detected by the aerial survey.

Wewak (*Vixen A* trials)

Burnings and explosive dispersals of beryllium, uranium and plutonium occurred at Wewak. The two plutonium burnings (involving a total of 0.41 kg plutonium of which approximately 0.4 kg was recovered) took place at the VK33 site that was subsequently treated by ploughing. Four explosive dispersals of plutonium, totalling approximately 0.57 kg, took place at sites VK60A and VK60C. Surrounding these sites were pieces of metal contaminated with plutonium. Figure 1.11 shows the extent of Am^{241} contamination at the Wewak site detected by the aerial survey.

TM100 and TM101

Explosive dispersals of plutonium took place at these locations. Some of these experiments involved secondary containment in which little of the material was released to the environment. Of the total of approximately 1200 g of plutonium used at the TM sites, approximately 500 g was returned to the UK in 1979 (DNDE 1980). There was a high concentration of plutonium contaminated fragments and smaller friable particles close to the firing sites (see Figure 1.11).

TM50

Uranium and beryllium were dispersed explosively at this site. A small area east of the roadway, just north of the concrete base marking the site of a former blockhouse, was contaminated with finely dispersed uranium and beryllium. It was insufficient to show in the aerial survey data and is not considered to be a hazard.

Kittens Lanes

Throughout the area surrounding these five lanes, there was a light distribution of metal debris, largely steel, which had been overlooked in earlier clean-up operations. Some of these metal pieces, in particular steel tubing and solid tripod-like structures, were lightly contaminated on the surface with natural uranium. There was also a smattering of other debris including old electrical cables and phosphor-bronze or brass canisters, none of which was found to be radioactive (Lokan 1985). No plumes of contamination were detected in the aerial survey.

A similar series of experiments that pre-dated the Maralinga *Kittens* experiments was carried out at Emu. However, no contamination was found at the sites of the *Kitten* trials at Emu.

Figure 1.16 Trig point at Kuli.

1.1.5 CONTAMINATION IN PITS REMAINING AT MARALINGA AND EMU FOLLOWING *OPERATION BRUMBY*

The minor trials and associated range activities resulted in debris being buried in over 100 'formal' debris pits and 'informal' rubbish pits of widely varying size. This was completed during *Operation Brumby*.

1.1.5.1 Contamination at the start of the project—the 'formal' debris pits

Other than the debris 'pit' called the *Marcoo* Crater, the British allocated numbers or letters to those pits known to contain radioactive materials. These 'numbered' pits are called the 'formal' debris pits in this report.

A summary of the expected content of the formal debris pits is given in a 1990 report by the Technical Assessment Group (TAG) to the Australian Government. In relation to the formal debris pits, TAG (1990, pp. 25 and 29) stated:

> *Status of burial pits*
>
> *A large amount of contaminated debris and soil, together with uncontaminated equipment and general rubbish, is buried in pits in the forward area at Maralinga. Data on pits is contained in the TAG Interim Report.*
>
> *Pits at Taranaki*
>
> *Twenty-one numbered pits at Taranaki are estimated to contain between two and twenty kilograms of plutonium in about 820 t of debris and 1150 t of soil from the Vixen B trials. The pits are capped with about 650 t of reinforced concrete.*
>
> *Other Numbered pits*
>
> *Four numbered pits at TM101 (Tietkens Plain) contain an estimated total of 90 g of plutonium, and a further six numbered pits at Dobo, Kuli, TM50 and the DC/RB area of Maralinga contain small quantities of radioactive and toxic materials. Some highly radioactive short-lived material is buried in concrete lined trenches in the Airstrip Cemetery. These pits contain about 100 MBq of thorium-228, 1-7 GBq of cobalt-60, 700 MBq of fission products and 22 kg of natural uranium. Five hundred grams of plutonium was repatriated from the Airstrip Cemetery to the UK in 1979.*

The lack of detail in the historical records of the tests meant that the TAG was unable to make an accurate estimate of the amount of plutonium (and other materials) from the *Vixen B* trials buried in the 21 concrete capped pits at Taranaki. Assuming a worst-case scenario, the TAG concluded that there could be up to 20 kg of plutonium in these pits—the quantity claimed in the British reports. Separately, the group estimated 2 to 4 kg would be present. Table 1.6 provides a summary of the contamination expected by TAG to be in the formal debris pits at Maralinga (see *Attachment 1.3*).

Table 1.6 Location and nature of the formal debris pits (as estimated by TAG [*see Attachment 1.3*]).

Location	**Formal debris pit**	**Description**	**Radioactive or toxic content**
Taranaki[1]	1 to 19, 19A and 19B	Debris from explosive dispersion of plutonium in *Vixen B* trials; steel plates, RSJs, lead, cable, concrete, barytes bricks.	Up to 20 kg plutonium
Airfield cemetery	A to K A, B, C A, B, C, D	11 pits Category 1 (high level) 3 pits Category 2 (medium level) 4 pits Category 3 (low level)	Th^{228}; Co^{60} GBq Pu^{239}; Th^{228}, Co^{60}; U natural Pu^{239} (pit III C)
Wewak[2]	20 and 21	Two concrete firing pads.	–
TM101	22	Debris from explosive dispersion of plutonium in *Tims* trials, steel plates, bitumen, latex, cables	70 g plutonium (160 GBq total alpha)
Tietkens Plain cemetery (within the TM101 site)	23	A pit containing miscellaneous debris from Wewak, *Kittens*, TM 100, TM101. A recorded but un-numbered second pit containing some plutonium on debris existed to the side of the first.	26 g plutonium (60 GBq total alpha)
Dobo	24, 25	Two pits from early *Rats* trials of metallic uranium; steel plates, lead, cables, uranium.	Trace Th^{228}
TM50	26	A pit containing residual uranium and beryllium from explosive dispersion of 88 kg natural or depleted uranium and 10 kg beryllium; steel plates, miscellaneous metal items & fragments.	Residual natural or depleted uranium & beryllium
Kuli[3]	27, 28, 29	Explosive dispersion of uranium. Steel plates, lead cables	Residual natural or depleted uranium & beryllium
DC/RB	30	22 vehicles & miscellaneous items deliberately destroyed by fire	possibly traces of alpha

[1] During the Project, the amount of plutonium in the Taranaki pits was found to be closer to 1 kg.

[2] The two so-called Wewak ‘pits’ numbered by the British were, in fact, concrete firing pads.

[3] The so-called ‘pits’ 28 and 29 at Kuli were also firing pads. However, in the case of pit 29, debris was found buried nearby during the course of the current clean-up. This debris was left in situ.

1.1.5.2 Contamination at the start of the project—the 'informal' rubbish pits

During all operational phases, and particularly during the final clean-up of *Operation Brumby*, the UK disposed of their uncontaminated rubbish by shallow ground burial. These rubbish pits were not formally recorded, so there is no historical information from the time of the tests as to either their number or location.

However, a broad indication of the nature and quantity of waste disposed of in this way during *Operation Brumby* is provided in Annex B of Cook's 1967 report—*Operation BRUMBIE, Final Report* (Table 1.7).

The informal pits were left by the British with the contents uncompacted and with minimal soil cover over the waste. The waste contents were unrecorded and uncharacterised and the size and locations of the pits were also unrecorded. It was intended that the wastes buried in them would be non-radioactive.

An overview of TAG's investigations of the informal rubbish pits and its conclusions as to their contents is given in *Attachment 3.5*.

Marcoo crater

The *Marcoo* crater was neither numbered, nor was an estimate of its radioactive content recorded. It was thought to contain 'target response vehicles' (including aircraft, lorries and a tank), and plutonium contaminated soil from Wewak. It was filled with clean soil to ground level.

Table 1.7 Examples of waste disposed of during *Operation Brumbie* [sic] (Cook 1967).

Item	Quantity	Item	Quantity
Dismantled fences	37.5 miles	Dismantled cable runs	45 miles
Dismantled buildings	33	100 ft towers	6
Steel telegraph poles	273	Star pickets	87 000
Vehicles	20	Caravans	3
Trailers	8	Disc ploughs	2
Aircraft wing sections	8	Aircrafts (swifts)	5
Radar cones	8	Railway wagon	1

1.1.6 CLOSURE OF THE MARALINGA RANGE BY THE UK

From 1965 onwards, the Maralinga Range (including Maralinga and Emu) was progressively closed down. In 1968, by agreement with the British Government, the buildings and other facilities that remained at Maralinga were transferred to the Australian Government. In return, the Australian Department of Supply accepted responsibility for the safety and control of the buildings and facilities at the site. The Australian Department of Defence retained control of the contaminated areas.

The text of the 1968 memorandum reached between the two Governments and dealing with the closure of the Range is given in *Attachment 1.1*. The text of the 1956 memorandum of arrangements referenced in the 1968 memorandum is included in *Attachment 1.1*.

1.2 BACKGROUND TO THE DECISION TO PROCEED WITH THE CURRENT CLEAN-UP (THE MARALINGA REHABILITATION PROJECT)

1.2.1 EARLY CONSIDERATIONS OF CONTAMINATION AND USE OF TEST AREAS

In December 1968, the Minister for Defence was able to revoke the declaration under the *Defence (Special Undertakings) Act 1968* (Cwlth). However the declaration, under the Supply and Development Regulations, was retained since the Department of Supply was made responsible for control and safety with respect to the residual radioactivity and any other hazards in the area.

As agreed in the 1968 memorandum, the buildings and other facilities remaining at Maralinga after the run-down was completed were handed over to Australia. In return, the Australian Government accepted responsibility for safety and control. In early 1971 the Department of Defence concluded that there was no valid reason for continuing to retain the area for defence purposes. In August 1971, the Minister for Defence approved the cessation of maintenance of all facilities, and approved a request that the Department of Supply should acquire, for Commonwealth purposes and control, those areas of the Maralinga Range where residual contamination was still significant.

On 31 August 1972, the Minister for Supply removed restrictions on the greater part of the Maralinga Prohibited Area under the Supply and Development Regulations. A strip of land, approximately 48 km wide and 240 km long, to the north of the Maralinga village was retained as part of the new Woomera Prohibited Area. Except for one site adjacent to the airfield cemetery, this strip of land contained all the former test sites and all the burial sites for radioactive waste.

1.2.1.1 Atomic Weapons Tests Safety Committee (AWTSC)

In December 1972 and February 1973, the Atomic Weapons Tests Safety Committee (AWTSC) (established by the Department of Supply to monitor and advise on safety aspects of the tests) considered the residual contamination at the Maralinga Range. It advised that the area of land to be acquired by the Commonwealth should cover the major test sites, and that the waste cemeteries (i.e. the contaminated pits at Taranaki, Tietkens Plain and Airfield) were not considered a hazard. Accordingly the area to be acquired by the Commonwealth and to remain under its control was confined to the major trial sites.

For a period in the mid-1970s, while options for future management of the test site area were being considered, there was no Commonwealth presence at any of the sites.

The AWTSC, which had earlier recommended acceptance of the result of the *Operation Brumby* clean-up was of the view that the test area would naturally revegetate rapidly, making the test area virtually indistinguishable from the surrounding environment. It therefore favoured removal of most of the fences and notices identifying contaminated areas, and not replacing the high wire mesh fences at the Taranaki and TM sites that had been installed during the tests. However, it did recommend a further review after a period of twenty years (AWTSC 1967).

1.2.1.2 Australian Ionising Radiation Advisory Council (AIRAC) and Report No. 4

In June 1974, the AWTSC's successor, the Australian Ionising Radiation Advisory Council (AIRAC), took an opposing view to that of the AWTSC and favoured the maintenance of the fences around radioactive waste disposal pits and the warning signs based on the gamma field of the ground zeroes and burial sites (AIRAC 1979). With respect to administrative control, AIRAC recommended:

> *… that the airfield cemetery area, and an area sufficient to include the nuclear weapons test sites, the minor trial sites and the enclosed burial grounds, should remain under Australian Government administration. It is not necessary to retain the intervening tract of land but that may be administratively convenient.*

In developing its report, AIRAC considered a range of studies undertaken by a team consisting of research staff drawn from the Australian Radiation Laboratory (ARL), the Australian Atomic Energy Commission (AAEC), the Bureau of Meteorology, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the South Australian Departments of Environment and of Mines. AIRAC's 1979 report *Radiological safety and future land use at the Maralinga atomic weapons test range* (Report No. 4) (AIRAC 1979, pp. ix–x) recommended:

> *RECOMMENDATION 1: Release of information*
>
> *The AIRAC report 'Radiological safety and future land use at the Maralinga atomic weapons test range' January 1979, including its annexes, should be published and made available to the public.*

RECOMMENDATION 2: Identification

The ground zeros of the seven nuclear explosions should be clearly marked as such in durable fashion, for example by a substantial concrete block into which the name is moulded. Four of the sites, One tree, Breakaway, Tadje and Biak, should also carry a plain language radiation warning sign. Suitable wording is: 'Levels of radioactivity at this point and for a few hundred metres around may be above those considered safe for permanent occupation, but are acceptable for short stays'.

The locations of individual burial pits should not be marked and if otherwise made evident, e.g. by subsidence, this should be rectified. Perimeter fences around areas containing burial pits should carry warning signs in plain language. Suitable wording is: 'No entry. Radioactive wastes are buried in this area'.

The approximate centres of the two plutonium-contaminated areas at the TM 100-101 experimental areas should be plainly marked, as provided for at the ground zeros of the nuclear explosions, and these areas should carry plain language warnings similar to those required at the four ground zeros which need them.

Survey reference points must continue to be maintained in perpetuity and records kept of the locations with reference to them, of all test sites, burial pits and other areas with radioactive contamination

RECOMMENDATION 3: Enclosures

The present security (HCM) fence in the Taranaki area should be maintained. The security fence at the airfield cemetery should be replaced, but located so that the new fence is about 50 m outside the boundaries of the cemetery area proper. The fence around the two pits, numbers 22 and 23 at TM101, which contain high activity debris, should also be replaced. Warning signs, worded as in 2(b) above, should be attached to the fences at appropriate places.

RECOMMENDATION 4: Airfield Cemetery

Those pits which contain Category Two (medium activity) burials of plutonium-239 (Pit B) or of cobalt-60 (Pit C) should be made more secure, e.g. by covering with a concrete slab as at Taranaki. Category One (High activity) burials of cobalt-60 (Pit 1K 21/22) should receive the same treatment. The Category One burial of plutonium-239 (Pit 1 I 18) also needs better protection against casual or malicious interference. It is understood that this plutonium will be removed; if it is not the pit should be made more secure. [Note: the 500 g of plutonium was repatriated to the UK in 1979].

RECOMMENDATION 5: Public access

Access to the three enclosed burial grounds should be prohibited to unauthorised persons. Access to all other regions may be permitted for periods up to seven days, or longer with special authority. Motor vehicles should not be permitted within 500 m of any radiation warning sign unless with special authority.

> *RECOMMENDATION 6: Future radiological survey*
>
> *The Range should be resurveyed for its levels of residual radiation and soil contamination, and for changes in the availability of plutonium for resuspension in the atmosphere and for inhalation not later than 1987. At that time a decision should be made on what further survey, if any, is necessary. At the same time the status of the burial pits should be reviewed.*
>
> *RECOMMENDATION 7: Administrative control*
>
> *At present the airfield cemetery area, and an area sufficient to include the nuclear weapons test sites, the minor trials sites and the enclosed burial grounds, should remain under Australia Government administration. It is not necessary to retain the intervening tract of land, though that may be administratively convenient. After the next radiological assessment, the question might be reviewed.*

AIRAC essentially confirmed the impression of the state of the Maralinga range and residual radiological hazards that had been provided by the British in the Pearce Report (Pearce 1968). This arose in part because of the short duration of the field work (less than two weeks), and because of inaccurate radiochemical determinations of Pu^{239} and the rejection by the laboratory of large fragments from soil samples when considering the inhalation hazard on the basis that they were not inhalable. The AIRAC report did not address the radiological hazard that could result from wound contamination.

AIRAC, in its consideration of the Pearce Report (Pearce 1968) on *Operation Brumby* realised that a discrete, potentially recoverable, 0.5 kg quantity of plutonium remained at the range. It recommended in its report that this source be removed or made more secure. The plutonium was repatriated to Britain in early 1979 and agreement reached that Australia would make no further claims for repatriation of nuclear materials to the UK (DNDE 1980).

1.2.1.3 Australian Ionising Radiation Advisory Council and Report No. 9

In the early 1980s, AIRAC again considered the nature and distribution of the fallout from the nuclear tests, and reported on this in its January 1983 report *British nuclear tests in Australia—a review of operational safety measures and of possible after-effects* (Report No. 9, AIRAC 1983). The primary focus of this report was the identification of potential harmful effects of test fallout on site personnel and the Australian public.

The report was prepared on the premise that the information available from the British was both complete and accurate.

1.2.1.4 Kerr Committee and report

The Minister for Resources and Energy established the Kerr Committee on 15 May 1984 to review the available data on atmospheric fallout arising from the British nuclear tests in Australia. It was required to report by 31 May 1984. It had 16 days in which to carry out its work, a totally inadequate time given the size of the task (Kerr et al. 1984).

The Kerr Committee was, nevertheless, able to identify a number of problems in the AIRAC No. 9 report. The committee concluded that with respect to page 35 of the AIRAC report:

> *… there was need for a comprehensive public account of the consequences of the British nuclear tests on Australians and their environment.*

1.2.2 ROYAL COMMISSION INTO BRITISH NUCLEAR TESTS IN AUSTRALIA

1.2.2.1 Formation

In June 1984, the Minister for Resources and Energy announced that, following his examination of the Kerr Report (Kerr et al. 1984) and discussions with Dr John Symonds who had been commissioned in early 1984 to write an official history of the British nuclear tests in Australia (Symonds 1985), he would be recommending to the Australian Cabinet that some form of public inquiry be held. The Minister noted that this inquiry would cover the conduct of the tests and their effects on servicemen and Aboriginal people of the affected areas. New surveys of the site by the ARL, which had detected plutonium contaminated fragments from the *Vixen B* trials, were cited as a further consideration in support of a public inquiry.

The Government announced in July 1984 that it would be establishing a Royal Commission into British Nuclear Tests in Australia (Royal Commission). The terms of reference of the Royal Commission emphasised the conduct of the tests, health effects among Australian participants and Aborigines, and future management and use of the test sites. The final item assumed greater significance with test site contamination forming a major element in Royal Commission recommendations and becoming the focus of the Government's response.

1.2.2.2 Recommendations

Four of the seven Royal Commission recommendations contained in its 1985 report were directed at the rehabilitation of the Maralinga and Emu test sites and at compensation for the traditional owners. These are paraphrased as follows:

Recommendation 3	*Maralinga and Emu should be cleaned-up so that they are fit for unrestricted habitation by the Aboriginal traditional owners*
Recommendation 4	*A Maralinga Commission comprising representatives of the traditional owners and the UK, Australian and South Australian Governments should be established to determine clean-up options and implement the clean-up*
Recommendation 6	*All clean-up costs should be borne by the British Government*
Recommendation 7	*The traditional owners should be compensated for loss of access to test site land since the beginning of the test program. Compensation should be by way of technology and services which Aboriginal people regard as necessary to re-establish their relationship with their land*

The issues of liability and compensation are addressed in *Section 1.4* of this report.

1.2.3 AUSTRALIAN GOVERNMENT RESPONSE TO THE ROYAL COMMISSION

The Australian Government responded to the recommendations of the Royal Commission in September 1986, accepting most of the recommendations. Recommendation 4 for the formation of a ‘Maralinga Commission’ was rejected, as was Recommendation 6, which recommended that the clean-up costs be entirely borne by the British.

The Government considered that responsibility for administration, site assessment, consultation and implementation of any remedial action was more properly a matter for a Department of State than an independent authority.

To deal with the scientific assessment and stakeholder consultation roles envisaged for the ‘Maralinga Commission’, the Australian Government established what came to be known as the Technical Assessment Group (TAG) and the Maralinga Consultative Group (MCG) in 1986.

1.2.3.1 Technical Assessment Group (TAG)

TAG was formed in February 1986 to report in detail to the Australian Government on the options and associated costs for the decontamination and rehabilitation of the former British nuclear test sites in Australia. Agreement was reached between the British and Australian Governments that TAG would carry out such field studies and laboratory research as was required to develop its report. As agreed at the time, TAG was comprised of five scientists—two British, two Australian and one American.

1.2.3.2 Maralinga Consultative Group (MCG)

Stakeholder participation was addressed through the MCG. The group was comprised of representatives of the Commonwealth, South Australian, Western Australian (because of the early use of the Monte Bello Islands) and British Governments, and the Maralinga Tjarutja.

The MCG acted as a forum in which to discuss all matters concerning test site rehabilitation. It was chaired by a senior executive officer of the Department of Primary Industries and Energy (DPIE).

1.2.3.3 Aboriginal participation

Apart from their participation from the outset in the MCG, the Maralinga Aboriginals had a close involvement with the scientists of TAG. Maralinga Tjarutja elders and legal representatives attended the first meeting of TAG in early 1986 to be briefed in detail on its operation. The anthropological and inhalation studies identified by TAG as a necessary input to support the technical assessment required direct interaction with the Aboriginal community.

The Consultative Committee (formed in response to Royal Commission findings) met in May 1987 at the Oak Valley Outstation on the Maralinga lands to introduce the community to its membership and the purpose of the group, and to explain the scope of the TAG study program in terms relevant to Aboriginal culture.

The April 1987 *Agreement on Access and Confidentiality for Maralinga Technical Assessment Group Studies* was concluded with Maralinga Tjarutja to ensure that the TAG study program did not impact adversely on the traditional life of the community. The agreement included a ban on introduction of alcohol and firearms onto the Maralinga lands and provided for information given to researchers by the Aboriginal people to be treated as confidential.

Maralinga Tjarutja was kept informed throughout early 1990 on the progress of drafting the TAG report, and received copies of the draft report through the Consultative Committee.

1.2.4 PRE-TAG DEFINITION OF THE PROBLEM

Towards the end of the Royal Commission hearings, the Commissioners had asked the AAEC (now the Australian Nuclear and Scientific Technical Organisation [ANSTO]) to prepare a report on clean-up options for Maralinga in order to render the site suitable for transfer to the traditional Aboriginal owners. A series of appendices to the AAEC report (AAEC 1985) detailed the results of an 'office review' into:

- Aboriginal lifestyles in semi-arid areas of central Australia;
- sources of bush tucker (natural foodstuffs);
- generic environmental transfer factors;
- potential exposure routes; and
- generic dust resuspension factors (S_f) for a range of natural and human disturbance situations.

Although the report did suggest engineering clean-up strategies and indicative costs, it concluded that these were not meaningful because of uncertainties in the assumed lifestyle and land use, and in the values for site-specific environmental transfer factors. The Royal Commission accepted this conclusion, and as noted, went on to recommend a 'Maralinga Commission' to identify possible clean-up options (Recommendation 4).

Counsel representing the traditional owners were present during the Royal Commission hearings and provided the first avenue for information exchange between the traditional owners and AAEC scientists, resulting in an early visit by the latter to the community's outstation at Oak Valley. These early exchanges reinforced two important messages. Firstly, the traditional owners identified the need for anthropological data to be both quantitative and community-specific. Secondly, the scientists identified a need to place less importance on the use of bush tucker and to put greater importance on the impact of a very dusty environment for children at play, in adult hunting and recreational pursuits, and in the sleeping and cooking quarters.

1.2.5 TAG STUDY PROGRAM

Following approval by the Australian and British Governments to proceed, TAG instigated a series of laboratory and field studies that would allow it to develop:

- clearance criteria for the sites; and
- engineering options and costs for rehabilitation works.

Included at *Attachment 1.2* is an overview of the key studies commissioned by TAG and their findings. The full TAG report and its attachments are attached at *Attachment 1.3*.

1.2.5.1 Basis of TAG assessments

Other than defining notional clean-up contours in terms of 'acceptable' levels of contamination, issues in risk assessment and risk management were not addressed during the Royal Commission but were addressed as part of the TAG program. Nevertheless, the risk assessment/management problem was simplified by certain premises, defined as starting points for TAG as a consequence of the Royal Commission's work, including:

- the Maralinga land would be returned to the traditional owners who would use it to support an outstation lifestyle; and
- Aboriginal aspirations focused on a return to traditional values by higher and higher percentages of indigenous people, through outstation development, and social structure stemming from the authority associated with land custodianship.

As a consequence of the above, future potential changes in land use were considered to not be an issue. It was, therefore, sufficient to demonstrate that the trappings of a European lifestyle (e.g. mattresses, tarpaulins, rifles, four-wheel drive vehicles) and the intent of Government social policy (improved infrastructure at outstations with respect to health, hygiene and education) would all, singly and collectively, mean that higher levels of contamination would be considered to be acceptable, compared to what would have been the case had none or few of these modifying factors existed. Societal risk was not considered an issue because of the small numbers of inhabitants involved (some hundreds at most).

There was an implicit understanding that, whatever clean-up option was adopted, the plan would be for risk reduction to the budgetary limit. In other words, even though within Australia regulatory use is made of the concepts of ALARA (as low as reasonably achievable) used in operational radiation protection, ALARP (as low as reasonably practicable) used in safety case development associated with research reactors, and BPT (best practicable technology) used in the mining and milling of uranium, these mandatory approaches to regulating current activities were not directly applicable to the rehabilitation of earlier practices such as Maralinga (see *Section 1.2.5.4* on interventions).

1.2.5.2 Risk assessment

The risk assessment/hazard consequence assessment adopted by TAG was based on a conventional series of component steps. However, no data was prescribed and it was necessary to develop a methodology consisting of:

- *source term definition*—aerial and ground surveys to define the extent of the contamination, particle sizing and fragment characterisation (e.g. specific activity);
- *bioavailability*—gut transfer, lung dynamics and translocation from wound sites in experimental animals; environmental transfer factors for vegetation, fruiting bodies and collectable food animals; soil profiles; physical concentrating factors—fire ash, hydrological run-on;
- *exposure routes*—quantitative anthropological studies into cultural habits, food sources, food-gathering and daily activities; instrumented 'mock' Aboriginal practices and pastimes in contaminated areas; quantification of natural and artificial dust-raising activities;
- *dose assessment*—standard International Commission on Radiological Protection (ICRP) dosimetric factors or experimental values if higher; effective dose equivalent; risk coefficients from the ICRP, the United Nations Scientific Committee on the Effects of Atomic Radiation and the US Advisory Committee on the Biological Effects of Ionizing Radiation of the National Research Council; and
- *uncertainty analysis*—value judgment on upper and lower bounds for experimental dosimetric parameters; 'worst-case' value judgments on parameters not amenable to experimental measurement (e.g. soil ingestion by infants).

1.2.5.3 Clean-up criteria

Since the ICRP (IAEA 1996) had not adopted life shortenings as the risk parameter, TAG retained 'individual fatality risk' as the parameter for management. It recommended that as a criterion for rehabilitation the annual risk of fatal cancer following the inhalation or ingestion of contaminated soil should not exceed 1 in 10 000 by the fiftieth year[6].

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[6] Beyond the age of 50 years, the projected risk increases with age, but the level of soil contamination which would correspond to this risk depends markedly on lifestyle, and changes in lifestyle which lead to a reduced exposure (e.g. a move by Aboriginals from camping to living in houses would be likely to lead to a lengthened lifespan for other reasons). A higher incidence of radiation-induced cancer with increasing age is then offset by the reduced exposure so that the lifetime annual risk at a given level of surface contamination is more or less independent of increasing lifespan.

1.2.5.4 Comparison with current intervention principles

Since TAG offered its options to the Government in 1990, the ICRP and the International Atomic Energy Agency (IAEA) have extended the concept of cost-benefit ‘optimisation’ of radiation protection from the regulation of normal radiation practices to interventions designed to reduce future exposures from existing sources, such as the contamination at Maralinga.

In intervention, as in radiation protection, measures undertaken should be optimised to produce the greatest net benefit in terms of cost, duration and scale. It is noteworthy that dose limits do not apply since the use of dose limits might lead to measures out of all proportion to the benefit obtained.

Currently the ICRP and the IAEA are preparing more specific guidance to assist agencies involved in the rehabilitation of contaminated land. They have proposed a ‘generic’ action level of 10 mSv/yr effective dose to an average member of the critical group, above which clean-up would normally be appropriate or restrictions on land use would need to be imposed. Optimisation considerations may point to a lower figure where further straightforward and cost-effective strategies are available.

Seen in this light, the earlier deliberations of TAG that led to the definition of an effective action level of 5 mSv/yr appear very reasonable and quite consistent with current intervention thinking.

1.2.5.5 Engineering work package

A series of engineering work packages were placed with engineering consultants by TAG. The purposes of these packages varied. In some cases, in particular for the 21 formal disposal pits containing plutonium contaminated featherbeds and other localised detritus from the *Vixen B* trials, the aim was to compare, contrast and cost clean-up options (e.g. grouting, exhumation/reburial and in situ vitrification [ISV]). In other cases (e.g. fencing, soil removal, trench disposal), the methodology was fairly well established and the aim was to generate unit costs.

1.2.6 TAG REPORT AND THE CLEAN-UP OPTIONS

TAG was not charged with recommending a particular clean-up option. Rather, its task was to propose and cost a range of options, from that of 'do nothing' (except to maintain existing security and surveillance) through to a situation where any and all the Maralinga lands could be permanently occupied as an outstation location.

In all, TAG considered nine main options and 26 sub-options. The cost estimates varied by a factor of 50, from $A13 million to $A653 million (1988 estimates). TAG made the point in its report that the cost data it developed was ... *of a preliminary nature and resulted from paper studies and minimal field test data* (*Attachment 1.3*, p. 9). Table 1.8 (using data from *Attachment 1.3*) summarises the broad scope of options considered (see TAG report at *Attachment 1.3*).

1.2.7 STAKEHOLDER RESPONSES TO THE TAG REPORT

1.2.7.1 Release of the TAG report

Government consideration of the future management/rehabilitation options started as soon as the final draft of the TAG report became available in August 1990. DPIE initiated discussions among Commonwealth Government departments and expert technical agencies concerning a preferred option to be recommended to the Government.

In November 1990, the TAG report was tabled in the Commonwealth Parliament, together with a Ministerial paper outlining issues the Government considered significant in identifying a preferred rehabilitation option. These issues included the need to effect a long-term solution at those sites seriously contaminated with

Table 1.8 Estimated cost of a broad range of options for Maralinga (*Attachment 1.3*, p. 15).

Options for rehabilitation at Maralinga (excludes Emu costs)	**Cost** ($ million)
Fencing the entire areas and providing a capital investment for maintaining an Australian Protective Services (APS) presence in perpetuity.	13
Replacing intrusion resistant fences, providing a warning fence around the plumes and either exhuming and reburying the contents of the pits, or using a variety of treatments for in situ stabilisation of the pits.	60–70
Fencing of the plumes, collecting and burying the soil from the heavily contaminated treated areas or, alternatively, operating a decontamination process to remove and concentrate the contamination for burial, together with a range of treatments for the burial pits.	80–120
Eliminate the need for fencing and surveillance by mixing of the plume areas to dilute surface contamination, or collecting and burying the contaminated soil. This cost range also incorporates previous options for the burial pits and for the treatment of heavily contaminated areas.	135–650

plutonium, such as the ploughed area and capped pits at Taranaki, and the likely impracticability of treatment of the 120 km^2 area of the *Vixen B* plumes on environmental grounds. The considerable cost of such a treatment (probably several hundreds of millions of dollars) was also a very significant implicit consideration.

The text of the media release issued by the Commonwealth Minister for Primary Industries and Energy on 14 November 1990 is shown as *Attachment 1.4*.

1.2.7.2 Australian Government's preferred option—TAG Option 6(c)

The Australian Government agreed that, as the basis for negotiations with the British, and subject to the outcome of consultations with the South Australian Government and Maralinga Tjarutja, its preferred clean-up option for Maralinga was TAG's Option 6(c).

TAG's Option 6(c) focused on the need for major remedial works at the plutonium-contaminated sites. In particular, it proposed that the:

- areas ploughed during *Operation Brumby* would be removed and buried in an engineered trench;
- formal debris pits would be stabilised using ISV;
- contents of informal rubbish pits would be sorted to recover radioactive objects (if any) and the remaining contents reburied at the same site; and
- *Vixen B* plumes would be delineated at the 5 mSv/yr dosimetric contour, with closely spaced durable warning fences and land-use restrictions applied.

For Emu, the Government agreed to what was defined as Option 9 in the TAG report. These rehabilitation requirements were much simpler as the site was used only for two major trials and a small number of initiator trials using short-lived radioactive materials. The focus at Emu was, therefore, on the removal of debris with souvenir potential.

1.2.7.3 Government consultations with stakeholders

The outcome of the TAG report was presented by the TAG convener at a meeting with the Oak Valley community. The TAG convener also accompanied Oak Valley elders around the Taranaki area to indicate the extent of the plutonium contamination plumes and to seek the views of the elders on the value of various parts of the test site for hunting. The site visit emphasised to the traditional owners the nature of the country contaminated by the *Vixen B* plumes that would be delineated by fences as suitable only for casual access under the Government's preferred rehabilitation option.

The views of the South Australian Government and Maralinga Tjarutja were formally sought through the Consultative Committee. In March 1991, following delays in convening a meeting of Maralinga Tjarutja on the traditional lands due to conduct of traditional ceremonies, Maralinga Tjarutja advised the Government that it endorsed TAG Option 6(c). The traditional owners agreed that, on environmental grounds, decontamination and revegetation of such a large area of sand hill country as covered by the *Vixen B* plumes would prove impracticable. Accordingly, they accepted that restriction of access rather than treatment would seem the appropriate course of action. This endorsement of Option 6(c) was, however, to be subject to payment of a $A45 million financial settlement for restriction of access to the fenced area of the *Vixen B* plumes.

1.3. OBJECTIVES AND SCOPE OF THE PROJECT

In summary, the objectives of the Project implemented at the former tests sites were as stated in the 1995 report of the Parliamentary Standing Committee on Public Works (PWC 1995):

> *The proposed clean-up will reduce the radiological hazard at the test sites to enable Aboriginal traditional land use and transit of the test site area, reduce and possibly eliminate the need for control and surveillance of the sites and remove potential Commonwealth liabilities arising from contamination. It will also enable the land to revert to control of the South Australian Government which has indicated its intention to add the land to Maralinga Tjarutja freehold land, pursuant to the Maralinga Tjarutja Land Rights Act 1984.*

The scope of works at Maralinga was effectively that defined by TAG.

1.4. SETTLEMENT OF CLAIMS ARISING FROM THE BRITISH TESTS

1.4.1 CLAIMS

Maralinga Tjarutja's claim for $A45 million was based on compensation for:

- the risk detriment and disadvantage of living around 120 km^2 of contaminated land in perpetuity;
- the loss of use and enjoyment of approximately 480 km^2 for that period; and
- having to ensure that all persons with traditional interests in the Maralinga lands, their visitors and descendants are kept aware of the contamination and the consequent risks for the next 240 000 years.

The South Australian Government advised the Commonwealth that it supported implementation of rehabilitation Option 6(c) and Maralinga Tjarutja's claim for compensation. It became clear that a major issue for the South Australian Government was to decide on a level of clean-up that was not only technically acceptable, but also acceptable to the traditional owners.

With the signing of the 1968 memorandum of understanding between the British and Australian Governments, the British Government was released, with minor (temporary) exceptions, from any future liability for the Maralinga test sites.

The 1985 report of the Royal Commission, however, recommended that all clean-up costs of the sites should be borne by the British Government. It also recommended that the traditional owners should be compensated for loss of access to test site land since the beginning of the test program by way of technology and services which Aboriginal people regard as necessary to re-establish their relationship with their land.

The Australian Government took the position that no rehabilitation work would proceed at the test sites until the British Government had agreed to make a significant contribution. Once the position of the Australian stakeholders was established, the Government proceeded to raise two issues:

- liability for the clean-up; and
- compensation for the traditional landowners with the British Government.

Australia's approach was to seek a significant contribution to the clean-up, and the entire amount of the $A45 million Aboriginal settlement claim.

1.4.2 SETTLEMENTS REACHED

Late in 1991, Australia's claims were put to the British Government, both at ministerial level and by officials. The British rejected any liability for Aboriginal compensation, but agreed to consider a contribution to the clean-up. Aboriginal delegations visited Britain in November 1991 and September 1992 to support Australia's claims and to underline the detriment suffered by the traditional owners by any delay or failure to resolve these issues.

In 1993, the British Government agreed to contribute a total of £20 million (then approximately $A45 million) in annual instalments over six years as a full and final ex-gratia settlement of Australia's claims concerning the British nuclear test program in Australia. This settlement was recorded in a treaty-level exchange of diplomatic notes. For a brief discussion of the Australian Government's subsequent approval in 1994 of an operational budget for the Project of $A104 million, see *Section 2.3* of this report. The British Government's contribution of £20 million, therefore, met only part of the costs of clean-up. Once the issue of the British Government's contribution was resolved and the Australian Government approved funding for the clean-up project, the Australian Government addressed the issue of compensation with Maralinga Tjarutja.

In December 1994, the Australian Government and Maralinga Tjarutja agreed that $A13.5 million was to be paid to Maralinga Tjarutja in settlement of its claims concerning the British nuclear test program in South Australia. This payment also finalised the liability of the Australian Government to make other payments to the Maralinga traditional owners under Recommendation 7 in the report of the Royal Commission.

In addition to the cash amount, the settlement with Maralinga Tjarutja included significant non-cash items. These included the provision of training opportunities for Aboriginal workers, allocation of works associated with the rehabilitation project to Maralinga Tjarutja, and the preservation of certain infrastructure so that the Maralinga village and airfield could be used as a community resource centre once it had been transferred to Maralinga Tjarutja upon conclusion of the clean-up (see *Chapters 2* and *6* of this report for further information).

The text of a joint media release issued by the Commonwealth Minister for Primary Industries and Energy, and the Administrator of Maralinga Tjarutja on 2 December 1994 is shown at *Attachment 1.5*.

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APPENDICES

1.1 Physical and biological characteristics of the Maralinga and Emu regions

1.2 Half-lives of selected radionuclides

ATTACHMENTS

1.1 Formal communications between Australian and British governments

1.2 Research carried out as part of the TAG Study Program

1.3 Technical Assessment Group (TAG) 1990, *Rehabilitation of former nuclear test sites in Australia*, Department of Primary Industries and Energy, Canberra

1.4 Press release (1990) announcing Maralinga rehabilitation

1.5 Press release Maralinga Tjarutja Settlement (1994)

1.6 Extract from a minute dated 28 November 1991, from JR Moroney, Head, Radioactive Section, Australian Radiation Laboratory

CHAPTER 2

ORGANISATION AND MANAGEMENT

2.1 GENERAL

Following the Australian Government's decision to proceed with the Project, and Maralinga Tjarutja's in principle acceptance of the TAG Option 6(c), organisation of the clean-up began.

The Project was developed and implemented so as to ensure achievement of the expected radiological outcomes; achievement and maintenance of good, safe working and living conditions at the site; and compliance with relevant Commonwealth and South Australian legislation.

The intent was to also maximise employment opportunities for Maralinga Tjarutja at both the individual level and through contracts with the community.

This chapter gives an overview of the:

- organisations and groups involved in the clean-up, their respective roles, and the relationships that existed between them;
- range of approvals that were required before the remedial works were able to proceed at the site;
- nature of the work carried out in the course of the Project;
- communication mechanisms used to promote an informed and cooperative work environment at the site;
- camp infrastructure and operation;
- local impact of the Project; and
- Project budget and expenditure.

2.1.1 THE MINISTER AND THE DEPARTMENT

The Government allocated responsibility for the implementation of the Maralinga Rehabilitation Project to the Minister for Primary Industries and Energy. Thus operational responsibility for the Project rested with the Department of Primary Industries and Energy.

The Manager of the Rehabilitation and Radioactive Waste Management Section in the Coal and Mineral Industries Division of the Department had the designated role of Project Director. The Project Director was responsible for the conduct of all Project operations, including the engagement and functioning of the expert and consultative groups to the Project.

2.2 THE PROJECT 'TEAM'

In addition to those working in the Department, the development and implementation of the Project was brought about by the effort of a diverse range of people working in a range of advisory and/or contractual roles. These included people associated with, or working for:

- the Maralinga Rehabilitation Technical Advisory Committee (MARTAC);
- the Maralinga Consultative Group (MCG);
- the Project Manager;
- the Commonwealth's expert regulatory and environmental monitoring agency; and
- several operational contractors, including those providing services such as earthworks, ISV, health physics expertise, camp management and catering expertise.

2.2.1 MARTAC

The Minister agreed to the formation of an independent expert group to provide high level technical and scientific guidance to the Project in August 1993.

The first meeting of what came to be known as the MARTAC was held in September 1993. MARTAC was comprised of members with expertise and experience in health physics, engineering, geology and nuclear site rehabilitation. Three of them had been members of the earlier TAG. The Department provided the secretariat to MARTAC.

TERMINOLOGY

After the 1998 Commonwealth election when several government portfolios were restructured, responsibility for the Project was transferred to the Industry, Science and Resources portfolio. At that time, Departmental staff employed on the Project within the DPIE transferred into DISR.

For reasons of simplicity, the following abbreviated terms are used in the remainder of this report:

- the 'Minister' refers to the Minister for Primary Industries and Energy (before the 1998 election) and to the Minister for Industry, Science and Resources (after the 1998 election)
- the 'Department' refers to the DPIE (before the 1998 election) and to the DISR (after the 1998 election).

MARTAC's role was to advise the Minister (and, by implication of operational responsibilities, his Department) on strategies for the implementation of Option 6(c). Progress reports were made by the convener of MARTAC to the Minister over the course of the Project. This report to the Minister is the final in that series.

MARTAC's role was advisory and is effectively defined in the Committee's terms of reference (see *Introduction*). Although MARTAC did not manage the Project, MARTAC's recommendations strongly influenced operational policy in relation to, for example, clearance levels and pit treatments, including the use of ISV technology (methodologies that were implemented in the course of the Project).

MARTAC's views were reflected in the scope of works of the Project, and MARTAC endorsed the health physics policy developed by the Regulator (see *Section 2.2.3*) for the Project. MARTAC acted as a source of expert advice on a range of potentially sensitive matters, such as the adequacy of worker protection measures, the extent to which the Project was satisfying its objectives and tasks that might practicably be undertaken by Maralinga Tjarutja Aboriginal community.

In order to be able to make informed recommendations, MARTAC asked that several studies and investigations be carried out over the duration of the Project. The nature and findings of these studies are discussed in *Chapters 3* and *4* of this report. *Chapters 3, 4, 5* and *6* of this report note the role MARTAC has played in relation to the Project.

Under Option 6(c), it was envisaged that major earthworks would need to be carried out in a remote location over large tracts of land (Taranaki, TM100/101 and Wewak), and a novel technique called 'in situ vitrification' (ISV) would be used to condition debris in formal debris pits at Maralinga thought to contain particularly high levels of plutonium. All of this meant that MARTAC was called on to consider and make recommendations on a wide range of technical and logistical issues both prior to and during site operations.

To develop its recommendations for the progress of the Project, MARTAC formally met as a full committee on 17 occasions between September 1993 and June 2001 and held three working party meetings. MARTAC held two joint meetings with the Maralinga Consultative Group in 1999 (see *Section 2.2.2*). Meetings were held at Maralinga, Adelaide and Canberra. In addition, MARTAC communicated extensively by electronic mail and carried out several teleconferences to refine its recommendations and positions regarding Project issues.

2.2.2 CONSULTATIVE GROUP

Following an invitation in September 1993 by the Minister to the South Australian Government and to Maralinga Tjarutja, the Consultative Committee, initially established to discuss and monitor the progress of the TAG study program, reconvened as a new consultative group, but without representatives from Western Australia, and met for the first time on 25 March 1994 to discuss the Project. This was welcomed by the South Australian Government and Maralinga Tjarutja who expected similar arrangements to apply to the implementation of the clean-up.

The Maralinga Consultative Group (MCG) was comprised of representatives of the Department, the Regulator, MARTAC, the Project Manager, Maralinga Tjarutja, the South Australian Government, and the Aboriginal and Torres Strait Islander Commission. Inclusion of the MARTAC convener in the membership of the group ensured a free flow of communication between the two forums. The convener of MARTAC provided summary information at MCG meetings and responded to requests for information on MARTAC's deliberation of Project issues. Communication was additionally promoted between the two forums through the use of informal debriefings immediately after MARTAC meetings. These involved MCG members and those MARTAC members who were able to remain longer in Adelaide and/or Maralinga. Minutes of MARTAC meetings were distributed to MCG members. Communication between MARTAC and the MCG is discussed in *Section 2.4.2*.

As was the case for the duration of the TAG, the MCG did not have a decision-making role. Its role was to serve as a forum in which to discuss and monitor the work being done at the site.

During the course of the Project, the MCG met formally on 19 occasions between March 1994 and August 2000. These meetings were held at Maralinga and in Adelaide.

2.2.3 TEAM STRUCTURE

Throughout the Project, the Department had primary responsibility for implementing Government policy on the clean-up.

From 1991 through until mid-1993, most work associated with the Project was policy-related. During this time, the Department, for example, worked towards agreement being reached between the Australian and the British Governments on the payment of funds towards the proposed clean-up, the establishment of MARTAC, and the reconvening of a consultative group.

In mid-1993, with an agreement imminent between the Australian and British Governments, and the Project verging on moving from the theoretical to the operational stage, the Department set in train those processes required for it to be able to enter into contracts for the delivery of Project-related goods and services.

At this time, the Department directly entered into major contracts with the Australian Radiation Laboratory, Australian Construction Services and Geosafe Corporation.

- Australian Radiation Laboratory (ARL)—contract for the auditing of health physics at the site (in a 'regulator' role), and for the establishment of soil removal boundaries, clearance-monitoring of the land and the provision of lung monitoring services (in an 'environmental monitor' role).

TERMINOLOGY

Over the course of the Project, the three primary organisations contracted to provide services to the Project underwent structural changes of one form or another. Fortunately for the Project, even though the organisations underwent varying levels of change, the personnel associated with the Project from within those organisations remained with the Project. This meant that corporate knowledge of the Project was retained throughout.

For reasons of simplicity, the following abbreviated terms are used in the remainder of this report to refer to the main organisations that underwent structural changes during the course of the Project:

- 'the Project Manager' refers to ACS (April 1994 to the end of 1995; ACS was restructured and renamed as WORKS Australia [WA]), WORKS Australia (early 1996 through to mid-August 1997; WORKS Australia was privatised and bought by Gutteridge, Haskins and Davey [GHD]), and GHD (from 15 August 1997 until the end of the Project);
- 'the Regulator' refers to the Australian Radiation Laboratory (ARL) in its 'regulatory' role as health physics auditor before February 1999 (when ARL amalgamated with the Nuclear Safety Bureau to form the Australian Radiation Protection and Nuclear Safety Agency [ARPANSA]), and then to the regulatory arm of ARPANSA (Regulatory Branch) after February 1999;
- 'the Environmental Monitor' refers to the Australian Radiation Laboratory (ARL) in its 'non-regulatory' role as the provider of radiological clearance monitoring of the site before February 1999 (when ARL amalgamated with the Nuclear Safety Bureau to form the Australian Radiation Protection and Nuclear Safety Agency [ARPANSA]), and then to the monitoring arm of ARPANSA (Environmental and Radiation Health Branch) after February 1999; and
- 'the ISV Contractor' refers to Geosafe Corporation (for Phases 1 and 2 of the ISV work) and to Geosafe Australia (for Phases 3 and 4 of the ISV work).

- Australian Construction Services (ACS)—contract for the engineering design, contract administration and project management of the campsite, operational health physics for the whole of the Project, and earthworks operations. In 1998, the Project Manager's role was also extended to include the project management of ISV operations at the site.
- Geosafe Corporation (Geosafe)—contract to determine the applicability and suitability of ISV to the types of debris expected to be in pits at Maralinga and the geological setting. By the time it became clear that ISV would be used at the site, a wholly owned subsidiary of the Geosafe Corporation, Geosafe Australia, had been formed. ISV application at the site was covered by a contract between the Commonwealth and Geosafe Australia.

A brief overview of the expertise that these organisations brought to the Project, and what they were contracted to provide over the course of the Project, is given in *Section 2.2.4*.

The Department also entered into a limited number of individual contracts for specialist engineering, scientific, health physics and geotechnical advisory services with the companies of several MARTAC members. As the needs of the Project changed over time, so did the Department's use of the following MARTAC members' companies as specialist advisers.

Kylwind Pty Ltd—Engineering Adviser and the Department's representative in relation to the Departmental contracts

During the pre-operational phases of the ISV work and the rehabilitation of large tracts of land, the Engineering Adviser was employed to scrutinise and report to the Department on the conduct of all work associated with the Project and to direct the Project Manager on any changes in the scope of the Project on the Department's instructions.

Radwaste Pty Ltd—Scientific Adviser (engineering)

During the pre-operational phases of the ISV work, the Scientific Adviser (engineering) was employed by the Department to scrutinise the work of the ISV Contractor and to provide oversight of the technical development work associated with the use of ISV at the site. Of particular note, the Scientific Adviser (engineering):

- summarised published data on the Taranaki debris disposal pits and associated firing pads;
- reviewed geochemical assessments of soil believed to be in each debris pit;
- proposed assumptions to make first estimates of the potential sulphur oxide and plutonium content of ISV gases;

- proposed use of radioactive tracers to give more information on plutonium in Taranaki melts; and
- recommended the introduction of plutonium into a trial ISV melt.

BWC Enterprises Inc—Scientific Adviser (Health Physics)

The Scientific Adviser (Health Physics) was contracted to provide:

- advice as a member of MARTAC for the implementation of the Project;
- advice on technical aspects of the site rehabilitation and health physics (including the conduct of health physics audits as part of a health physics review team);
- advice on developments with radioactive waste disposal and test site rehabilitation in the US; and
- such other services as might be agreed between the Department and the scientific adviser.

Geoprojects Pty Ltd—Geotechnical Adviser

The Geotechnical Adviser was contracted to provide professional geological, geophysical, hydrogeological, geotechnical and related advisory services to the Department. In particular, the Geotechnical Adviser:

- was contracted to carry out a range of geotechnical and hydrogeological investigations to support decision making on, for example, the siting of the burial trenches and for the installation of groundwater supply wells for use in dust suppression during the soil removal phases at Taranaki and the TM sites;
- undertook geological and geochemical site characterisation drilling in support of the ISV work on behalf of the Department and/or MARTAC;
- recommended the use of magnetic survey site clearance procedures; and
- reported on the outcomes of the ISV process as applied to certain Taranaki formal debris pits.

In addition to these specialist advisers, the Department contracted the services of HydroGen Pty Ltd and continued its pre-existing contractual relationship with Australian Protective Services.

HydroGen Pty Ltd—a small South Australian-based company

HydroGen Pty Ltd maintained a continuous technical presence at the site to:

- maintain utility supplies (water, electrical generation and telecommunications);
- directly interface with and train Maralinga Tjarutja; and

- conduct a general clean-up of uncontaminated or lightly contaminated waste not covered in the scope of works of the Project Manager.

HydroGen also acted as the Department's representative at the site, fulfilling a 'clerk of works' type role.

Australian Protective Services (APS)

APS provided site security services at Maralinga throughout the life of the Project.

For a discussion of the security arrangements implemented for the Project see *Section 2.5.5* of this report.

Subcontractors

On behalf of the Government and the Department, the Project Manager (as a representative of the Commonwealth) contracted a range of specialist contractors to provide:

- exhumation and general earthworks—Thiess Contractors Pty Ltd (Thiess);
- operational health physics at the site—CH2M Hill Australia Pty Ltd (CH2M Hill); and
- camp services, such as meals and accommodation—SHRM (Australia) Pty Ltd. During the course of the Project, SHRM was taken over by Eurest Australia.

On the privatisation of the Project Manager in August 1997, the Department became the Commonwealth representative in these contracts.

In addition, the Project Manager used the services of AEA Technology (the Health Physics Manager) as a subconsultant to develop the health physics regime and to provide health physics management at the site.

In the course of the Project, the ISV Contractor contracted an Australian organisation, AMEC Mayfield, to carry out design and construction work associated with the ISV equipment. AMEC was also subcontracted to provide operational and maintenance services during ISV operations at the site.

The organisational structure of the Project team in the lead up to the start of full-scale ISV operations at the site is shown in Figure 2.1.

The organisational structure of the Project team during the operational ISV phase and the earthworks phase associated with the rehabilitation of the pits is shown in Figure 2.2.

Figure 2.1 Organisational structure of the Project team (until start of operational ISV at the site).

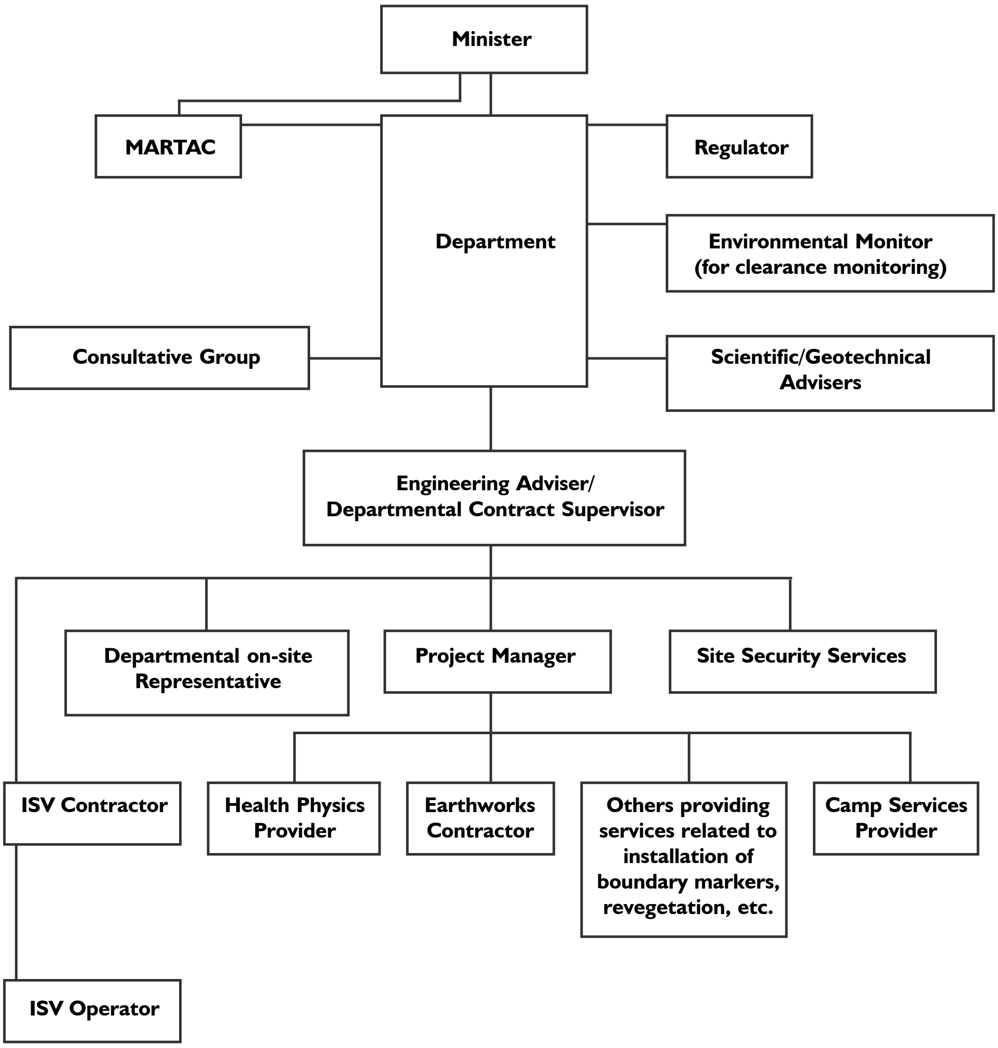
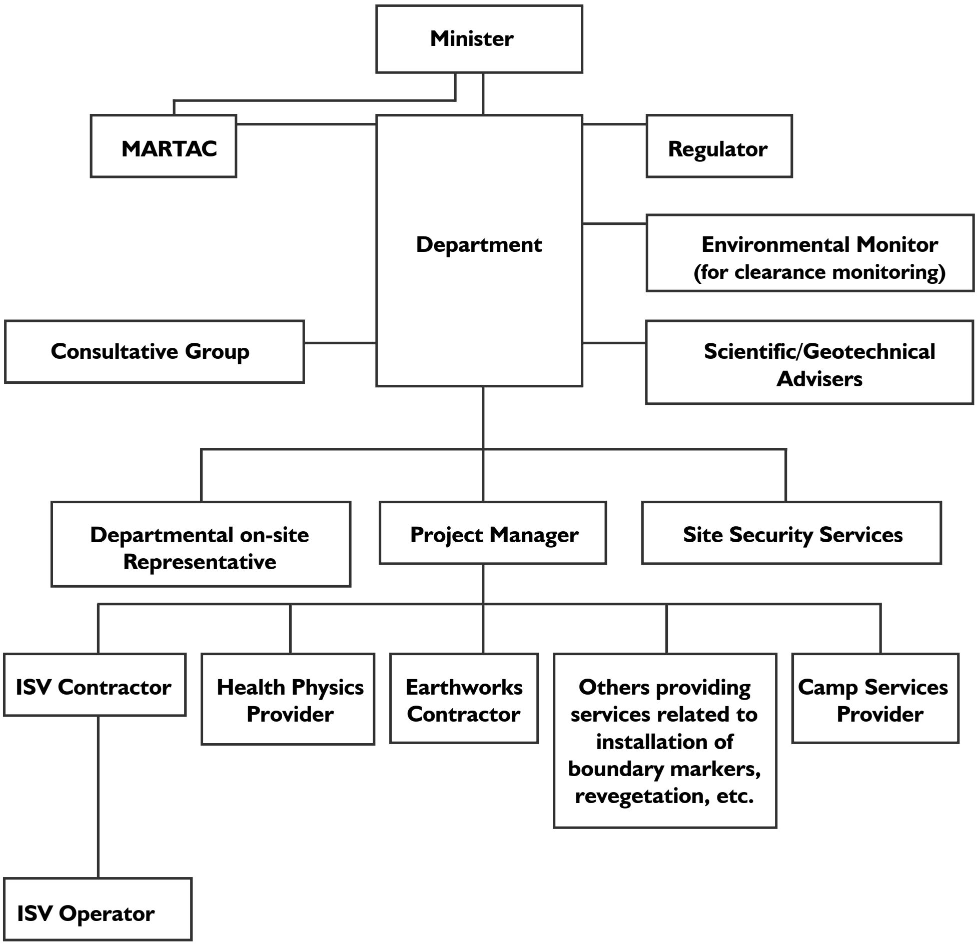


Figure 2.2 Organisational structure of the Project team (after start of operational ISV at the site).



2.2.4 EXPERTISE AND ROLES OF THE PRIMARY CONTRACTORS

2.2.4.1 The Regulator/Environmental Monitor

Prior to 1999, when the *Australian Radiation Protection and Nuclear Safety Act 1999* (Cwlth) was enacted and the ARPANSA was formed, a Commonwealth organisation with a formal regulatory role in the area of radiation protection did not exist.

MARTAC recognised that the clean-up at Maralinga needed some form of regulatory oversight and recommended to the Minister in its first report of 16 November 1993, that the Commonwealth's ARL be contracted to the Project to provide ... *regulatory review and approval of all proposed health physics procedures*. Not only was ARL internationally recognised as a leading source of expertise in health physics and environmental radiation, but a number of its employees had also carried out research at Maralinga since 1978 and were highly familiar with the region and its contamination. A listing of journal articles and publications published by the Regulator on Maralinga can be accessed through the Regulator's website at <http://www.arpansa.gov.au>.

Since 1998, when ARL was subsumed into ARPANSA and ceased to exist as a separate entity, ARPANSA has been the formal regulator of the Project.

Following on from MARTAC's recommendation, the Regulator was contracted to the Project in 1994 to not only provide a regulatory (auditing) role, but also to provide a wide range of health physics and environmental monitoring services to the Project.

The Regulator set out the radiation protection standards and conditions that had to be met by those working on the Project in *Policy on radiation protection practices in the rehabilitation of former nuclear tests sites at Maralinga*. The policy statement was endorsed by MARTAC, the text of which is included at *Attachment 5.1*.

TERMINOLOGY

For reasons of simplicity and consistency of referring to contractors involved with the Project, the following abbreviated terms are used in the remainder of this report to refer to the Project's primary subcontractors:

- 'the Health Physics Manager' refers to AEA Technology;
- 'the Earthworks Contractor' refers to Thiess Contractors Pty Ltd;
- 'the Health Physics Provider' refers to CH2M Hill Australia Pty Ltd;
- 'the Camp Services Provider' refers to SHRM (up until late 1998) and after that to Eurest Australia; and
- 'the ISV operator' refers to AMEC Mayfield.

The content of the policy drew heavily on the joint National Health and Medical Research Council/National Occupational Health and Safety Commission's publication *National standard for limiting occupational exposure to ionizing radiation* (1995) and its associated *Recommendations for limiting exposure to ionizing radiation* (1995). In its specific guidance, the policy document made extensive use of Australia's operating experience and regulatory management of the uranium mining and mineral sands industries[7].

The Regulator formally approved all health physics procedures and had the opportunity to review all 'radiological work permits' and 'method of work statements' that subsequently followed. From time to time, auditors from the Regulator made on-site visits to conduct impromptu inspections of field operations. Formal audit reports were prepared by the Regulator, copies of which were provided to both the Health Physics Manager and the Department.

The Environmental Monitor also provided sensitive lung monitoring services for all 'designated employees' at the site and at their main laboratory in Melbourne (see *Chapter 5* in this report for detail on Regulator's health physics and audit role at the site).

In its Environmental Monitor role, ARL/ARPANSA, for example, determined soil removal boundaries and provided final certification that soil clearance criteria had been achieved (see *Chapters 3* and *4* in this report for detail on the Environmental Monitor's activities in relation to environmental monitoring and assessment).

In 1999, the *Australian Radiation Protection and Nuclear Safety Act 1999* (Cwlth) was enacted and ARL combined with the Nuclear Safety Bureau to form the new organisation ARPANSA, which then took on the role of Regulator. On 4 August 1999, the Department formally applied to the Chief Executive Officer (CEO), ARPANSA for a licence to cover the remaining rehabilitation activities still outstanding at the time at Section 400.

2.2.4.2 The Project Manager

Expressions of interest were invited in September 1993 for the role of Project Manager. Seventy-three requests for information were sought from the Department, with 36 responses being lodged by the 29 October 1993 deadline.

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[7] The health physics regime (including health physics procedures, radiological work permits and method of work statements) that was developed and implemented at the site throughout the life of the Project was focused on ensuring compliance with the policy (see *Chapter 5* of this report, the Health Physics Provider's report [*Attachment 4.7*] and the Project Manager's report [*Attachment 4.4*, *Chapter 13*] for further detail).

In January 1994, these were short-listed to three organisations that were then invited to tender for the Project Manager role. The request for tender documentation included the conditions of tender, a statement of requirements, background information, and a draft contract. The scope of work was left to be finalised as part of the contracted work. At that stage, project management of the expected ISV work was not included in the role of the Project Manager.

The Project Manager brought a team of people with a wide range of expertise and experience in such things as project management and administration, health physics, quality assurance, revegetation, and engineering (electrical, mechanical and civil) to the Project (see the Project Manager's report included at *Attachment 4.4*, *Chapter 2* for details of the Project Manager's capabilities).

The organisational structure of the team put together for the Project by the Project Manager is given in Figure 2.3.

The Project objective defined in the original contract between the Department and the Project Manager was to:

> *Rehabilitate the Maralinga test sites to the level specified by the Department. This will require the collection and burial of contaminated soil, treatment of the contents of some pits, and monitoring of the contents of some …* [informal rubbish] *… pits, erection of some boundary markers, and other minor rehabilitation processes.*

The contract provided for the Project Manager to investigate, design and project manage:

- development of the site infrastructure needed to support the site rehabilitation works; and later
- the actual rehabilitation works (excluding the ISV works).

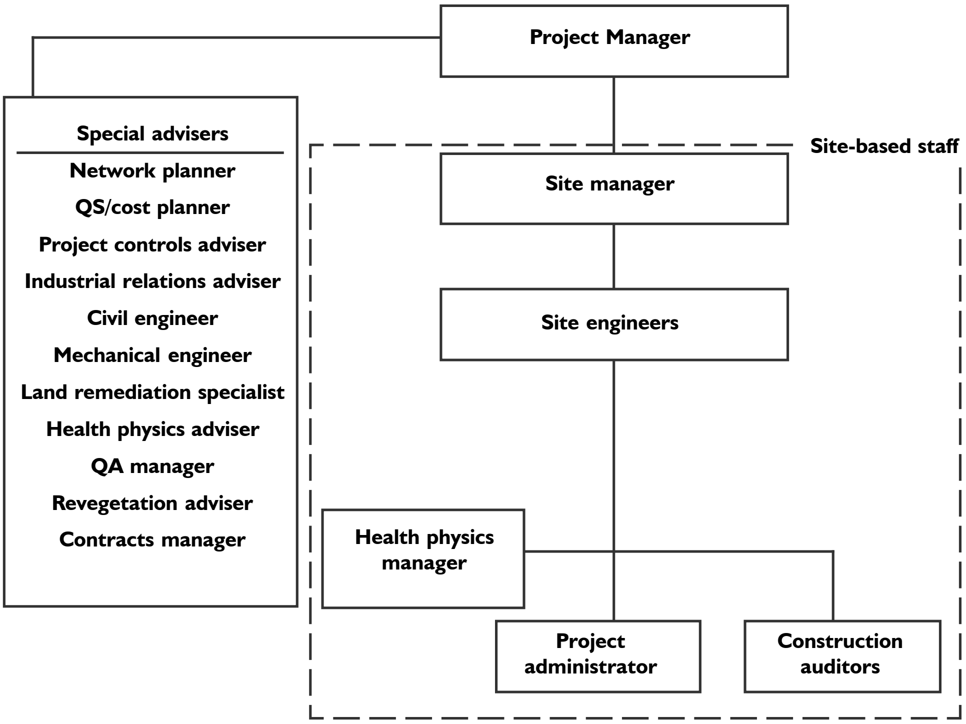
When its contract was varied in 1998 to project manage the ISV Contractor's work, the Project Manager became responsible for all major works at the site.

The Project Manager's role was mainly defined by the scope of works specified in the contract (see *Attachment 2.1*). Over the course of the Project, the Project Manager had responsibilities that included:

- installation of the camp at the Maralinga village and upgrading of village services;
- upgrading of the general site infrastructure, including roads, sewerage, water supply, power generation and the railway siding at Watson;
- installation of forward area facilities at the three soil removal areas at Taranaki, TMs and Wewak;
- construction of burial trenches for containment of contaminated material;

- collection of contaminated soil at Taranaki, TMs and Wewak, placement in the burial trenches and covering with clean soil;
- removal of the contents of several nominated debris pits for burial in the trenches;
- general clean-up and surface restoration around other debris pits and selected areas;
- installation of boundary markers at Taranaki and Emu;
- revegetation of disturbed areas;
- oversight of operational ISV works;
- general rehabilitation of hazards in the Maralinga village area;
- decommissioning of site operations at the conclusion of the project; and

Figure 2.3 Resources and expertise provided to the Project by the Project Manager.



- control and management of radiation protection and occupational safety and health.

The methods of rehabilitation to be used in several areas of the site were not defined in the scope of work, so the Project Manager was required to define and propose several methodologies for consideration by, for example, the Department. In the course of the Project, the Project Manager developed and documented methodologies for the completion of each component of the rehabilitation identified by the Department in its scope of works. These included reports on:

- contaminated soil removal methodology;
- ISV pit slab removal;
- informal debris pits;
- planning of forward area facilities;
- operational plant modifications;
- burial trench methodology;
- formal non-ISV pits treatment options;
- special treatment areas;
- outline design personnel decontamination units;
- plant decontamination units; and
- disposal of plant and equipment from the rehabilitation program.

For a full discussion of the scope of works, changes made to it in the course of the Project, and so on, see *Chapters 3* and *4* of this report, and the Project Manager's report included at *Attachment 4.4*.

As previously indicated in Figure 2.3, in order to fulfil its core responsibility for the control and management of radiation protection at Maralinga, the Project Manager contracted AEA Technology to take on the role of Health Physics Manager as a subconsultant (as defined in the health physics policy included at *Attachment 5.1*), and CH2M Hill to take on the more operational role of Health Physics Provider. For a discussion of health physics at the site see *Chapter 5* of this report.

2.2.4.3 The ISV Contractor

As proprietary owners of the technique, Geosafe Corporation was engaged by the Department as the expert contractor to perform research and development activities to evaluate the potential application of ISV technology at the Taranaki site. Later, its subsidiary, Geosafe Australia, was contracted to carry out the full-scale commercial application of ISV at the site. Geosafe Australia subcontracted to an Australian company, AMEC Mayfield, to construct the ISV equipment and trained AMEC Mayfield staff in the full-scale operation of the ISV technology.

Under the TAG Option 6(c), it was envisaged that the formal debris pits would be treated by ISV, a technique that had the perceived advantage of … *immobilising the pit contents without first exhuming them* (see *Attachment 1.3*, p. 183). The role of the ISV Contractor was to develop, trial, and if appropriate, tailor the ISV process to the specifics of the Maralinga geology and geochemistry, and to the nature of the debris expected from historical records to be present in the formal debris pits.

Application of the ISV technology at Maralinga by the ISV Contractor proceeded in four sequential phases, with the first two being carried out by the parent organisation, Geosafe Corporation, and the last two phases by Geosafe Australia (see *Chapter 4* of this report for full details of the work of each of the phases). For the Maralinga application, the ISV process would melt the soil and debris contained in the pits. The plutonium would be incorporated into a stable leach resistant vitreous/ceramic block with steel debris melting to form an encapsulated steel ingot (Thompson & Constello 1996).

Phase 1

In Phase 1, the ISV Contractor carried out a range of tests and technical evaluations (Geosafe Corporation 1994) to:

- determine the general feasibility of applying ISV at the formal debris pits;
- develop an understanding of the physical site, including the geochemical nature of the near-surface soils; and
- develop baseline information from modelling, crucible melts and small-scale ISV tests to determine how the ISV process would behave in these soil types.

Phase 2

In Phase 2, the ISV Contractor carried out ten engineering-scale tests and three intermediate-scale demonstrations at Maralinga. The work consisted of (Geosafe Corporation 1996):

- on-site tests and demonstrations of the ISV process;
- preparation of a preliminary equipment design for the full-scale ISV plant for use at Taranaki during pit rehabilitation; and
- preparation of a remedial design plan that established the operational plans and logistical considerations for the full-scale rehabilitation operation.

The main objectives of the Phase 2 engineering-scale tests were to collect:

- site-specific data on certain ISV processing characteristics to support the design of subsequent intermediate-scale demonstrations; and
- data to support the preparation of the equipment design and the remedial design plan.

The principal objectives of the Phase 2 intermediate-scale demonstrations were to:

- collect sufficient data to determine if the ISV process could be expected to effectively treat the contaminated soil and debris combinations expected to exist in the Taranaki pits; and
- obtain data to confirm the behaviour and fate of plutonium and plutonium surrogates in the ISV process.

NAMING OF DISPOSAL PITS

During the course of the Project, MARTAC recommended that the only formal disposal pits to be treated by ISV should be those located at Taranaki. As a result, although the ISV Contractor initially carried out work to determine the feasibility of application of ISV to all of the formal debris pits, final testing was only carried out in relation to those formal debris pits at Taranaki.

A discussion of MARTAC’s deliberations is included in *Chapter 3*.

Phases 3 and 4

The Phase 3 scope of work (Geosafe Australia 1996) required the ISV Contractor to:

- prepare the final detailed design of the ISV plant;
- construct the ISV plant and deliver it to the Taranaki site;
- prepare all necessary operating and safety documents to support the operation;
- assemble and commission the ISV plant to ensure it was fully functional and ready to commence operations;
- procure and deliver to the Taranaki site certain supplies and related equipment including diesel fuel and heavy equipment needed to support the ISV operation;
- prepare the site including concrete cap removal from one existing numbered pit and construct the corresponding sand berm as needed to perform the 'operational acceptance test' (OAT);
- hire and train a work force and conduct the OAT; and
- evaluate the OAT and determine whether Phase 3 had been satisfactorily completed including readiness of the plant and staff to commence full-scale treatment operations.

The original scope of work for the ISV Contractor in Phase 4 (Geosafe Australia 1996) was:

- upon completion of the successful OAT, continue with the melting operation to result in the completion of one of the 26 melts;
- continue with the cap removal activities in advance of the ongoing melting operations;
- conduct soil berm construction activities over the tops of the pits and other necessary site preparation activities in advance of the ongoing melting operations;
- conduct ISV operations at 21 Taranaki pits (anticipated to require 26 individual melts);
- as individual pits are completed, the subsidence void created by the melting process will be filled with soil, the area graded, and the concrete cap replaced; and
- decontaminate and or dispose of equipment and demobilise from the site.

For full details of the ISV work carried out at the site by the ISV Contractor, see *Chapter 4*.

2.3 APPROVALS REQUIRED BEFORE REMEDIAL OPERATIONS COULD START AT THE SITE

From the time the Australian and South Australian Governments and Maralinga Tjarutja agreed in 1991 to the rehabilitation of the former nuclear test sites, until the time operations physically started at the site in 1996, a number of Commonwealth legislative and procedural requirements had to be checked and met. These did not happen sequentially, but in a series of concurrent or overlapping timelines. The approvals and procedures required were interdependent—they all had to happen and all responses had to be received before actual work on the rehabilitation at Maralinga could begin. Table 2.1 summarises milestone events in the movement of the Project from the initial acceptance that the Project would go ahead, through to the start of earthworks at the site.

2.3.1 CABINET AND FINANCE APPROVALS

Although the Australian Government and Maralinga Tjarutja agreed to the implementation of Option 6(c) in 1991, it was not until June 1993 that the basis for settlement of outstanding claims against Britain was developed (Evans 1993). The Australian Government announced its ‘in principle’ acceptance of the £20 million offer from the British Government on 29 June 1993 (Evans & Crean 1993).

In August 1993, the negotiated proposal, whereby the British Government finally agreed to contribute £20 million, required Cabinet to again consider the Project. Cabinet reconsidered the TAG Report and Option 6(c), and agreed to a Project budget being established to cover the work. It gave the go-ahead for the Project at an estimated cost of $101 million (±30%). In September 1994, after some refinement of estimated Project costs, the Minister for Finance approved a Project budget of $104.4 million (at 1994/95 prices), but with a narrower range of uncertainty of +15%/-5%. The Project Manager provided assistance to the Department in refining the Project costs.

2.3.2 PARLIAMENTARY STANDING COMMITTEE ON PUBLIC WORKS

The *Public Works Committee Act 1969* (Cwlth) requires that a Joint Parliamentary Committee (Committee) examine major public works funded from the Budget and report back to Parliament. The terms of reference of the Committee required it to consider the:

- stated purpose of the work and its suitability for that purpose;
- necessity for, or the advisability of, carrying out of the work;

Table 2.1 Milestone 'approval' events.

Date	Organisation	Action
1991	SA Government and Maralinga	Indicated acceptance of the Commonwealth Government's preferred option, subject to compensation of Maralinga Tjarutja Tjarutja for denial of access to remaining, but less contaminated, test areas unsuitable for permanent occupancy by Aboriginals living an outstation lifestyle
Jun 1993	Commonwealth and British Governments	Accepted 'in principle' a UK offer of £20 million
Aug 1993	Cabinet	Reconsidered the Project and approved the go-ahead of the Project at a projected cost of $101 m (±30%)
Jun 1994	Department/ Project Manager	Briefed the PWC on the proposed Project
Sept 1994	Department	As proponent of the Project, submitted a 'notice of intention' to the Commonwealth EPA under the *Environment Protection (Impact of Proposals) Act 1974* (Cwlth)
Dec 1994	House of Representatives	Referred the proposed Project to the PWC for its consideration and report to Parliament. At the time of referral, the estimated cost of the Project was $104.4 million (+15%/-5%)
Jan 1995	Department/ACS	Section 30 Referral Report and the CMP provided to the Australian Heritage Commission
Feb 1995	Australian Heritage Commission	Accepted and provided comment on the Section 30 Referral Report and the CMP
Feb/Mar 1995	PWC	Inspected former test sites, held a public hearing in Ceduna on the Project, and received further written submissions
May 1995	Minister for the Environment, Sport and Territories	Advised that the Commonwealth EPA was satisfied that appropriate measures were to be put in place for the Project to deal with the radiological and toxic decontamination of the sites
20 Jun 1995	PWC	Tabled a report recommending the Maralinga Rehabilitation Project proceed subject to an independent assessment of the ISV
27 Jun 1995	Parliament	Approval for the Project to proceed
20 Jun 1996	PWC	Approval of the use of ISV at Maralinga

- most effective use that could be made of the moneys to be expended in carrying out of the work; and
- present and prospective public value of the work.

On 7 December 1994, the House of Representatives referred the Project to the Committee for its consideration.

2.3.2.1 Public comment

As is normal with proposed major public works, the Committee processes allowed for public comment on the Project and an opportunity for Committee members to ensure that all other requirements of Commonwealth legislation had been satisfied in the Project planning stage.

To this end, in February 1995, the Committee inspected several of the sites used for atomic tests and trials, and held a public hearing on the Project at the nearest township of Ceduna. Representatives from organisations and groups appeared and presented submissions to the Committee and responded to questions from the Committee. They included:

- the Department;
- Australian Construction Services;
- MARTAC;
- Greening Australia (SA) Inc;
- Maralinga Tjarutja;
- District Council of Ceduna;
- Australian Radiation Laboratory;
- Aboriginal and Torres Strait Islander Commission;
- Friends of the Earth Australia;
- Mr RH Ashby; and
- Mr Barry Wakelin MP.

Additional written submissions were made to the Committee by:

- Australian Heritage Commission;
- Environment Protection Authority;
- Greenpeace; and
- Tjutjunaku Worka Tjuta Inc.

A number of issues that were responded to by the Department and others associated with the Project were raised in the submissions.

For the most part, those presenting submissions to the Committee expressed support for the Project, citing the environmental gains to be achieved in terms of the end state of the land, and the possible increase in employment opportunities and social benefits that might be generated. Greening Australia took the opportunity to highlight their experience in direct seeding broadacre revegetation. Several pointed out the potential for Aboriginal employment at the site during the clean-up.

Maralinga Tjarutja pointed out in their submission that the Minister had undertaken to effect the clean-up as close as possible to that set out in TAG Option 6(c), and that any variation from it would be fully discussed with them. They commented that the proposed rehabilitation work was extremely cost-effective in comparison with other clean-up options that would have required the total clean-up of the site.

Greenpeace and the Friends of the Earth Australia welcomed the commitment of the Commonwealth to carry out the Project, but expressed concern at the proposed shallow burial of radioactive material and the use of an 'unproven technology' in the form of ISV. As an alternative, they suggested that contaminated material be stored above ground so that it could be retrieved in future and conditioned when technology had advanced.

Other concerns expressed by respondents related to the:

- potential for cost blow-outs in the Project;
- potential problems in removing widespread soil contamination and revegetating the cleared areas; and
- possibility that items of heritage and historical value at the sites might not be appreciated after the hand back of the land to Maralinga Tjarutja.

For a brief discussion as to whether or not any of these concerns were realised, see *Chapter 6* dealing with the long-term stewardship of the site.

2.3.2.2 Conclusions and recommendations of the Committee

On 20 June 1995, the Committee tabled a report in Parliament that made the following conclusions and recommendations:

> *There is a need for remedial action to be undertaken at Maralinga to reduce the radiological hazards at the test sites sufficiently to enable Aboriginal traditional land use and transit of the test site area, to reduce and possibly eliminate the need for control and surveillance of the sites, and to remove potential Commonwealth liabilities arising from site contamination.*
>
> *An independent audit of the results of the in situ vitrification trials of material containing plutonium should be undertaken by competent experts not associated with the project.*
>
> *If the results of the review indicate the in situ vitrification process provides encapsulation and mixing of material to prescribed standards, the process can be extended to full scale treatment of burial pits at Taranaki.*
>
> *If the results of the in situ vitrification trials are inconclusive, or do not provide results to prescribed standards, the further direction of the project should be reviewed.*
>
> *Based on the evidence submitted to the Committee, the burial of contaminated soil and other debris appears to be the more appropriate solution compared with above ground storage.*
>
> *Based on the evidence presented, including advice from technical experts both from Australia and overseas, personnel work practices to be applied during the clean-up appear to be adequate.*
>
> *The proposed clean-up can be implemented under an effective radiological protection regime to ensure that exposure to radiation is kept within internationally accepted limits.*
>
> *This regime will include thorough training of workers to make them aware of the potential radiological hazards involved in the clean-up operation.*
>
> *Detailed procedures covering all aspects of work in contaminated areas will be developed for approval by the Australian Radiation Laboratory, the regulatory body for the project.*
>
> *The Committee recommends the Maralinga rehabilitation project proceed at an estimated cost of $104.4 million at November 1994 prices.*

2.3.2.3 Operational approval of the Project by Parliament

On 27 June 1995, Parliament accepted the Committee's report and gave approval for the Project to proceed as proposed, and with a review of the use of ISV as recommended by the Committee.

Included at *Attachment 2.2* is a copy of the report subsequently developed by ANSTO titled *A report to the Parliamentary Standing Committee on Public Works on mixing and encapsulation of plutonium in situ vitrification trials at Maralinga* (PWC 1996, pp. 8–17). The PWC approved the use of ISV at Maralinga on 20 June 1996.

2.3.3 AUSTRALIAN SAFEGUARDS OFFICE

Under the Commonwealth's *Nuclear Non-Proliferation (Safeguards) Act 1987* (Cwlth), Australia has obligations for the prudent management of fissile radioactive material. With this in mind, the Department approached the Australian Safeguards Office (the Office) prior to the development of the Project, and asked for its advice in relation to the proposed rehabilitation works at Maralinga and Emu.

The Office advised that, although the Project involved nuclear materials, it would only need to be consulted if the Project involved concentrating or enriching special fissionable material (plutonium or enriched uranium). Since the Project involved neither, the Office did not place any obligations on the Project.

2.3.4 HERITAGE CONSIDERATIONS

2.3.4.1 Aboriginal heritage considerations

The Department started consultations with Maralinga Tjarutja at the second meeting of the MCG on 29 July 1994 in an effort to determine those sites at Maralinga and Emu that are of significance to the Aboriginal community. The Department was told at the meeting that Aboriginal heritage issues had already been addressed by Maralinga Tjarutja when it endorsed (subject to compensation) the TAG Option 6(c) which was specific in terms of the sites to be remediated. Specifically, it was noted that the clean-up provided for the protection of sites such as the Piling Rockhole that had been identified as significant by the community.

2.3.4.2 Other heritage considerations

In 1990, two areas associated with the nuclear tests were listed on the Register of the National Estate, by the Commonwealth Minister for the Arts, Sport, the Environment, Tourism and Territories, as being of historical and social significance. They were 'Maralinga village' (see Figure 2.4) and 'forward area, Maralinga atomic weapons testing range'; and 'Emu Field village site and range'.

Maralinga village and forward area, Maralinga atomic weapons testing range

Specifically, the area was defined to include the entire village (see Figure 2.4) and airfield; the minor trial sites and *TM50, Kuli, Dobo, TM2, TM100, TM101* and *Rodent* and *Wewak*; the major trial sites (at *Taranaki, Breakaway, Biak, Marcoo, Tadje, Kite, One Tree)*; the track system connecting the sites; and the forward area and track system.

Emu Field village site and range

Specifically, the area was defined to include the Emu claypan and airstrip, Emu village site at the junction of the Maralinga and Mabel Creek tracks; four *Kittens* sites 7 km east of the track junction; Camera tower sites 11.5 and 21 km east-south-east and south-east of the track junction respectively; *Totem 1* and *Totem 2* sites; the track network connecting all of the mentioned sites; and the area generally north-east of the *Totem* sites containing the downwind range and track network.

The placement of the two areas on the register created statutory obligations on the Department under the *Australian Heritage Commission Act 1975* (Cwlth). In particular, Section 30 of this Act requires that Commonwealth departments refrain from taking any action that might:

- adversely affect a place entered in the register unless there is no feasible or prudent alternative (in which case, all reasonable efforts must be taken to minimise the adverse effects); and

Figure 2.4 Maralinga village, looking east, airfield in background (circa 1990). Only about five of the original British buildings remain.

- affect to a significant extent a place entered on the register until the Australian Heritage Commission (AHC) has had the opportunity to consider and comment on that action.

In 1994, the Department asked the Project Manager to develop both a strategy to ensure the sites on the register would be protected during the Project and a Section 30 Referral Report to the AHC that requested advice as to the appropriateness of the planned strategy.

The AHC responded in February 1995, noting that the main adverse impacts expected at the Maralinga and Emu sites would result from the re-occupation of the Maralinga village, the physical disturbance of areas included in the hazard reduction works, and general disturbance from the intensive use of machinery and vehicles. The AHC noted that the policies and guidelines contained in the conservation management plan (CMP) would form the basis for planning of the Project and for ensuring appropriate measures were taken to protect the National Estate values of the registered areas.

In keeping with the AHC recommendation that public documents for the Project acknowledge that the flora of the area includes a nationally rare species, *Eucalyptus Pimpineana*, it is pertinent to note that this small tree is reasonably widespread throughout the area (see Figure 2.5).

Figure 2.5 A nationally rare species found at Maralinga—*Eucalyptus Pimpineana*.

In February 1997, the AHC recommended that once the Project had been completed and consideration was being given to the future of the site, the AHC should be consulted and a Section 30 referral made to it. The AHC also asked that, although it focuses only on the conservation of heritage values in areas, it would welcome involvement in any consideration of possible tourism ventures in the areas and to be kept informed on the matter.

2.3.5 ENVIRONMENTAL ISSUES

Before any remedial work could proceed at the site, the *Environment Protection (Impact of Proposals) Act 1974* (Cwlth) required that the Department consider the potential for the environment to be affected to a significant extent by the proposed Project.

To this end, the Department developed documentation outlining the Commonwealth's intentions for the test sites in the form of a 'notice of intention' (NOI) and carried out consultations in relation to the development of the Project. The NOI and details of consultations were submitted to the Commonwealth Environment Protection Agency (EPA) in September 1994.

On 24 May 1995, the Minister for the Environment, Sport and Territories formally advised that the Commonwealth EPA had examined the NOI and consultation processes involved in the development of the Project, and had:

> *... advised that it is satisfied that appropriate measures are in place to deal with the radiological and toxic decontamination of the sites, to manage the clean-up of radiological wastes, and to minimise the possibility of any adverse environmental impact.*
>
> *In light of the EPA advice, I have determined in accordance with paragraph 3.1.1(b) of the Administrative Procedures under the Environmental Protection (Impact of Proposals) Act 1974 (the Act) that neither an Environmental Impact Statement nor a Public Environmental Report is required for the purpose of achieving the object of the Act.*

In consultation with the Commonwealth EPA and stakeholder groups, including Maralinga Tjarutja, the South Australian Government and the Project Manager, the Department developed an Environmental Management Plan. Copies of the plan were subsequently made available to all employees and contractors entering the site from mid-October 1996. The Project was conducted in a manner consistent with the undertakings given in the NOI.

2.3.6 RADIATION PROTECTION AND OCCUPATIONAL HEALTH AND SAFETY (OHS) ISSUES

Although these matters are addressed in detail in *Chapter 5* of this report, it is relevant to highlight a couple of matters at this stage.

2.3.6.1 Radiation protection

As previously outlined in *Section 2.2.4.1*, until the Australian Radiation Protection and Nuclear Safety legislation was enacted and took effect in 1999, there were no statutory requirements for the Department in relation to radiation safety at the site.

In the absence of a federal regulator, and with recognition of a need to be seen to be subject to control by a credible body, the Department negotiated an arrangement with the ARL to act as the health physics regulator. The ARPANSA formally took on that role under the Australian Radiation Protection and Nuclear Safety legislation.

2.3.6.2 Occupational health and safety (OHS)

The *Occupational Health and Safety (Commonwealth Employment) Act 1991* (Cwlth) imposed a range of duties on the Department to protect the health and safety of contractors and third parties, to the extent that the Department has control over the workplace and the activities carried out there. No formal approvals were required from the Commonwealth's OHS regulator, Comcare Australia, for the work carried out at Maralinga.

On the basis of legal advice obtained from the Office of General Counsel in 1996, the Department noted:

- to the extent that a contractor has control over the activities that it performs at the site, the contractor is responsible under the South Australian *Occupational Health, Safety and Welfare Act 1986* for its employees and subcontractors while undertaking those activities;
- in relation to contractors with particular expertise, individual contractors have OHS responsibilities commensurate with their level of control over their work; and
- individual contractors must comply with the duties imposed on them under the South Australian OHS legislation.

Contractors at the site, therefore, had responsibility for ensuring that, for example, they only employed appropriately certificated persons and used appropriately registered plant. The level of attention paid to OHS varied substantially from one contractor to the next (see *Chapter 5* of this report).

2.4 PROJECT COMMUNICATION

Given the complexity of the Project, the number of different organisations and specialists involved in the Project, and the remoteness of operations, attention was necessarily paid to the lines of communication that would need to be implemented during the course of the Project. As well as the use of informal channels of communication, a more formal system of meetings and reports was instigated aimed at achieving an informed, efficient, cooperative and harmonious Project environment. Although not without problems, for the most part these aims were achieved. For details of the arrangements that were put in place to engender communication and cooperation at the site, see the Project Manager's report included at *Attachment 4.4*, *Section 17.3.2.*

2.4.1 OPERATIONAL MEETINGS

A system of site and project management meetings was implemented during the Project that focused on different aspects of the Project. Table 2.2 gives an overview of the types of meetings used.

Table 2.2 Types and functions of meetings implemented during the Project.

Name and focus of meeting/committee	Organisations involved	Frequency
Project management meeting The focus of this meeting was to update the Department on latest developments with the Project and on any emerging issues that needed to be resolved or watched. The meeting allowed for a free exchange of views between the Department and Project Manager.	Department and Project Manager	Monthly
Site coordination & consultative meeting The focus of this meeting was to ensure that the operations of all parties at the site were coordinated and that the site functioned in an efficient, harmonious and safe manner. The committee addressed issues that were relevant to the management and operation of the site as a whole.	All organisations at the site	Every four weeks
Site safety meeting The focus of this committee was to monitor the level of overall site safety, to coordinate actions to improve site safety and to investigate any safety incidents. The meeting considered such things as: performance in relation to contractors' OHS plans, safety incidents and accidents, and training adequacy.	All organisations at the site	Every four weeks
Work planning meeting These meetings were held to coordinate field operations and to ensure that the different parties at the site were clear on the work to be undertaken in the coming week and of the implications that this may have on their operations.	All organisations involved in rehabilitation activities at the site	Weekly

In addition to the previously mentioned meetings, two ‘partnering’ workshops were held that involved senior managers from all of the organisations at the site and the Department. These workshops were aimed at identifying at a high level any communication and organisational issues that existed at the site and which could, if left unchecked, present a problem to the efficient implementation of the Project. Charters of relationship and project objectives were developed at these workshops. Actions were subsequently taken to address identified issues and monthly partnering meetings were held at the site to monitor performance against objectives.

2.4.2 COMMUNICATION BETWEEN MARTAC AND THE CONSULTATIVE GROUP

For the duration of the Project, MARTAC’s recommendations to the Department for Project-related activities and changes to Option 6 (c) were provided to members of the MCG through:

- provision of the minutes of MARTAC meetings to MCG members;
- participation of the convener of MARTAC in the MCG; and
- holding, when scheduling allowed, joint MARTAC/MCG meetings.

Both the convener of MARTAC and Departmental representatives conveyed the ideas and concerns of the MCG to MARTAC members.

In addition, after most meetings held at Maralinga, a debrief on the MARTAC meeting was held in Adelaide for members of the MCG who were able to attend. At these debrief sessions, the convener of MARTAC advised on the outcomes of MARTAC’s decisions and recommendations, and on the reasoning behind them.

The convener of MARTAC also:

- visited the Oak Valley community on several occasions to provide briefing on progress with the Project and to discuss on different occasions the objectives of Option 6(c), the proposed program at Emu, the installation of boundary markers at Emu and the hybrid option for the ISV process; and
- attended the ‘Conference of Experts’ held by Maralinga Tjarutja in July 1997 at the Maralinga village to discuss future options for the use of the village by Maralinga Tjarutja after the remedial works at the site had been completed.

The members of the MCG and Maralinga Tjarutja were given several opportunities to visit the site, in the company of the MARTAC convener, to view the progress being made with the rehabilitation, and to discuss specific remedial proposals, such as those relating to Kuli.

2.4.3 SITE REPORTS

The major contractors and subcontractors to the Project (e.g. the Project Manager, the Health Physics Provider, the primary Earthworks Contractor and the ISV Contractor) provided monthly progress reports on their activities to the Department. The Project Manager also provided detailed monthly (generally) reports to the Department on their project management activities and any issues arising from them. Copies of all health physics reports were provided direct to the Regulator by the Project Manager. An overview of the various site reports developed over the course of the Project, included such things as reporting frequency and general content is given in the Project Manager's report included at *Attachment 4.4*, *Section 17.3.3*.

2.4.4 PROJECT BUDGET AND EXPENDITURE

The Project was completed within the budget allocation. Table 2.3 shows the breakdown of final costs for the various work packages of the Project against the respective budget estimate of costs approved by the PWC in November 1994. It may be noted that both the estimated and final costs of ISV were significantly higher than was anticipated in the TAG report. This increase in cost was offset to some extent by savings associated with the work done at Emu, and on the non-Taranaki formal pits and the informal pits. *Chapter 3* of this report details the reasons for the changes that were made to the Project scope of work.

Table 2.3 Breakdown of budgeted cost and actual expenditure for the Project.

Work package	Estimated cost[#] ($M)	Actual expenditure ($M)
Infrastructure (including camp operation)	21.1	12.8
Soil collection and burial	16.4	12.0
Site trials for soil collection	0.2	0.2
Site equipment	1.1	2.7
Boundary markers	0.3	0.5
ISV process[A]	27.2	32.7[B]
ISV trials	2.7	6.5
ISV support (includes exhumation)	1.2	6.9
Non-ISV pits	2.1	0.5
Special treatment areas	0.2	0.2
Revegetation	3.9	0.7
Operational health physics	10.4	9.0
Emu rehabilitation	0.6	–
Department costs	2.0	2.2
Monitoring by ARL/ARPANSA	2.1	5.3
Geotechnical investigations	0.8	0.4
Reimbursibles (including charter flights)	1.9	1.8
Design fees	3.5	3.8
Construction fees	4.3	7.9
Tendering contingency	2.5	–
Total	105	106

[#] Not allowing for inflation increases in budget over time.

[A] With hindsight, MARTAC believes that the cost estimates for the ISV process costs supplied to TAG were unit costs that excluded all but the ongoing operational costs with the possibility that these costs also excluded energy costs.

[B] Only 13 melts of the 26 initially envisaged were completed.

2.5 PROJECT CAMP INFRASTRUCTURE AND OPERATION

The location, design and operation of the Project's camp was developed by the Project Manager and approved by the Department. A policy decision was made early in the Project by the Department to locate the camp at the village and to use, as far as practicable, the existing infrastructure and facilities. Figure 2.6 shows the rear of the old hospital building that was used during the recent Project to accommodate APS staff and where MARTAC meetings were held.

Not only was the village located in a relatively attractive part of Section 400, but it also had the advantage of being at some distance from contaminated areas. Facilities were planned to operate only for the life of the Project, and to be removed on its completion. The camp facilities were designed to address the welfare needs of workers at the site and possible operational problems associated with the remote location of the camp, extremes of climate, shift work and extended work cycles. Work cycles were of four weeks duration, made up of three weeks at the site, followed by one week of rest and recreation in Adelaide. This was changed in March 1998 to a fifteen-day work/six-day recreation cycle which was more appropriate for the ISV phase of the project (see *Chapter 6* of this report for a discussion of the camp facilities and services in the context of the short-term stewardship of the site).

Figure 2.6 Rear of old hospital building.

For a full description of the camp infrastructure and operation, see the Camp Services Provider's report included at *Attachment 2.3*. A brief description of what was developed for use during the Project follows.

2.5.1 CAMP FACILITIES AND SOCIAL ACTIVITIES

During the atomic tests, the Maralinga village was a large establishment. When the Project started, only a few buildings remained, including the hospital, VIP quarters, a bedding store, fire station and some portable accommodation to support the TAG program. The only habitable building that remained from the test period was the hospital, and it had been used in the intervening years since the tests for accommodating APS personnel.

For the Project, a variety of demountable buildings were erected in the village area. They were used for personnel accommodation, medical centre, toilet and ablution blocks, kitchen and messing, recreation, offices, stores and laboratories.

All accommodation, work and indoor recreation areas were fitted with split-level reverse cycle airconditioning. Individual workers' rooms were fitted with a small refrigerator, wardrobe, work area, television shelf, chair and bed.

Attention was paid to the social needs of workers at the site. External sports facilities were constructed, including an above-ground swimming pool, gymnasium area and sports court for tennis, basketball and volleyball. Sports competitions were run, quiz nights were held, videos were shown and attention was paid to providing time off from work to watch national events such as the Melbourne Cup and final rugby and football matches. Figure 2.7 shows the demountable mess area and outdoor relaxation area at the site.

Figure 2.8 shows the view of the outdoor area between kitchen and mess on the south and the recreation facilities containing the pool table, TV, library and relaxation areas, and bar.

2.5.2 INFRASTRUCTURE SERVICES TO THE CAMP

As part of the Project, a range of infrastructure services were either installed or upgraded at the village. These included:

- upgrading and extension of telecommunication facilities, including easy access to a public phone system that allowed workers to call outside the camp;
- significant upgrading of the water supply, with the provision of new bores and a reverse osmosis treatment plant, replacement of an existing elevated water tank, new reticulation to the village, and upgrading of the system for collecting rainwater runoff from the airfield runway;

Figure 2.7 Mess and recreational facilities.

Figure 2.8 Indoor and outdoor recreational facilities.

- installation of a new 'Envirocycle' type treatment plant for treating sewage, with the effluent disposed of to an evaporation pond through existing reticulation;
- installation of additional diesel fuel storage and dispensing facilities for use in the camp power station generators and vehicles; and
- installation of a new load-sensing power supply for the village—it was installed in such a way as to minimise its noise impact in the village area.

2.5.3 TRANSPORT SERVICES

2.5.3.1 Air access

Maralinga airfield was found to be in good condition at the start of the Project and, apart from the erection of barrier fencing to restrict the movement of people and vehicles on to the airfield, did not require any upgrading. Figure 2.9 shows the old airfield building at Maralinga.

For the most part, workers flew in and out of Maralinga by charter aircraft. Ross Aviation Pty Ltd provided air charter services that were reliable and flexible enough to meet the varying needs of the Project over time.

Figure 2.9 Old airfield building at Maralinga.

2.5.3.2 Rail access

The Watson siding, located approximately 40 km south of the village and connected to it by a sealed road, was upgraded in the course of the Project to a state that would allow for the transport of equipment, materials and supplies to site by train.

2.5.3.3 Ground transportation

The strategy adopted by the Department for the roads to be used during the Project was to:

- maintain for the life of the Project those sealed sections of road that would be needed for the duration of the Project; and
- maintain by grading, for the relatively short periods during which work would need to be undertaken to particular sites, the unsealed roads to those sites.

A program of initial repairs to the roads and ongoing maintenance was developed and implemented accordingly for the duration of the Project. A range of road signs were installed along the various roads limiting speed, advising of tight bends, identifying key locations and identifying priorities at intersections.

Motor pools consisted of Commonwealth-owned vehicles and contractor-purchased vehicles with the maintenance on these vehicles being performed by a contractor, HydroGen Services Pty Ltd, in the Maralinga village. These vehicles were used for transport of workers, staff and visitors to and from the job site and the airfield, and for security surveillance.

2.5.4 CATERING AND CLEANING SERVICES

The Camp Services Provider provided a high standard of catering, accommodation and cleaning service at the site throughout the Project. This was particularly true when it came to the provision of canteen services at the site with a generally plentiful, healthy and varied range of food being supplied to workers. This is thought to have contributed to a low employee turnover rate and generally high level of morale, compared to similar remote operational sites.

For a discussion of the services provided by the Camp Services Provider, see its report included as *Attachment 2.3*.

2.5.5 SITE SECURITY SERVICES

Section 400 was a prohibited area throughout the Project and was administered by the Department. Access to the site was strictly controlled and monitored by APS personnel throughout the life of the Project. A minimum of two APS staff was based at the site at all times. Entry to the site was only permitted to visitors and Project workers who had obtained prior authorisation from the Department to do so. The only people allowed at the site were those with a valid reason.

Although some occasional visitors (e.g. local police, Parliamentarians and medical services to community members) were allowed onto Section 400, their movements at the site were supervised by Project management staff. Recreational visitors, such as four-wheel drive enthusiasts, were consistently refused entry. Movement records of people arriving and leaving the site each day were faxed to the Department by APS staff on a daily basis.

For detail relating to security of movement of workers on-site, see *Chapter 5* of this report.

2.5.6 FIRST AID AND EMERGENCY PREPAREDNESS SERVICES

The Project Manager developed and implemented systems at the site to ensure a good level of first aid and emergency preparedness at the site during the Project. These covered such things as resourcing, training and access to the Royal Flying Doctor Service.

For a discussion of the arrangements that were implemented at the site, see *Chapter 5* of this report.

2.6 LOCAL IMPACT

Other than improving the local environment by removing radiological contamination and general hazard reduction, the rehabilitation works carried out at the former test sites were designed to have minimal impact on the sites.

2.6.1 REVEGETATION

As far as practicable, those areas that were disturbed during the Project have been revegetated with local plant species. *Attachment 4.4*, *Chapter 16* describes the methodology used. It is recognised that revegetation will be a slow process, because of the general aridity and salinity of the environment. *Chapter 6* of this report provides information on the final state of the areas at Maralinga.

2.6.2 SIGNIFICANT SITES IN THE AREA

The CMP and associated Section 30 Referral to the AHC placed a requirement on the Department to ensure that the impact of the rehabilitation works on the features of conservation significance identified in the CMP were minimised.

The CMP recognised that features such as the radiating pattern of roads at Taranaki which are of conservation value, would be partly removed where the roads were in the area where contaminated soil was removed. For the most part, there was no impact on the features of conservation value identified in the plan resulting from the rehabilitation works. Overall, the project complied with the requirements of the CMP. The Project Manager's report on compliance is given in *Attachment 6.1* to this report.

2.6.3 ABORIGINAL EMPLOYMENT

Before the Project started, the Australian Government and Maralinga Tjarutja agreed that attempts should be made to maximise opportunities for Aboriginal employment on the Project. Employment and training opportunities were included in the non-cash part of the compensation agreement between the Commonwealth and Maralinga Tjarutja. This agreement included training Aboriginal apprentices and using Aboriginal workers (in conjunction with State Flora) in the revegetation part of the project. The agreement also provided for Maralinga Tjarutja to tender for transport work on the Project and for the erection of boundary markers.

Maralinga Tjarutja personnel undertook collection of local native seed in late 1995 under the guidance of State Flora, South Australia. This seed was stored for later revegetation work.

Early in the Project, a thirteen-week introductory training course in diesel mechanics was run by a qualified diesel mechanic at Maralinga for two Aboriginal trainees in preparation for apprenticeships as diesel mechanics. While the two trainees enjoyed the training, they did not pursue apprenticeships as they did not have the needed literacy or numeracy skills, and were uncomfortable with the formal structure of apprenticeships.

As no other candidates were put forward by Maralinga Tjarutja for apprenticeships, the Department met with Maralinga Tjarutja to seek their advice on more appropriate, alternate training. It was agreed that short competency-based courses might be more suitable.

Short courses were subsequently developed and undertaken by members of the Aboriginal community to allow them to do boundary marker installation work. This training included basic OHS, first aid and driver training. Training in the use of a tractor with posthole digger and rock hammer attachments was also provided.

An agreement between the Department and Maralinga Tjarutja for the casual employment of traditional owners in the clean-up of non-radioactive areas around the village was finalised in February 1996. The proposed work included the clean-up of building debris, dead and fallen trees and other vegetation from around the village, spreading of aggregate around Project buildings, cleaning out of soil and vegetation from the water collection channels at the airport, respraying the water collection dam with bitumen emulsion, as well as recontouring some uncontaminated rubbish pits near the village. The Maralinga Tjarutja administrator and several elders inspected the proposed work shortly before the agreement was signed. Although the work was subsequently agreed and priced, Maralinga Tjarutja were unable to provide workers for the contract.

Aboriginal participation with other subcontractors on the Project was encouraged through the activities of the Project Manager and the Ceduna office of the Department of Employment, Education and Training. This resulted in seven Aboriginal workers being employed by the primary Earthworks Contractor, and one Aboriginal worker being employed by the Camp Services Provider. The Aboriginal workers employed by the primary Earthworks Contractor worked as either plant operators or as utility workers.

A major item of Aboriginal employment on the Project in January 1998 was the erection of a line of boundary markers 80 km long around the plutonium contaminated plumes at Taranaki and 10 km long at Emu. A total of eight Aboriginal workers were employed on this task. During January and February 1998, two Aboriginal workers were employed to clear the weed caltrop from areas of the site, and in August and September 1998, two workers were employed to construct concrete paths in the village camp.

The Health Physics Provider also engaged two Aboriginal employees to do general utility work to support health physics services at the site, including basic radiation monitoring work and record keeping activities. In October 1999, another earthworks contractor (Ceduna Bulk Hauliers [CBH]) employed an Aboriginal worker as a plant operator. In November 1999, one of the Aboriginal workers initially employed by the Health Physics Provider was engaged by CBH. Figure 2.10 shows one of the Aboriginal workers employed on the Project using a foot and hand monitor.

In October 1999, after discussions with, and recommendations from, Maralinga Tjarutja, three Aboriginal workers were employed to carry out some of the general hazard reduction works being undertaken around the village, and for the erection of signs around Kuli.

In response to a proposal by Maralinga Tjarutja to locate a trainee at the village to learn how to operate and maintain the village infrastructure, the Commonwealth funded a trade's assistant trainee position in September 1999. The position provided an opportunity for a member of Maralinga Tjarutja community to gain training and skills in the operation and basic maintenance of the facilities at the village, particularly in the ordering of stores, record keeping, maintenance scheduling and related issues.

The Department asked Maralinga Tjarutja to choose its best candidate for the position. The Project's primary provider of camp maintenance, HydroGen Services Pty Ltd, provided supervision and training. The person recommended by Maralinga Tjarutja did not have the formal trades training and background necessary to make routine maintenance decisions without constant supervision (e.g. problems reading gauges and interpreting data). As a result, the trainee's employment ceased in February 2000. Maralinga Tjarutja's Administrator was invited to discuss with the Department the possibility of the Commonwealth funding another trainee, but this time, one who had formal trade qualifications or who was undertaking an appropriate trades course. It did not prove possible for this opportunity to be taken up.

In 2000, the 'revegetation contractor' (Eyre Native Seeds) employed an Aboriginal worker to carry out revegetation works.

2.6.4 CONSUMABLE GOODS AND SERVICES

Goods and services for the operation of the Project were generally sourced out of Adelaide. However, some goods (such as food and fuel) were sourced from Ceduna and the local region.

Figure 2.10 Aboriginal worker using foot and hand monitor at the site.

2.7 PROJECT ACTIVITY SUMMARY

Although discussed in detail in *Chapters 4* and *6* of this report, it is useful at this stage to give an overview of the major types of activity carried out as part of the Project. Table 2.4 gives an overview schedule of the main activities carried out as part of the Project.

Table 2.4 Schedule of the main activities carried out as part of the Project.

Activity	Start date	Finish date
Construction camp		
Install	15/9/95	12/12/95
Operate	8/5/96	5/5/00
Soil collection and burial		
Modify plant for Class II operations	22/7/96	24/10/96
Install Taranaki 'forward area facilities'	8/5/96	11/9/96
Excavate 'soil burial trenches'		
Taranaki	17/6/96	18/9/96
TMs	27/10/96	19/2/97
Wewak	11/2/97	14/5/97
Clear contaminated soil from defined areas and bury soil in 'soil burial trenches'		
Taranaki	24/10/96	10/8/97
TMs	8/7/97	7/10/97
Wewak	6/10/97	2/11/97
Cap the 'soil burial trenches'		
Taranaki	4/6/97	3/10/97
TMs	27/9/97	13/12/97
Wewak	14/11/97	15/12/97
Windrow cleared areas and seed		
Taranaki	31/5/97	28/11/97
TMs	21/11/97	13/12/97
Wewak	11/12/97	22/1/98
Pit exhumation and restoration		
Exhume debris pits		
Taranaki	27/7/97	20/9/97
TMs	21/10/97	23/10/97
Wewak	16/11/97	30/11/97

Table 2.4 Schedule of the main activities carried out as part of the Project (continued).

Activity	Start date	Finish date
ISV burial trench		
Excavate	5/10/97	30/5/99
Fill	20/11/97	3/4/00
Cap	29/9/99	7/4/00
Taranaki debris pits		
Exhume untreated pits	29/4/99	15/6/99
Remove ISV blocks from treated pits	3/8/99	11/9/99
Final soil placement and seeding	7/1/00	16/3/00
ISV operations		
Phase 2 tests at Taranaki	24/8/95	19/10/95
Design and fabrication of ISV plant	26/6/96	Nov 97
Off-site plant trials	mid-Nov 97	27/2/98
Mobilisation of ISV plant to site	30/3/98	21/5/98
Treatment of Taranaki pits by ISV	21/5/98	21/3/99
Demobilisation of ISV plant	5/11/99	9/12/99
Kuli soil clearance operations		
Collect uranium fragments/particles	28/3/98	4/10/98
Remove and bury soil	1/7/99	10/7/99
Boundary markers/signs		
Install at Taranaki/Emu	6/6/97	11/1/98
Install at Kuli	11/1/99	22/2/00
Install signs/plinths at trenches and at *Marcoo*	5/4/00	1/5/00
Minor works		
Remove and bury asbestos	23/11/99	19/1/00
Debris removal and general hazard reduction program	15/10/99	17/1/00
Site disestablishment		5/5/00

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ATTACHMENTS

2.1 Project roles of members of the Project Manager’s team

2.2 ANSTO report to the PWC

2.3 Camp Services Provider’s report

CHAPTER 3

CRITERIA, STANDARDS AND REHABILITATION METHODOLOGY

3.1 OVERVIEW

The primary focus of the terms of reference for TAG was to propose a set of costed options for the rehabilitation of the Maralinga and Emu sites under a defined range of land uses. From the range of options presented in the TAG report, the stakeholders collectively selected a particular option—Option 6(c)—for implementation.

In the case of MARTAC the primary focus was as put to Senator Parer when he was elevated to Government:

> *Refining the details of the clean-up option 6(c) to ensure that the objectives of the option are met in an internally consistent way.*

Consequently the 'criteria and standards' of the clean-up program were predetermined, even if not quantified, and the emphasis of MARTAC was on the methodology to implement Option 6(c) and the further quantification of the criteria and standards to ensure cost efficiency.

This chapter outlines MARTAC's considerations and recommendations for the Project aimed at meeting the objectives:

- achievement of a substantial reduction in radiological hazards at the former nuclear test sites sufficient for the areas to be safely released from access control for use by Aborigines living an outstation lifestyle; and
- reduction, or possibly elimination, of the need for surveillance of the sites.

3.2 SCOPE OF WORKS—OPTIONS 6(C) AND 9

The original scope of works defined by TAG's Option 6(c) proposed that the:

- areas ploughed during *Operation Brumby* (i.e. areas at Taranaki, Wewak and TMs) would be removed and buried in an engineered trench (see *Section 3.3* of this report for a discussion of the clearance criteria and scope of work implemented for this part of the Project);
- formal debris pits for radioactive waste, numbered by the British, would be stabilised using ISV (see *Sections 3.4* to *3.6* and *Appendices 3.3* and *3.4* of this report for a discussion of MARTAC's considerations and recommendations for these pits);
- contents of the informal rubbish pits would be sorted to recover radioactive objects and the remaining contents reburied at the same site (see *Section 3.7* and *Appendix 3.2* of this report for a discussion of MARTAC's considerations and recommendations for these pits); and
- *Vixen B* plumes would be delineated so as to enclose the 5 mSv/yr dosimetric contour, with a single wire boundary fence (see *Section 3.3.6* of this report for a discussion of MARTAC's considerations and recommendations for the delineation of the plumes).

In relation to Emu (Option 9), the focus was primarily on treatment of contaminated plumes of soil resulting from the two *Totem* explosions (see *Section 3.8* of this report for a discussion of MARTAC's considerations and recommendations for Emu).

3.2.1 CHANGES MADE TO THE SCOPE OF WORKS OVER THE COURSE OF THE PROJECT

MARTAC's primary role was to identify and recommend the work to be done to achieve the objectives of Option 6(c). To varying degrees, MARTAC recommended changes to TAG's interpretation of each component of Option 6(c). Table 3.1 summarises the changes to the scope of works that were made over the course of the Project.

This chapter deals with MARTAC's deliberations and recommendations in relation to the scope of work (see Table 3.2 for a 'road map').

3.2.2 CONTAMINATION AT THE START OF THE PROJECT—THE PLUMES

As previously mentioned, the contamination of the plumes originating at Taranaki was determined by an aerial radiological survey as part of the TAG studies. The results of the survey are discussed in *Section 1.1.4.1* of this report.

Table 3.1 Summary of changes made to the scope of works over the course of the Project.

Aspect	Change made to the scope of works[1]	Rationale
Areas ploughed during *Operation Brumby* (at Taranaki, Wewak and TMs).	Boundary determined by radiological considerations rather than by what was ploughed previously.	*Operation Brumby* boundary did not correlate well with radiological status.
Formal debris pits at Taranaki (i.e. those pits assumed to be heavily contaminated with plutonium).	Only half of the pits treated by ISV, with remaining pits excavated and contents reburied in a deep trench.	Explosion occurred during the ISV treatment of pit 17 causing a re-evaluation of the safety of the ISV process in the Taranaki pits.
	ISV material from ISV treated pits was excavated and buried in a deep trench.	Significantly less plutonium found to be in the pits than had been expected.
		Exhumation and burial of pit contents assessed as an appropriate, long-term treatment method. Site experience in the exhumation of pits and reburial of pit contents in trenches demonstrated the safety and cost-effectiveness of such a rehabilitation approach.
Non-Taranaki formal debris pits[2].	ISV not applied to any of the pits.	ISV not cost-effective due to high establishment costs at widely separated locations.
	Contents exhumed and reburied in deep trenches.	Depth of burial of original debris made exhumation and reburial at an appropriate depth mandatory, particularly where radiologically significant quantities of waste were possibly present.
Informal rubbish pits.	No exhumation and sorting.	Not radiologically justified.
Vixen B plumes.	Fence changed to boundary markers.	Use of a continuous fence would not have been consistent with allowed land use of the plume area.
Emu site.	No soil stripping.	Error in TAG's dose assessment. Once error corrected, found to be no radiological justification for the work.

1 Details are provided in Appendices to *Chapter 3*.

2 Other than at the decontamination and radiobiology (DC/RB) pit 30, for which exhumation and reburial of its contents was proposed, Option 6(c) proposed ISV treatment for all of the formal debris pits).

Table 3.2 Planned 'scope of work'.

Work envisaged under Options 6(c) and 9	**Area of site work**	**Reference in** *Chapter 3*
Areas ploughed during *Operation Brumby*	Taranaki, TM100, TM101 and Wewak	*Section 3.3*
Formal debris pits (radioactive)	Taranaki outside Taranaki Kuli	*Section 3.4* *Section 3.5* *Section 3.6* *Appendix 3.4*
Informal rubbish pits (general debris)	Site-wide	*Section 3.7* *Appendix 3.2*
Vixen B plumes (delineation)	Taranaki	*Section 3.3.6*
Totem plumes	Emu	*Section 3.8*
Marcoo	Marcoo	*Section 3.9*
TM50	TM50	*Appendix 3.1*

3.2.3 CONTAMINATION AT THE START OF THE PROJECT—THE FORMAL DEBRIS PITS

Although the British numbered the formal debris pits reported as containing radioactive debris, they left little quantitative detail on their physical state and radiological content.

Table 3.3 summarises the radioactive contamination thought to be in the pits at the start of the Project (Pearce 1968), as well as MARTAC's estimates over the course of the Project and actual levels determined.

The references to pits 20, 21, 24, 25, 28 and 29 that were included in Table 1.6 have not been included in Table 3.3 for the following reasons.

Pits 20 and *21* (Wewak). These areas were found to be concrete firing pads from the Wewak operations, each contaminated with 0.02 GBq total alpha (10 mg plutonium) from trials of explosive dispersion. A layer of concrete poured onto the firing pads during *Operation Brumby* had locked the plutonium contamination between the two concrete layers. The concrete 'sandwich' was broken up and buried in the Wewak disposal trench.

Pits 24 and *25* (Dobo). These contained only very short-lived radioactivity and were of no radiological significance by the time the Project started.

Pit 28 (Kuli). This was found to be a firing pad. No treatment was required and it was reburied with the contaminated soil.

Pit 29 (Kuli). This was found also to be a firing pad. It was covered with soil as part of the recontouring exercise along with steel scrap and concrete slabs (which probably originated from a blockhouse) that were found to have also been buried there.

No further mention is made of these pits in this report. For a detailed description of what was done at pits 20 and 21, see the Project Manager's report included at *Attachment 4.4*, *Section 9.4*.

Table 3.3 Contamination in the formal waste disposal pits[1].

	Contents (Pearce 1968)	MARTAC (1995)	MARTAC (1998)
Taranaki (Pits 1 to 19, 19A and 19B) UK description: Debris from explosive dispersion of plutonium in *Vixen B* trials (i.e. steel plates, RSJs, lead, cable, concrete, barytes bricks, enriched uranium and beryllium metal, natural or depleted uranium, and polystrene [mentioned for pit 17])	20 kg Pu	1 to 4 kg	1 to 2 kg
Airfield (Pits A to K) UK description: 11 pits; Category 1 (high level)	Th^{228}, Co^{60}	Unchanged	Unchanged
Airfield (Pits A, B & C) UK description: 3 pits; Category 2 (medium level)	Pu^{239}, Th^{228}, Co^{60} & U-natural	Unchanged	Unchanged
Airfield (Pits A, B, C & D) UK description: 4 pits; Category 3 (low level)	3 g Pu^{239} (pit III C)	3 mg to 3 g	Probably close to 3 mg
TM101 (Pit 22) UK description: Debris from explosive dispersion of plutonium in *Tims* trials, steel plates, bitumen, and latex; cables	70 g plutonium (160 GBq total alpha)	Unchanged	Unchanged
Tietkens Plain (Pit 23) UK description: A pit containing miscellaneous debris from *Wewak*, *Kittens*, *Naya*, *TM 100*, *TM101* An unrecorded second pit, containing some plutonium on debris, was known to exist	26 g plutonium (60 GBq total alpha)	Unchanged	Unchanged
TM50 (Pit 26) UK description: A pit containing residual uranium and beryllium from explosive dispersion of natural or depleted uranium, and beryllium; steel plates, miscellaneous metal items, and fragments	Residual, natural or depleted, uranium and beryllium	Unchanged	Unchanged
Kuli (Pit 27) UK description: Explosive dispersion of uranium, steel plates; and lead cables	Residual, natural or depleted, uranium and beryllium[1]	Unchanged	Unchanged
DC/RB (Pit 30) UK description: 22 vehicles and miscellaneous items deliberately destroyed by fire.	Possibly traces of alpha	Unchanged	Unchanged

[1] TAG assumed that about 7 tonnes of uranium was buried at Kuli.

3.2.4 HAZARDS IDENTIFIED BY MARTAC AS NEEDING TO BE ADDRESSED IN THE SOIL CLEARANCE WORKS

MARTAC noted that one of the studies commissioned by TAG found that the Aboriginal outstation lifestyle is important in determining the potential hazard associated with the radioactive contamination of the land (Palmer & Brady 1988). Sleeping on the ground in wiltjas (brush shelters), and a range of activities that cause resuspension of dust, makes inhalation the predominant exposure pathway for both adults and children. In addition, dosimetric modelling had demonstrated that the ingestion of soil was a significant potential exposure route for infants in the first year of life (Haywood & Smith 1990).

Overall, plutonium and associated Am^{241}, uranium and metallic fragments were identified by MARTAC as being the primary hazards to be addressed in the rehabilitation of the sites if the sites were to be made suitable for future use by the traditional owners. Table 3.4 provides a brief overview of MARTAC's comments on each of these hazards.

Of lesser significance to the development of the clearance criteria and standards to be met, MARTAC identified and noted the secondary hazards set out in Table 3.5.

Table 3.4 An overview of primary hazards at the site[1].

Primary hazard	MARTAC's comments
Plutonium	Plutonium presents a health risk if it enters the body through inhalation, ingestion, or through cuts and wounds. The plutonium at Maralinga is in the form of insoluble oxides. Plutonium and its associated americium, in the form and quantities present at Maralinga, do not present a health hazard so long as it is outside of the body. If retained in the lung, plutonium could be a potential risk of lung cancer. In other parts of the body, the greatest risks are of bone cancer or cancer of the liver.
Uranium	Chemically toxic, but radiologically much less significant than plutonium. The toxicological effects are discussed quantitatively in *Appendix 3.5*.
Metallic fragments	Large numbers of plutonium contaminated fragments exist on, or close to, the surface at Taranaki, Wewak, TM100 and TM101. Handling of the fragments could result in the ingestion or inhalation of significant quantities of plutonium. Fragments pose a significant hazard as a source of injury and simultaneous contamination of the wound. With the possibility of greater access and risk of being taken as souvenirs, they pose a risk and therefore cannot be allowed to remain. Large numbers of uranium fragments exist at Kuli. *Section 3.6* and *Attachment 3.4* assess this situation.

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[1] The significance of each of these potential hazards is discussed throughout the rest of this chapter.

Table 3.5 An overview of secondary hazards at the site.

Secondary hazards	MARTAC's comments (Appropriate reports with more detail are appended or referenced)
Ordnance and explosives	Ordnance (shells, ammunition, detonators, and so on) was used during the target response trials at the time of the atomic weapon detonations in 1956. High explosive was part of all assemblies used at all the minor trial sites. Only one item of ordnance, a 25 pound shell, was not accounted for. This shell had been fired during a proving trial, and had not been observed to explode. During *Operation Hercules* a large quantity of ordnance was uncovered at *Tadje*. It was rendered safe. A site within the XA area (the road to Kuli) had been used for disposal of residual munitions from weapons effects trials, and was cleared as safe on two separate occasions, the first clearance given following a major UK/Australian investigation in 1963. Recent examination by Defence munitions experts concluded that the items of concern were inert and confirmed the earlier findings. Confidence was expressed that the danger from explosives at Maralinga and Emu was negligible (see *Attachment 3.1*). Investigations following an explosion during ISV treatment of pit 17 at Taranaki proved inconclusive as to the cause. Further information was sought from the UK but contained no positive lead. *Attachment 3.1* provides the collection of expert advice on the likely current state of any, as yet, unexposed explosive material that was provided to a range of parties during the investigation of the pit 17 explosion.
Beryllium	About 100 kg of beryllium was used in the experiments at Kuli, TM50, Taranaki, and Wewak (see Table 1.4). Much was dispersed, but a quantity is likely to have been buried at these locations. Up to 34 ppm of beryllium were measured during the mid-1960s in samples of surface soil at the firing pad for TM50.
Asbestos	Little is known about the use of asbestos as a building material in Maralinga, but traces of asbestos may have been found during the random backhoeing and sampling exercise through the informal burial pits. Entry into, and scavenging of, the contents of these pits might carry a small potential hazard of pulmonary disease (mesothelioma). A considerable quantity of asbestos pipe and sheeting was located in and around the village (see the Project Manager's report at *Attachment 4.4*, *Section 19.3.6.6* for a discussion on the asbestos that was identified and the removal work subsequently carried out).
Miscellaneous hazardous substances	It is possible that hazardous substances (e.g. heavy metals, organic solvents and polychlorinated biphenyls) are associated with the informal debris pits. These substances could present a minor risk to scavengers.

3.3 REHABILITATION OF *OPERATION BRUMBY* PLOUGHED AREAS AND SETTING OF THE OUTER BOUNDARY

3.3.1 THE PLOUGHED AREAS UNDER TAG OPTION 6(C)

TAG's Option 6(c) envisaged that the soil in those areas that had been severely contaminated with plutonium, and which had been ploughed during *Operation Brumby*, would be removed and disposed of in a purpose-designed burial trench under 5 m of uncontaminated rock and soil cover. This area amounted to approximately 1.5 km^2 at Taranaki, 46 ha at TM100/TM101 and 29 ha at Wewak. These areas are shown in Figures 3.2, 3.3 and 3.4.

3.3.2 KEY EVENTS IN THE ESTABLISHMENT OF SOIL REMOVAL BOUNDARIES AND AREA CLEARANCE

The sequence of steps followed by MARTAC and others to finalise the soil clearance work at the site is shown in Figure 3.1.

3.3.3 ISSUES CONSIDERED IN THE ESTABLISHMENT OF THE MARTAC SOIL REMOVAL CRITERIA

In its development of the soil removal criteria to be applied at these sites, MARTAC noted that the three sites differed from each other in one particularly important respect—their prospective uses. It was noted that:

- the Taranaki site after soil removal would be suitable for unrestricted use by the traditional owners, but for operational convenience was nevertheless expected to remain within the restricted land-use enclosure defined by the boundary markers where activities are limited to hunting and transit; whereas
- the TM100/101 and Wewak sites, after the soil removal clean-up, would be well clear of the restricted land-use enclosure.

A brief discussion of the general issues MARTAC considered in its development of the clearance criteria, follows. *Sections 3.3.4*, *3.3.5* and *3.3.6* include maps of the areas cleared during the Project and the boundary of the restricted land-use area.

Figure 3.1 Key events in the establishment of soil removal boundaries and area clearance.

Step	Body	Activity
1	MARTAC	Defined criteria for contamination levels above which soils would need to be removed. **See Note 1**
2	Regulator	Determined in the field the physical boundaries for the soil removal. **See Note 2**
3	Earthworks Contractor	Removed soil within the boundaries such that contamination levels were believed to fall below the soil clearance criteria for contamination levels. Progressively evaluated by Project Manager using monitoring data determined by Health Physics Provider. Put removed soil in large burial trenches. **See Note 3**
4	Regulator	Carried out monitoring to confirm that the residual contamination on the ‘cleared’ areas met the specified limits. Issued clearance certificates for the cleared areas. **See Note 3**
5	Health Physics Provider	Estimated plutonium contamination in soil disposal trench. **See Note 3**

1 MARTAC noted that the ground radiological surveys conducted in 1985 by the ARL (Lokan 1985) of the inner Taranaki area and TAG’s aerial radiological survey (EG&G 1990) indicated that the boundaries of the ploughed areas along the northwest plume had not fully enclosed the area exceeding the criterion set by the UK at the time. This arose because of insensitive instrumentation and in part because the UK survey which preceded *Brumby* had used a polar coordinate system, so that at greater distances the density of measurements became very sparse.

Although this lack of boundary definition was not important for TAG’s exploration of the range of clean-up options and preliminary costings, when it came to the development of appropriate, practical specifications for the scope of the engineering works during the Project, the lack of a specific boundary definition was important. Therefore, as part of the Project, MARTAC had to develop a set of verifiable criteria for the soil-clearance work. The criteria developed by MARTAC for the plutonium-contaminated sites are set out in *Sections 3.3.4* and *3.3.5*.

2 Using MARTAC criteria for a guide, the Regulator carried out field monitoring to define the operational boundaries of the soil removal work.

3 Steps 3, 4 and 5 are dealt with in *Chapter 4* of this report.

3.3.3.1 Issue 1: Occupancy factor

Occupancy factor is an important parameter in radiological assessments. A requirement arising from TAG's terms of reference was to assume traditional owners would occupy the Maralinga lands on a full-time basis while practising an outstation lifestyle.

Quantification of the activities undertaken in an outstation lifestyle and the time spent on them followed from the anthropological studies commissioned by TAG (Palmer & Brady 1988).

In transposing the anthropological findings to future kangaroo hunting, two changes—one recent, the other in the near future—have to be borne in mind:

- since fettlers are no longer stationed at the Watson siding, on the transcontinental railway line, it is no longer a 'service centre' for the community, offering tyre repairs, minor vehicle repairs, skinned rabbits and so on; and
- the community plans to develop the Maralinga village into a resource centre to provide a range of services.

Accordingly, MARTAC assumed that the time that was spent in opportunistic hunting of kangaroos in the environs of Watson and during the journey from Yalata to Oak Valley would in future be replaced by opportunistic hunting between Maralinga village and Oak Valley, via the Murpu track, West Street and Western Avenue route. This area, plus the area not specifically identified by Palmer and Brady (1988), was equated to the lands enclosed by the boundary markers since, broadly, the area north of the enclosure and to the west of it are separately treated hunting areas in the anthropological study and hunting there is undertaken for cultural reasons (see Figure 10.7, Palmer & Brady 1988). The areas equated here to the restricted enclosure account for 36% of the total time spent hunting.

The dosimetric study commissioned by TAG (Haywood & Smith 1990) used the anthropological study data together with the experimental data on dust loading and intakes reported by TAG Study Reports 3 and 8 (AAEC 1990a, 1990b) to compose tables on average dust loading for the range of activities undertaken by community members and the time spent per week on those activities. The parts of this information as it applies to adult male members of the community are reproduced here as Tables 3.6 and 3.7.

These tables show that 13 hours per week is spent on hunting and associated driving. Of this, 36%, or 4.7 hours is considered to take place within the restricted land-use area.

Two major components in the radiological risk to users of the land—wound contamination and inhalation—occur within the enclosed area.

3.3.3.2 Issue 2: Hunting and dust inhalation

TAG determined that the dust loading weighted average over all aspects of the outstation lifestyle was, for adults, 1 mg/m^3 of inhaled air. During hunting, dust loadings ranged up to 10 mg/m^3 for some components and the weighted average value for that activity was 5 mg/m^3. Thus, while adult males only spend an average 13 hr/week on hunting and driving, the hunting activity is responsible for approximately 39% of the weekly dust intake. Of this quantity 36% arises from within the enclosure.

3.3.3.3 Issue 3: Wound contamination and hunting in the enclosure

TAG commissioned animal studies in an attempt to quantify the risk associated with wounds that are contaminated with Am^{241} and plutonium. The results were very variable, perhaps because of the nature of the substrate (e.g. plastic, iron, aluminium, silica) and the temperature of the substrate at the time it was dispersed by the *Vixen B* explosion.

Over and above that variability, the probability of a known surface fragment density leading to a contaminated wound involves a series of compounding factors, most of which can only be approached as a ‘best guess’.

Table 3.6 Average activity profile of adult male members of the community.

Activity	Time spent (hr/week)
Sleeping	79.5
Sitting, talking, playing cards	35
Eating	21
Gambling, coin games	4.5
Hunting, driving	13
Cooking, butchering	4
Vehicle repair	7
At Watson	4

Table 3.7 Average dust loadings for adults of the community.

Group activity	Rounded average dust loadings (mg/m^3)
Adult: passive (sleeping, sitting, talking, eating, playing cards)	0.5
Adult: semi-passive (cooking, butchering, vehicle repair)	1
Adult: active (hunting, digging, driving)	5

Consequently, neither TAG nor MARTAC were prepared to ‘estimate’ the substance of the wound contamination exposure route. Nevertheless, both committees acknowledged that the risk coefficient would be much higher (probably orders of magnitude higher) for fragments of sufficient size and level of contamination that could cause the wound and contaminate it at the same time.

A risk assessment for this pathway is much more concerned with fragments that arose through explosively dispersed debris from the weapon support system and surrounding monitoring gear (e.g. paraffin wax, steel, aluminium, lead, plastic) that were contaminated by plutonium plateout, than with the finer particles formed through coalescence and condensation within the burning plutonium plume.

3.3.3.4 Issue 4: Regulator’s advice regarding fragments

As a result of extensive field experience, the Regulator was able to advise MARTAC that if all contaminated soil within a 40 kBq/m^2 Am^{241} contour (approximately 280 kBq/m^3 Pu^{239}) were removed, then they would expect all debris type fragments to have been eliminated.

The Regulator also investigated and published data on the surface density of fragments contamination above a range of specified levels for areas heavily and moderately contaminated and for areas drawn from a location believed to be contaminated only with fallout from the plume (Burns et al. 1986).

MARTAC decided to impose the characteristics of the last mentioned plume area with respect to contaminated fragments and soil. *Sections 3.3.3.5* to *3.3.3.6* set out the criteria MARTAC developed for defining the soil removal boundary and soil removal.

3.3.3.5 Issue 5: Radiological risk from hunting in the enclosure

Using data for the Taranaki north-west plume area, TAG determined that the boundary markers could be located on lands no more contaminated than 3.5 kBq Am^{241} per square metre (1987 Pu:Am ratio; approximately 7.2 for NW plume). If ten-year-olds spent all their time undertaking all their activities on lands with this level of contamination then their annual dose commitment would not exceed 5 mSv. Because of different daily activity profiles and differing dust loadings associated with adult activities, the corresponding figure for adult males is 4.1 mSv/yr with inhalation contributing 88% of this figure (Haywood & Smith 1990).

For the situation envisaged by TAG, all activities were conducted along the boundary defining the enclosure containing the plutonium-contaminated plumes that arose from the safety trials at Taranaki. TAG further assumed that after the removal of the soil from the plumes areas previously ploughed by the British then the area within the enclosure would be suitable for all uses short of an outstation class of occupancy.

For TAG's boundary situation the annual dose for an adult is 4.1 mSv/yr with 88% of this (3.6 mSv/yr) arising from inhalation. Since hunting accounts for 39% of the total dust intake, then 0.39 x 3.6 = 1.4 mSv/yr arises from inhalation during hunting. The remainder of the annual dose (4.1 – 1.4 = 2.7 mSv/yr) arises from all activities other than hunting that are carried out at the boundary location.

When hunting is allowed within the enclosure, the two extra factors needed for assessing this dose are:

- the time spent hunting within the enclosure (i.e. the dust inhaled during this activity); and
- the degree to which this dust is more contaminated than that which would have been inhaled at the boundary situation.

The overall requirement is that this extra dose arising from hunting in the enclosure does not raise the total annual dose to more than 5 mSv/yr. Since the total annual dose for TAG's boundary situation was 4.1 mSv/yr then there is a requirement that the extra dose arising from hunting in the enclosure be less than 1 mSv/yr.

The enclosure provides grounds for 36% of the time spent on hunting.

For hunting, only that carried out in the enclosure above 3.5 kBq Am^{241} per square metre leads to an additional committed dose since this is the only area used for hunting that is contaminated above 3.5 kBq/m^2. The hunting in this zone involves random paths between limits of contamination of say 3.5 kBq/m^2—the outer boundary—and the soil removal boundary criterion. For the moment, suppose this to be 40 kBq/m^2. The average activity experienced during these random paths would be determined by the average, weighted by the product of total area at each band of contamination.

For simplicity consider the following derivation of the area of the plumes relative to the total area of the enclosure (approximately 475 km^2). The north-west plume can be approximated to a triangle with a base of 18 km, a half height of 4.2 km, and an area of approximately 76 km^2. The northern plumes can be approximated to two rectangles each of area 15.6 km by 1 km for a total area of approximately 32 km^2. Thus there is an area 'dilution' of 475/108 (i.e. 4.4). This ratio is so large because a large area of uncontaminated land is included in the land-use restricted zone; a consequence of conservatism by the Regulator in defining the northern extremity of the contaminated area and the desire of the traditional owners to have the boundary markers follow, wherever practical, the existing road system. Outside of the 3.5 kBq/m^2 contour for the plume the Am^{241} surface contamination falls rapidly to zero. For the plumes the average Am^{241} surface contamination can be set at the arithmetic average of 40 and 3.5 (i.e. approximately 22 kBq/m^2). The average Am^{241} surface contamination level then is determined by 108 km^2 of 22 kBq/m^2 and 367 km^2 of 0 kBq/m^2, which gives 5 kBq/m^2 of Am^{241} for this average.

Thus the extra annual dose arising from hunting in the enclosure is the fraction of total hunting time spent in the enclosure (0.36) multiplied by the annual dose arising from hunting at the marker boundary situation (1.4) multiplied by the degree to which the average surface contamination within the enclosure is greater than that for the marker boundary situation (5/3.5 = 1.4) (i.e. 0.36 x 1.4 x 1.4 = 0.7 mSv/yr).

MARTAC therefore judged that hunting in the enclosure from which soil with an Am^{241} surface concentration of greater than 40 kBq/m^2 had been removed would lead to a dose that fell within the requirements of Option 6(c).

Since the surface activity concentrations at the soil removal boundary were generally in the range of 15 to 20 kBq/m^2, the contribution from hunting was closer to 0.3 rather than 0.7 mSv/yr. Further since most of the boundary to the enclosure is on uncontaminated land, the dose resulting from living on the boundary is less than 0.6 mSv/yr (*Attachment 6.2)* so the total annual dose *from all activities* for the hunter is less than 1 mSv/yr.

3.3.3.6 Issue 6: Natural resuspension

The primary radiotoxicant at Maralinga is Pu^{239}. For the most part, because it was explosively dispersed into the environment, it exists in the high-fired oxide form, making it very insoluble as a metabolite. Because plutonium decays by alpha emission, it requires very close proximity to living cells for significant periods of time to be a potential concern to health. This makes inhalation the pathway of concern.

In order to perform dose estimates for people who will be occupying plutonium-contaminated land, a number of relevant factors must be known. A few of the important physical parameters are:

- size of the contaminated area;
- wind speed;
- particle size distribution;
- enhancement factor;
- soil type; and
- vegetative cover.

Church (1997) lists additional detail. These and other physical conditions affect the ability of the plutonium-contaminated particle to resuspend and become available in the breathing zone of a potential recipient.

Resuspension is largely an area phenomenon that requires a fairly large area where the contamination is on or very near the soil surface. This footprint area (known as the 'footprint fetch') influences high volume air sampling (Shinn & Gouveia 1992). The worst case discussed by these authors is for bare soil, and indicates that for a sampler at a height of 1.13 m, 90% of the representative flux can be influenced by particles coming from as far away as 175 m. When soil cover (e.g. vegetation) is present, the distances are much reduced. Because of this area influence, measuring or determining plutonium soil activity as an area average (e.g. Bq/m^2) is important.

The parameter that has been observed to be a good indicator of the ability to influence dose is the 'resuspension factor'. This parameter is expressed as a unit of inverse metres (m^{-1}). Data presented by Church (Church et al. 2000), shows this parameter measured at three desert sites where plutonium was explosively dispersed and where other conditions are similar, to also be similar.

A noteworthy difference is at Palomares in Spain—an agricultural site where a nuclear weapon's chemical high explosive detonated after having been accidentally dropped from an over-flying US aircraft. The resuspension factor (S_f) observed at inner Taranaki prior to the remedial action was 6.0 E-11 m^{-1} (with vegetative cover) and 3.2 E-10 m^{-1} immediately after clean-up (bare soil and calm conditions), and 4.7 E-9 m^{-1}, under windy conditions. At Palomares, the S_f was 1.0 E-7 m^{-1} immediately after the explosive dispersal, reducing to 1.0 E-9 m^{-1} at two months, and 1.0 E-10 m^{-1} after a few years. Bioassay samples of the Palomares residents present and out of doors at the time of the plutonium dispersal were positive. However, those individuals born or moving to Palomares later have failed to show positive bioassay samples.

Both the resuspension factors measured and actual human data acquired indicate that plutonium deposition that is aged approximately two months or more is minimally resuspended and available to potentially expose a human. This same observation was obtained during the Maralinga clean-up where data from 4505 samples had only one result exceeding the action level of 100% of the derived air concentration (DAC) (0.6 Bq/m^3 of alpha contamination). That only one sample exceeded the action level and in an area where personnel worked in modified plant, shows that occupational exposure to environmental airborne contamination was very low.

Another major observation occurred during a dust storm from the north just as the most contaminated areas in central Taranaki had been opened up during the soil-removal phase. The storm was strong enough to reduce visibility to zero for five to ten minutes. None of the perimeter air samplers recorded a significant reading for that day.

These combined experiences and observations leads one to conclude that aged plutonium deposition in the environment where the pathway for exposure is inhalation is of minor concern.

Consequently, the land-use restrictions for the area enclosed by the boundary markers restrict use to those activities that would not introduce infants to the area. For infants, the concern is soil ingestion. This arises in part through the value used by TAG for the amount of soil ingested per day by an infant (10 g) and in part because the value recommended by the ICRP for the transfer of plutonium through the walls of the gut of an infant is a factor of ten higher than the value recommended for the adult gut.

3.3.4 TARANAKI

The presence of large numbers of highly active fragments and particles at inner Taranaki led to additional criteria being developed since the contamination of wounds represented a further exposure pathway and there was potential for deliberate collection and souveniring of plutonium-contaminated debris. Thus, the final soil removal boundary at Taranaki was set to satisfy the following overall criteria:

- the average level over a hectare would not exceed 40 kBq/m^2 Am^{241};
- no particle or fragment exceeding 100 kBq Am^{241} would be present; and
- particles of activity greater than 20 kBq Am^{241} would not exceed a surface density of 0.1 per square metre.

After soil removal, the residual Am^{241} surface activity concentration, averaged over a hectare, was not to exceed the value of 3 kBq/m^2 (1998 Pu:Am ratio[8]), the value that defined the fence line for unrestricted occupancy in 1998. This value has the virtue that should a future re-assessment dictate lower levels for the soil removal boundary, then it is unlikely that further removal of soil would be required from the area already treated. However at Taranaki and at the other sites, the Regulator was given the discretion, for circumstances where further improvement would be extremely difficult, to clear lots where individual hectares may exceed the clearance value by up to a factor of three. Typically, lots were 3 to 5 ha in area (see *Chapter 4* for details).

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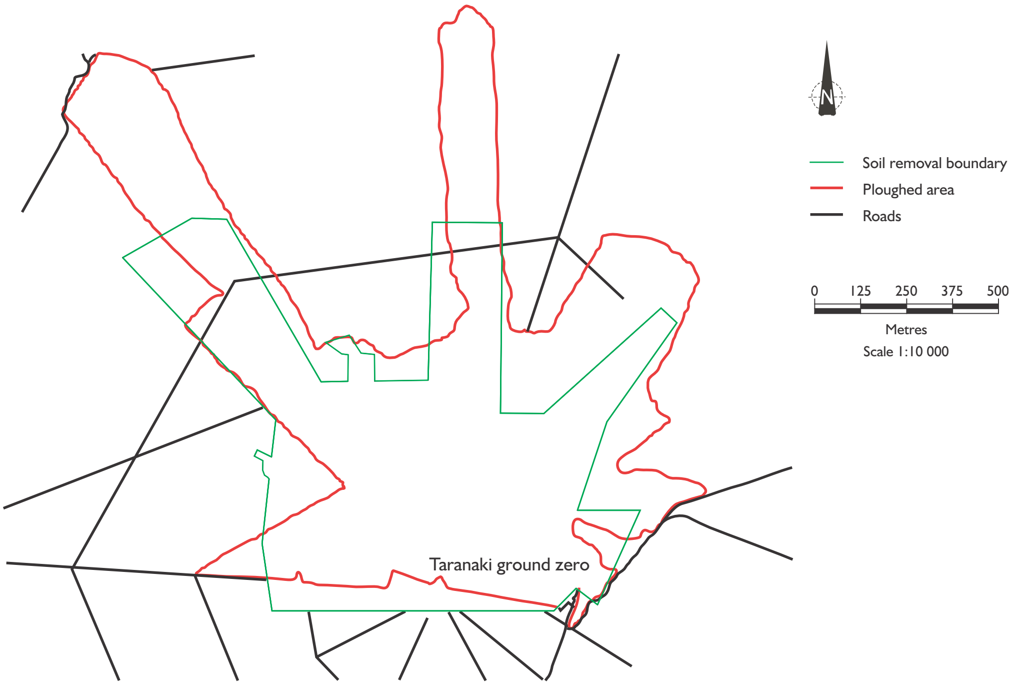
[8] The Pu^{239}:Am^{241} activity ratio decreases over the first 70 years as Am^{241} grows in from the shorter-lived Pu^{241}. Beyond 70 years it declines slowly as the Am^{241} itself decays. The values used by TAG were as measured in 1988. Since then, the ratio had fallen by approximately 16%. As a consequence 3.5 kBq/m2 reduces to 3.0 kBq/m2 of Am^{241}.

In the event, this only occurred for five individual hectares at Taranaki, and in all cases, the average for the lot was well below the clearance value. For operational practicality the value of 3 kBq Am^{241}/m^2 was averaged over a hectare.

The boundary of the area (149 ha) scraped at Taranaki is shown in Figure 3.2. Also shown is the area previously ploughed during *Operation Brumby*. Most of the change relative to the acreage ploughed relates to the north-west plume and the extremities of the ploughed areas that were recorded with zero final contamination during *Operation Brumby*.

Figure 3.2 Area cleared of contaminated soil and fragments at Taranaki and area previously ploughed by the UK.



3.3.5 TM100, TM101 AND WEWAK

No formal soil-removal boundary criteria had been defined by the Environmental Monitor for the TMs and Wewak, and the quantification of the boundaries were set in joint discussions between MARTAC and the Environmental Monitor to match the inhalation dose criteria that had been applied at Taranaki. Accordingly, soil was to be removed to ensure that the final average over 3 km^2 should not exceed:

- 1.8 and 4.0 kBq/m^2 at TM100 and TM101 (see Figure 3.3); and
- 1.8 and 0.7 kBq/m^2 for the Wewak plumes and the VK33 plutonium burning site at Wewak respectively (see Figure 3.4).

The Environmental Monitor took these levels as clearance criteria and took 1 ha as the appropriate averaging area. This is described in an internal ARL document—*Procedures for Clearing Lots, February 1997*—that drew its inspiration from an exchange of correspondence in 1994 between ARL, the Department and the MARTAC convener. This was based on the general policy that annual inhalation doses for continual occupancy should not exceed 5 mSv. The values took into account differences in the Pu:Am ratio, enhancement factors and solubility classes for plutonium. Criteria for particle removal remained the same as they were for Taranaki.

Although the fragment and particle criteria for the TM sites and Wewak were the same as for Taranaki, in practice all fragments and particles above 30 kBq Am^{241} were removed. This was because their relative abundance and the generally lower radiation background made it easy to locate them at these sites.

The ability to average over 3 km^2, used to define the fence line for unrestricted occupancy at Taranaki, meant that the area averages given above would have been met without any soil removal at the TM and Wewak sites, because the areas were so small. ARL, therefore, set the boundary at five times the clearance levels stated above, when averaged over a hectare.

In the final analysis, the fragment and particle criteria always determined soil removal boundaries; surface activity concentrations at the boundaries were usually one-half to one-third of the values specified for residual surface activity concentration.

The boundaries to the areas so treated at TM100, TM101 (47 ha) and Wewak are shown in Figures 3.3 and 3.4 respectively. Both also show the area previously ploughed by the UK.

Figure 3.3 Area cleared of contaminated soil and fragments at TM100 and TM101 and areas previously ploughed.

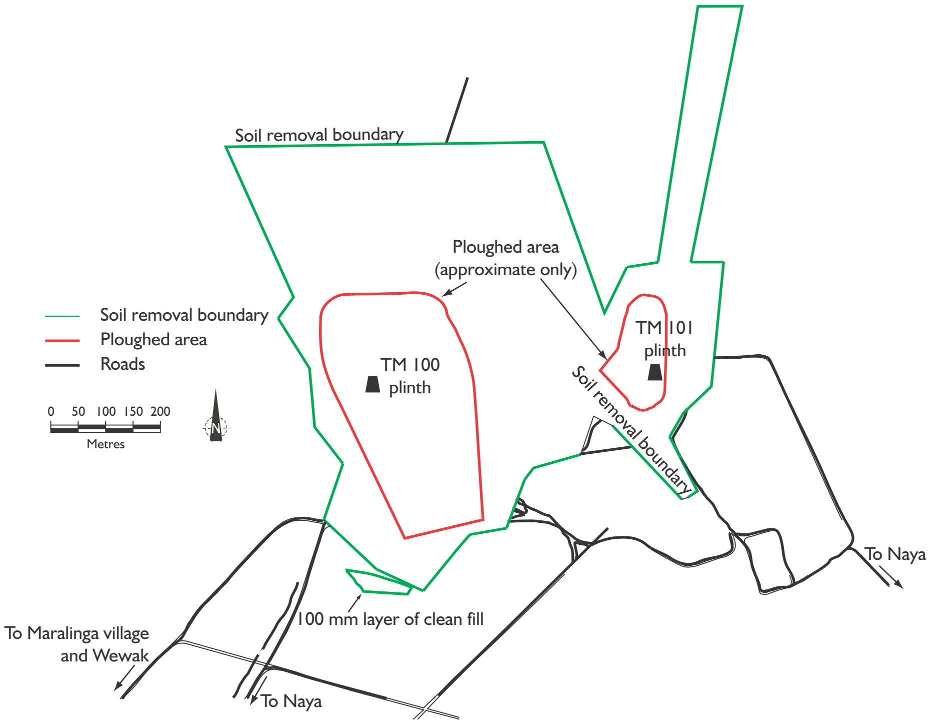
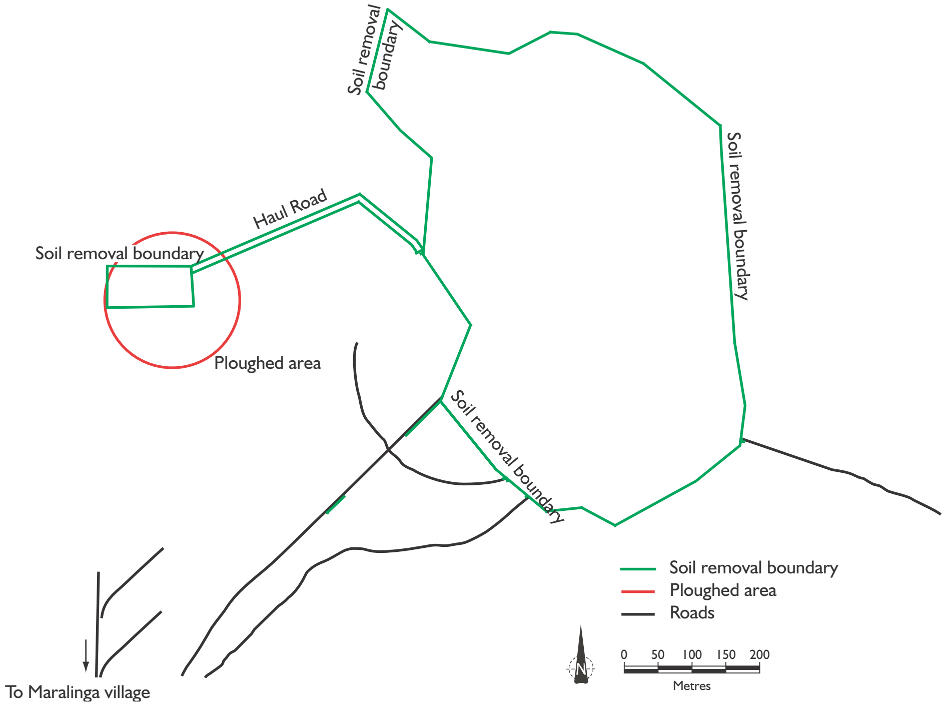


Figure 3.4 Area cleared of contaminated soil and fragments at Wewak and area previously ploughed during Operation Brumby.



3.3.6 SETTING OF THE ‘OUTER FENCE LINE’ ON THE UNTREATED PLUMES

3.3.6.1 Defining the outer fence line

The TAG Option 6(c) allowed for unrestricted land use outside of a fence line enclosing the restricted land-use area of the Taranaki plumes. In principle, a community outstation could be located permanently at the boundary to the enclosure, except for the movement of the centre of population that occurs from time to time, and which is a feature of outstation living.

Using the aerial radiological survey data tapes developed for TAG, the Regulator transformed the TAG risk criteria into recommendations for the location of the ‘fence line’. To overcome irregularities in the soil activity data (e.g. ‘islands’ of higher activity inferred from the aerial radiological data) the Regulator applied the MARTAC criterion of averaging over an area of 3 km^2 in order to take account of movement of the centre of population of an outstation.

Having conceptually located the fence line, the Regulator then used its high sensitivity detection system ‘the OKA’ (see Figure 4.3) to confirm that the boundary was conservatively defined and relocated it where necessary. The OKA survey included detailed measurement along and west of West Street.

TAG considerations in defining the siting of the outer fence line

TAG was required to assume a 100% occupancy factor for traditional owners living an outstation lifestyle on the Maralinga lands. TAG also conservatively assumed that the 100% occupancy would apply to a location at the boundary for the purpose of determining the acceptable level of Pu:Am surface soil contamination that defines the location of the boundary to the restricted land-use enclosure.

TAG recommended that as a criterion for rehabilitation, the annual risk of a fatal cancer following the inhalation and ingestion of contaminated soil should not exceed 1 in 10 000 by the fiftieth year. This level of risk equated to an exposure to 5 mSv in the fiftieth year following an annual exposure of 5 mSv from birth. For earlier years, the annual risk associated with an annual exposure of 5 mSv is less than 1 in 10 000.

TAG considered that the contour corresponding to an annual committed dose of 5 mSv was the borderline between risk that is ‘acceptable’ and that which is ‘unacceptable’. It was based upon knowledge of the present outstation lifestyle and life expectancy of the Aboriginal community. This is clearly an upper bound of dose, in view of the likelihood that when practising a outstation lifestyle a person will spend much more time in the extensive areas of lower contamination. Further, if the lifestyle should become more westernised, then a stated level of contamination will give rise to an even lower dose even though its practitioners relocate less frequently.

The Regulator's recommendations for the boundary line were endorsed by MARTAC and the MCG in early 1999. The location of the fence line (as defined by the Regulator) is shown in Figure 3.6. Details of the Regulator's measurements are given in their report on the Project (see *Attachment 4.3*).

The area enclosed by the boundary markers is 412 km^2, but the area of the plumes enclosed by them is only 108 km^2. As a consequence virtually all of the boundary line is located on uncontaminated land. If an outstation were established anywhere on the boundary line then, with a very few exceptions, the community would receive radiation doses close to natural background rather than the 5 mSv/yr calculated by TAG at an activity of 3.5 kBq/m^2. The estimate of the inhalation component of the dose by APANSA, based on OKA measurements at the established boundary, is 0.22 mSv/yr.

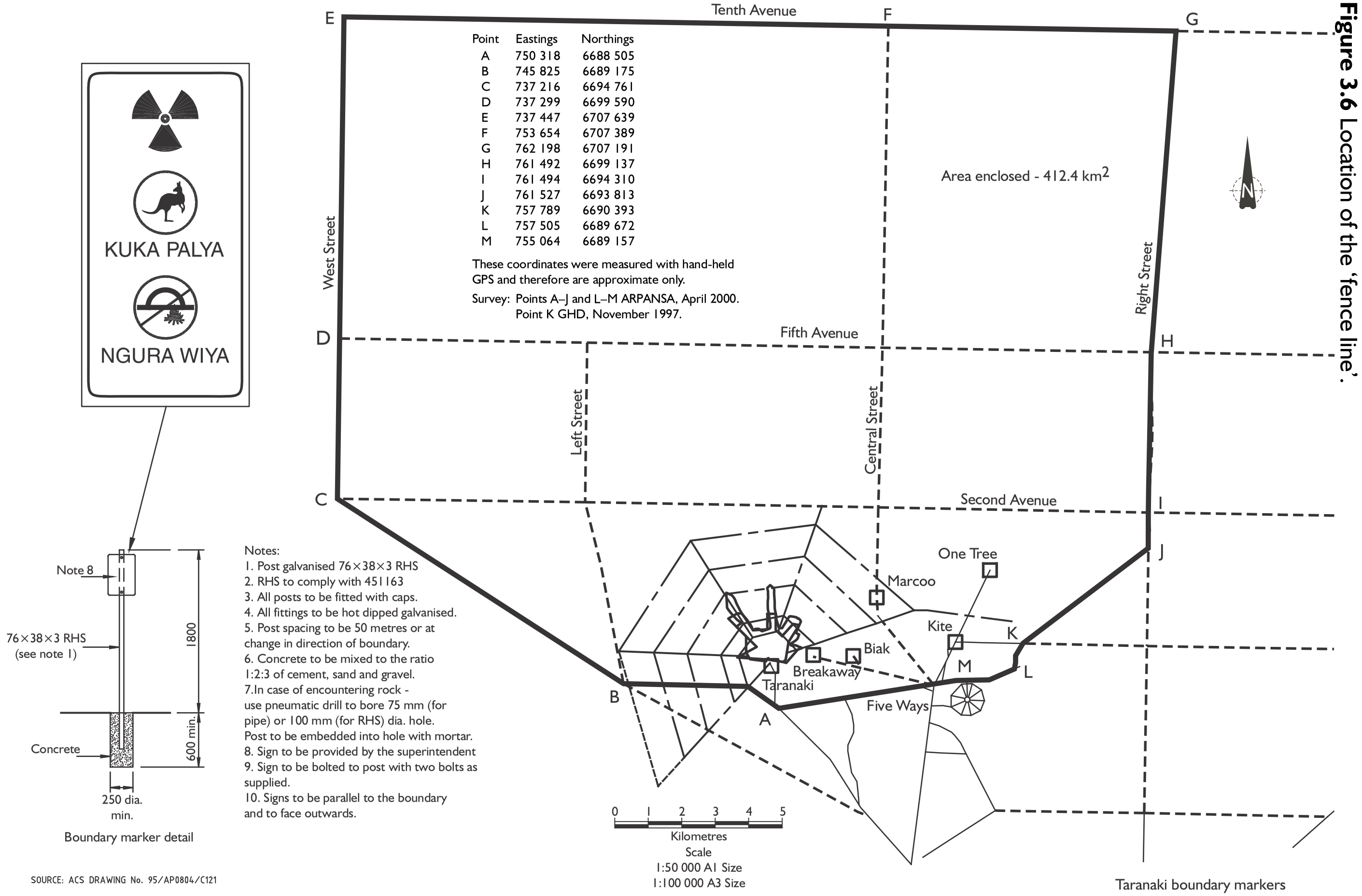
3.3.6.2 Defining the fencing

Option 6(c) anticipated that a wire-stranded, continuous fence would be constructed to enclose the regions which would have continuing land-use restrictions placed on them.

MARTAC observed that such a fence would inhibit the remaining use of the enclosure for hunting. Accordingly, MARTAC recommended that instead of a fence, boundary markers should be installed approximately 50 m apart along the 'fence line'. These boundary markers took the form of posts (76 x 38 mm rectangular galvanised section), set in concrete, and with a warning sign of design shown in Figure 3.5.

Figure 3.5 Boundary marker sign, used to define the 'fence line' marking the restricted use area at the Taranaki plumes.

Figure 3.6 Location of the 'fence line'.



Point	Eastings	Northings
A	750 318	6688 505
B	745 825	6689 175
C	737 216	6694 761
D	737 299	6699 590
E	737 447	6707 639
F	753 654	6707 389
G	762 198	6707 191
H	761 492	6699 137
I	761 494	6694 310
J	761 527	6693 813
K	757 789	6690 393
L	757 505	6689 672
M	755 064	6689 157

These coordinates were measured with hand-held GPS and therefore are approximate only.

Survey: Points A–J and L–M ARPANSA, April 2000.
Point K GHD, November 1997.

Notes:
1. Post galvanised 76×38×3 RHS
2. RHS to comply with 451163
3. All posts to be fitted with caps.
4. All fittings to be hot dipped galvanised.
5. Post spacing to be 50 metres or at change in direction of boundary.
6. Concrete to be mixed to the ratio 1:2:3 of cement, sand and gravel.
7. In case of encountering rock - use pneumatic drill to bore 75 mm (for pipe) or 100 mm (for RHS) dia. hole. Post to be embedded into hole with mortar.
8. Sign to be provided by the superintendent
9. Sign to be bolted to post with two bolts as supplied.
10. Signs to be parallel to the boundary and to face outwards.

SOURCE: ACS DRAWING No. 95/AP0804/C121

3.4 REHABILITATION OF THE FORMAL DEBRIS PITS TARANAKI

3.4.1 SOURCE OF THE BURIED RADIOACTIVE WASTES AT TARANAKI

The wastes in the formal debris pits arose from the three separate series of *Vixen B* trials in 1960, 1961 and 1963. In each series plutonium, approximately an equal amount of enriched uranium and some beryllium was dispersed by the detonation of high explosives.

The three series (referred hereafter as *VB1*, *VB2* and *VB3*) were responsible for varying amounts of plutonium. *VB1*, consisting of three detonations plus a calibration round which did not involve any plutonium, dispersed 4.2 kg, *VB2* (5 shots plus one calibration) 10.3 kg and *VB3* (4 shots plus one calibration) 7.7 kg for an grand total of 22.2 kg (Cornish 1987).

All detonations were carried out on a heavy structure called a featherbed. Figure 3.7 shows the firing installation used for the *VB1* series.

Figure 3.7 Configuration for *VB1* series (from Cornish 1987, Figure 8).

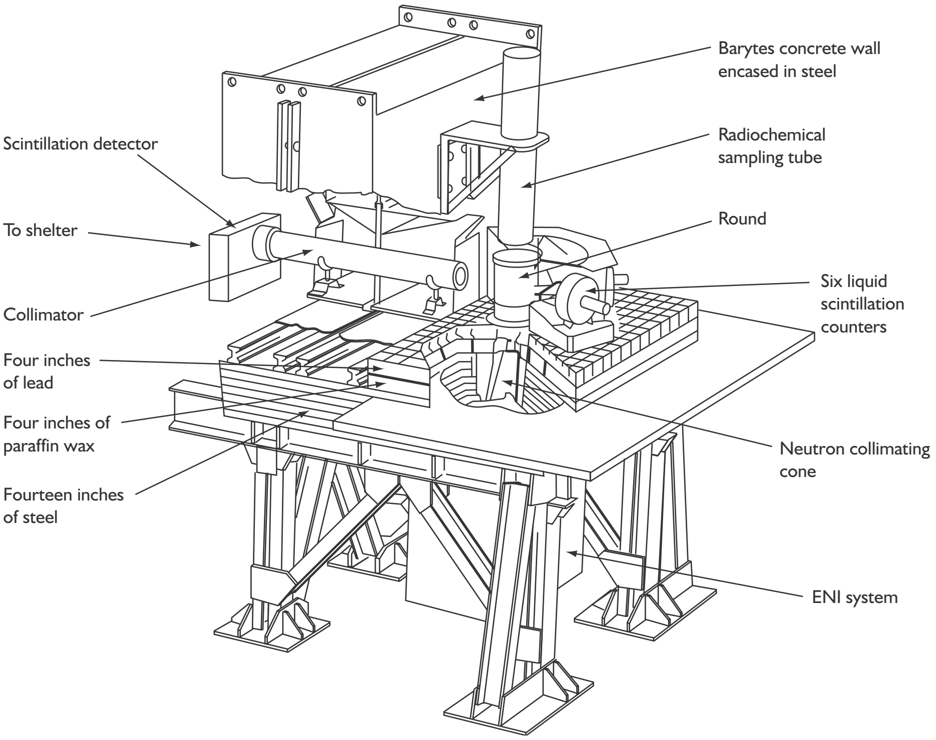
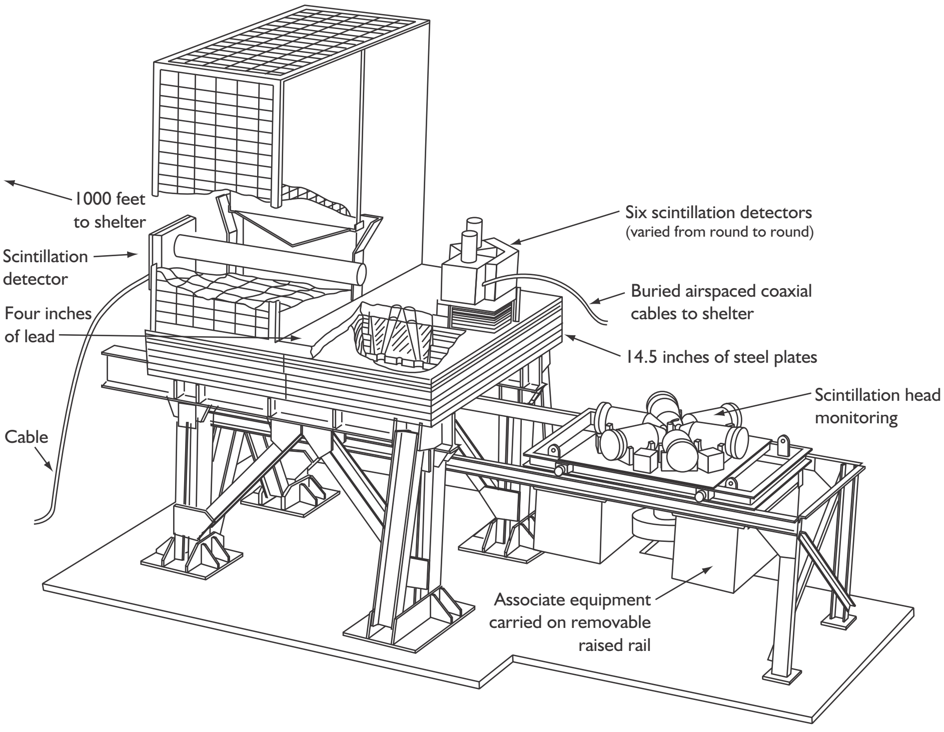


Figure 3.8 shows the firing installation for the *VB3* series (provided in a letter from UKMOD to the Department dated 10/6/99).

The photographs and diagrams of the *VB1* and *VB3* experimental arrangements should be viewed in the knowledge of Figure 3.9 showing the schematic diagram for them. The combination allows the association of function with physical appearance and puts 'body' to the British historic descriptions of the order in which the Taranaki waste debris pits were filled.

Figure 3.8 Illustration showing the firing installation for the *VB3* series (from letter from AR Wilson to J Harris, 29 April 1999, D/ACSA(N)/15/8/8).



The firing arrangements for each trial were practically identical.

While initially intended for re-use, each featherbed was heavily damaged by the detonation. Figures 3.10 and 3.11 (from Cornish 1987) illustrate the extent of damage done to the featherbeds after detonation.

During the exhumation works of some of the Taranaki pits and the examination of the outcomes from the ISV treatment of others, it became obvious that not only was there less than expected plutonium attached to the debris that had been buried, but also that the principal contaminated items were the barytes brick blast walls and a few of the heavy steel plates—presumably those exposed to the blast. Other contamination on instruments, cabling and other structural steel accounted for very little of the total (see *Attachment 4.10)*.

A review of the quantity of plutonium expected to remain at the firing site was undertaken by Carter (1985). He concluded that the consequences of surrounding the explosive charge with various (collapsible) structures was not easy to assess. In the first instance, the availability of exposed surfaces for the entrapment and scavenging of plutonium in the fireball suggested that a significant enhancement of contamination on the debris could have occurred, compared to the levels observed in other field experiments. However this did not appear to be the case and a contributory reason for this seemed to have been the presence of the slab of paraffin wax on the featherbed. Most of the wax was fragmented or melted and ejected widely around the firing point. As a consequence, its presence caused some problems during decontamination of the area. However, a detailed examination of ground contamination in the region of 20 to 80 m from the firing point indicated the presence of numerous beads or spheroids of congealed wax, often approximately 1 mm

Figure 3.9 Schematic diagram for the *Vixen B* experimental arrangement (from Schofield 1985).

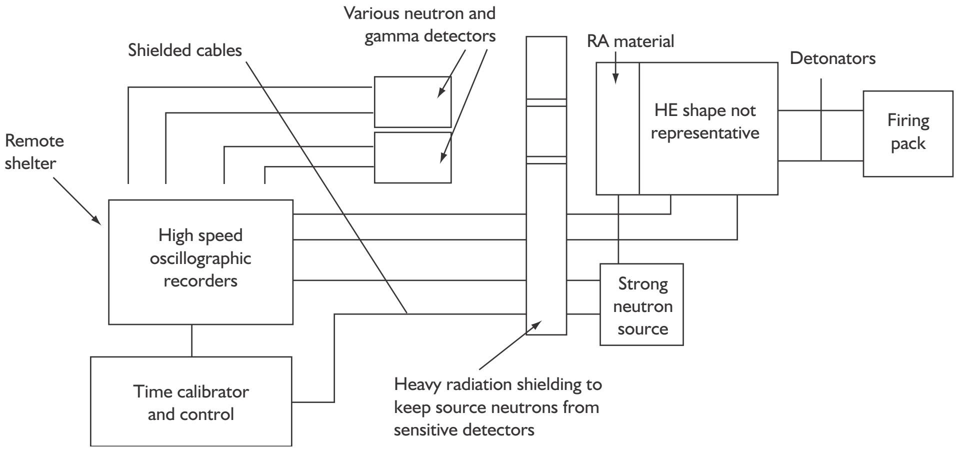


Figure 3.10 Featherbed after detonation (Cornish 1987, plate 3, p. 125).

Figure 3.11 Featherbed after detonation showing sand bags (Cornish 1987, plate 4, p. 125).

diameter, but variable in size, shape and colour. Some were highly contaminated, and others were not. Significantly, some were fragile hollow shells of highly carbonised wax. Thus it appeared that the slab wax acted much as an ablative layer during the explosion, with the scavenged or impacted plutonium being ejected from the firing point structure (Carter 1985).

Other evidence of the part played by the featherbed components in the formation of heavily contaminated fragments comes from proton-induced x-ray emission spectroscopy analysis carried out on some collected fragments (e.g. particle GNE 12 contained mass concentrations of 23% iron and 18.9% plutonium, while particle FW [F50] contained mass concentrations of 11.4% iron, 35% lead, and 19.8% plutonium [Burns et al. 1990]).

Table 3.8 lists the quantities of material estimated to have made up the 15 featherbeds used at Taranaki and understood to have been buried in the 21 formal disposal pits at Taranaki (Table 13 in Cornish 1987).

In *Chapter 4*, mention is made of a joint US/UK experimental Series 'roller coaster' event '*Double Tracks*' (USDOE 1997). Its first objective was to evaluate the dispersal of radionuclides in the environment from an assembly structured to give meaningful comparison with the accidental detonation (non-nuclear) of the high explosive in a nuclear weapon. Other events in the series specifically looked at effects of various

Table 3.8 Calculated contents of cores of Taranaki pits (15 'featherbeds') (in Cornish 1987, Figure 13).

Material	**Volume** (m^3)	**Density** (g/cm^3)	**Mass** (tonnes)
Steel plates, 210, each 2.4 x 1.2 x 0.05	30	7.9	237
Barytes brick (possibly 215 x 105 x 65 mm each), as 2.4 x 2.4 x 1.2 m wall on each structure (encased in steel for 12 of the shots and probably not fractured on firing)	104	3.5	364
Lead, 100 mm layer over 2.4 x 1.2 m area, using standard interlocking 50 mm thick bricks, perhaps 9000 bricks	4.3	10.8	46
Rolled steel joists (RSJs); maximum length 3.2 m, assemblies not necessarily unbolted	10	7.9	79
14 concrete firing pads, each 3.6 x 3.6 x 0.3 m	54	2.5	136
Total plates, bricks, lead and steel	202	–	862
Assume 10% of 694 m^3 as large air voids	69	–	–
Additional soil, cabling, instruments, clothing, etc. (assume 1.3 g/cm^3)	423	1.3	550

configurations of storage facilities. The stated objective for the *Vixen B* trials was related, in the sense that the British were trying to determine the nuclear safety of weapons from a single point accidental detonation, which might result from fire, transportation accident or plane crash.

The firing arrangement for *Double Tracks* (Eberline 1966) was different from the featherbeds described above. The explosion occurred in the open 300 mm (one foot) above a steel plate 2.4 m x 2.4 m (8 ft x 8 ft) supported by 6.1 m x 6.1 m x 0.3 m (20 ft x 20 ft x 1 ft) concrete slab. The test device was composed primarily of depleted uranium and plutonium with a uranium to plutonium ratio of 4.35. No fissions occurred (USDOE 1997).

These differences between the *Vixen B* and *Double Tracks* experiments mean that the applicability of the more detailed data on the distribution of plutonium on the various waste components from *Double Tracks* is limited when attempting to use it to reduce the uncertainties in the quantities of plutonium estimated to be in the various disposal trenches associated with the rehabilitation of the Taranaki site. Also of importance is the design of the *Vixen B* experiments for which, at detonation, as McLean (1961) states:

> *... the very pronounced jet of material thrown vertically upwards suggests ... that it would be of major importance in the subsequent dispersal, of plutonium.*

This factor could mean that the appropriate comparison to make between *Double Tracks* (Eberline 1966) and the *Vixen B* experiments is not the plutonium plated out on the featherbed structure/steel firing plate, but rather the amount of plutonium contamination in the immediate environment of the detonation (i.e. the amount of plutonium in both the soil and debris disposal trenches at Taranaki). For *Double Tracks* this amount was approximately 20% of the total amount of plutonium involved in the detonation. It could also be an important factor to consider when comparing the amount of plutonium found on the walls from the *VB1* series compared to those from the *VB2* and *VB3* series (see *Attachment 4.10*).

3.4.2 ESTIMATE OF THE AMOUNT OF PLUTONIUM IN THE TARANAKI PITS—HISTORICAL

The remains of the featherbeds and of their various components together with the concrete slabs on which the assemblies stood, and some soil scrapings from around the firing pads, were disposed of in the 21 Taranaki formal debris pits. Both TAG and MARTAC needed to form an opinion on the quantity of plutonium deposited on these waste items in order to formulate/implement a sensible treatment of the pits.

Estimates of the plutonium contamination were made by:

- operational staff for the *Vixen* trials (see McLean 1961; and below);
- those with continuing administrative responsibility at the end of each *Vixen B* series (see letter from AE Oldbury to N Pearce, 4 September 1962; and below);
- those working for the transfer of responsibility for the Maralinga Range back to Australia from the UK in 1968 (see Pearce 1968; and Table 3.9);
- within the UKMOD in more recent times (see note from R Carter to F Morgan 6 May 1980 [AT/FX/80/1]; Carter 1985; and Table 3.9); and
- in official government to government correspondence (letter from AR Wilson to J Harris 29 April 1999 [D/ACSA(N)/15/8/8]).

No matter who made the estimates or when, two major difficulties are present. Carter (1985) described them as:

> *The problem of quantifying the plutonium accounted for by contamination of the feather bed debris is complex, and suffers from a lack of useful measurements. At this time (1960) the first production version of the 1320X monitor was available, but this was inadequate for the task, suffered from the inevitable self-absorption and shielding errors, and in any case, the massive debris at the firing point rendered any simple measurements impracticable …*

By that time (1985) it was abundantly clear that some original field records had been lost, and that elementary monitoring data, obtained purely for safety reasons, 25 years previously, now assumed an importance unforeseen at the time. Inevitably, key personnel involved in the field trials had died, retired or simply forgotten points of detail.

Table 3.9 provides a detailed summary of the historical estimates and reports of the amount of plutonium expected to have been in the Taranaki pits.

Table 3.9 Historic estimates of the amount of plutonium within the Taranaki pits.

Who reported	**What was reported at Taranaki**
McLean (1961)	The total amount of plutonium deposited at Taranaki between the firing pads and the boundaries from the VB1 series estimated at < 256 g, with: • 6 Ci (96 g) for round 1; and • < 5 Ci (< 80 g) for each of rounds 2 and 3 (96 + 80 + 80 = 256). The amount of plutonium on the debris from the VB1 series in the immediate vicinity of the three pads and surrounds, estimated to be in the range 1.5–6 Ci (24–96 g), with: • about 1 Ci (16 g) on the debris for each of the three firings (range estimated for each from 0.5 to 2 Ci [8–32 g]). The amount of plutonium deposited on the range up to about 25 miles (40 km) away estimated at about 10 Ci (160 g). It was noted that this may have been underestimated by a factor of 2 to 3. **See Note 1**
Oldbury (1962)	*VB1* Four large Taranaki pits located outside the array, containing, in total, up to about 8 Ci (128 g) of plutonium on debris from the VB1 series, with: • one pit, NW from shelter possibly containing up to 5 Ci (80 g) of plutonium; and • three pits, possibly containing < 1 Ci (< 16 g) of plutonium per pit. *VB2* A total of about 80–160 g plutonium in five pits associated with the VB2 series pads, with an estimated 1–2 Ci (16–32g) of plutonium in each of the five pits. **See Notes 2 and 3**
Pearce (1964)	The contents of Taranaki pits numbers 1–19 contained 20 kg of plutonium.
Pearce (1968)	Restated that the total plutonium in Taranaki pits numbers 1–19B was 20 kg.
AUSTDEF LONDON (1977)	Suggested that: • the estimate of 20 kg was more likely to be an overestimate than an underestimate; • the 20 kg was distributed approximately between the 21 pits; and • plutonium was in the form of an oxide and was non-uniformly distributed over the steel sheet, girders, lead, and concrete surfaces that surrounded it at the time of explosion. **See Note 4**

1 The claim is made (Carter 1985) that McLean understood his estimates of about 1 Ci of plutonium for the (firing) pad contamination were underestimates but no such statement appears in the report for the amount of plutonium associated with the pads or pits.

2 There was no pit exactly north-west of the shelter. The nearest to this requirement was pit 10.

3 Letter from AE Oldbury to N Pearce, 4 September 1962.

4 Telex W Saxby (AWRE) to Defence Canberra 25 January 1977.

Table 3.9 Historic estimates of the amount of plutonium within the Taranaki pits (continued).

Who reported	**What was reported at Taranaki**
Carter (1980) (an interim note) and Carter (1985) (a preliminary note)	The thrust of both reports was to use all available data to narrow the estimates. The 1985 statement provides a numeric review of the surface contamination monitoring data that underlies the conclusions of the 1980 statement. It is based on: • Taranaki data, 0.4–3 kg; • Double Tracks data, 2–3 kg; and • other Maralinga minor trials, about, but > 0.4 kg. It concluded that the quantity of plutonium in the pits was 1–3 kg. The 1985 statement repeated this conclusion but with the words 'probably of the order of 2 kg'. **See Notes 5, 6 and 7**
Lokan (1985)	Measurements of surface inventory of plutonium accounted for 10–20% of that dispersed in *Vixen B* series. In the absence of other information, it was assumed that the major proportion (80–90%) of the plutonium used was likely to be contained within the Taranaki burial pits.
Cornish (1987)	Advice from the UK that the pits were unlikely to contain more than a few kilograms of plutonium.
TAG (1990)	Using data from the *VB1* series, coupled with evidence from joint US/UK trials of a similar nature, concluded that: • the likely residual on/close to the featherbed debris was 10% of the plutonium used in the firings at Taranaki; and • a probable upper limit of plutonium in the Taranaki pits was 15% of the 22 kg used, namely about 3 kg.
TAG (1990)	A conservative view was taken that the twenty-one formal debris pits at Taranaki contained between 2–20 kg of plutonium.
UKMOD (1999)	2.2 kg with an estimate of its distribution across the 21 pits. **See Note 8**

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5 Interim note on the 'plutonium content of the Taranaki pits at Maralinga' from RF Carter to F Morgan, 6 May 1980, NAA AT/FX/80/1.
Preliminary note from RF Carter (*Residual Plutonium Contamination at the former Maralinga Range - South Australia*), June 1985.

6 Within the Australian context, the Pearce Report was of major importance and, in any case, provided the only estimate available. It was this report that formed the basis for the technical acceptance of the responsibility for the Maralinga Range passing back to Australia in 1968. AIRAC, after discussions with Professor Titterton (Chairman AWTSC), concluded in AIRAC 4 (1979) that the 21 pits at Taranaki ... *contained in all about 20 kg of plutonium-239 contaminating about 800 tonnes of debris* ....

7 Carter (1980, 1985) makes mention of a final report under preparation. Among other things, it was to refine the various estimates and provide a compilation of a complete data file on contamination measurements related to the trials. UKMOD has been unable to locate the final report.

8 Letter from AR Wilson (UKMOD) to J Harris (the Department), 29 April 1999, NAA D/ACSA(N)/15/8/8.

3.4.3 IMPLICATIONS OF THE HISTORICAL ESTIMATES OF PLUTONIUM IN THE TARANAKI PITS

3.4.3.1 TAG's deliberations

Although TAG was not involved in making recommendations, TAG considered and costed a range of acceptable clean-up options.

In relation to the Taranaki pits, TAG (*Attachment 1.3* , p. 39) considered a relatively narrow band of options, stating that:

> *For the numbered pits, and particularly those in Taranaki which contain up to 20 kg of plutonium, there are two possible remedial measures. The first involves improved isolation through in situ stabilisation. This would present lesser technical problems and a reduced risk to workers. It would not provide a permanent solution in an area otherwise cleared for unrestricted access. The second is excavation and disposal of the contents in a way consistent with international practices for wastes containing high levels of long-lived radioactive materials, i.e. disposal in stable geologic formations. Shallow land burial is not an appropriate disposal route for wastes of this type but, subject to a detailed safety assessment, it may be acceptable to dispose of wastes packaged in concrete at an intermediate depth.*

The origin of the 'up to 20 kg of plutonium' reference in the TAG report was the Pearce Report (Pearce 1968). The restriction on options considered by TAG members came about because of a belief that they were dealing with 'high levels' of long-lived, alpha-emitting waste.

It became apparent, after the soil removal, that the location of the concrete pit caps was only loosely related to the position of the pits, and sometimes not at all. In addition, the volume of pit material exceeded, by a factor of approximately five, that indicated in the British documentation.

TAG'S ASSUMPTIONS VERSUS REALITY

On the basis of records available at the time, TAG assumed:

- a quantity of plutonium now known to be too high by a factor of approximately 20; and
- spread through a volume approximately five times less than has proved to be the case.

This led TAG to assume a concentration of plutonium in the Taranaki pits some 100 times greater than was found to be the case[9].

3.4.3.2 MARTAC's deliberations

MARTAC deliberated on the expected amount of plutonium in the Taranaki pits on many occasions from 1995.

Throughout the Project, MARTAC's consensus view of the upper limit of plutonium in the pits was that it amounted to approximately 20% of the original inventory (i.e. at 4 kg). The lower limit, however, was progressively lowered until by December 1998 it was estimated as being approximately 100 g of plutonium per trial (i.e. a total of approximately 1.2 kg). It is doubtful whether a consensus was reached on the most likely value, with some favouring the upper limit, others the lower limit.

Estimates have now been made of the amount of plutonium consigned to the pit exhumation trench from contaminated soil and steel in the outer pits, and from the ISV blocks which were ultimately disposed of in these trenches. The value arrived at was 650 g. The details are provided in *Chapter 4.*

3.4.3.3 Location of the Taranaki pits and pads

For the majority of time during the Project, the location of the pits at Taranaki was defined by the map shown in Figure 3.12. This figure shows the directions of close-in fallout from the 12 *Vixen B* firings at Taranaki, with associated firing pads.

An alternative plot of the *Vixen B* pits and pads is given in Figure 3.13. It provided the clue for discovering further pits in central Taranaki (see *Section 4.8.1.1* and Figure 6.4).

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[9] This meant that when MARTAC was forced to re-evaluate the use of ISV at the Taranaki pits after the pit 17 explosion in 1999, given the lower levels and concentration of plutonium in the pits, MARTAC was able to seriously reconsider the use of shallow land disposal of the debris in the pits as a realistic alternative to treatment by ISV.

Figure 3.12 Location map showing the directions of close-in fallout from the 12 *Vixen B* firings at Taranaki, with associated firing pads (Burns 1990).

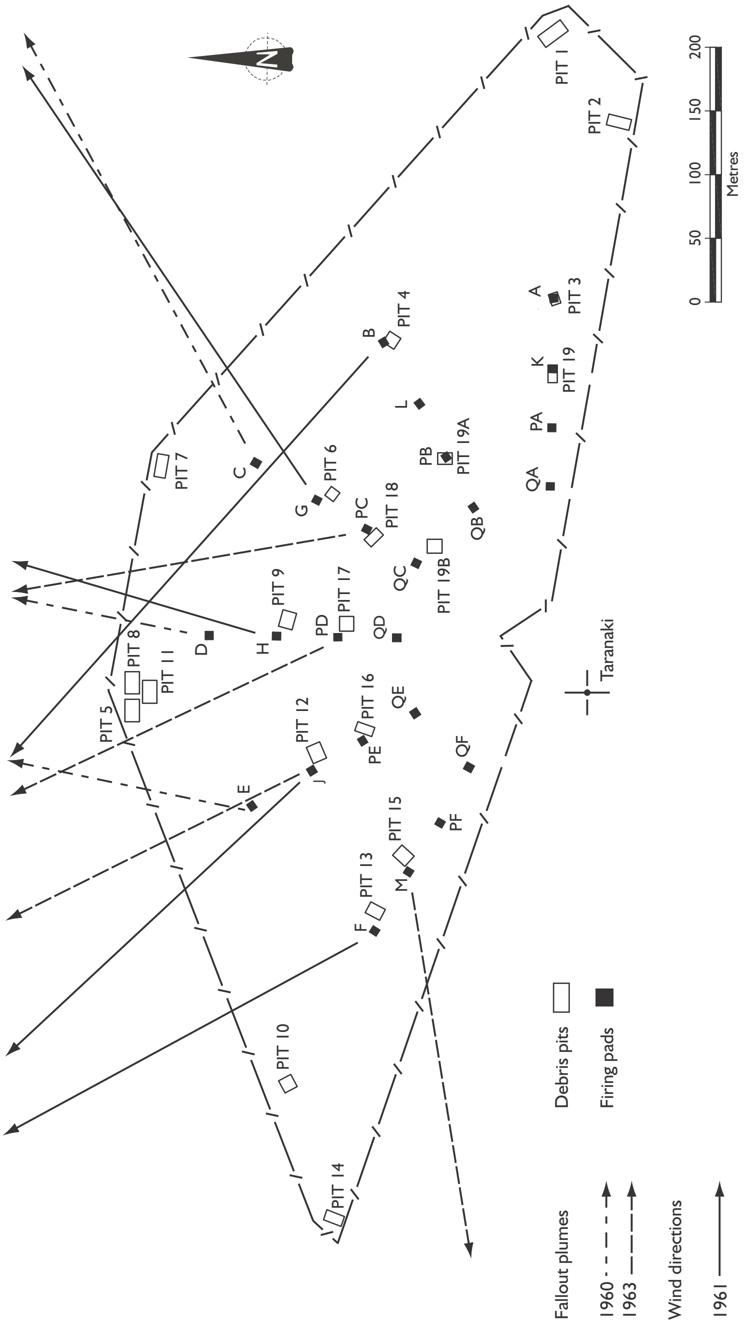
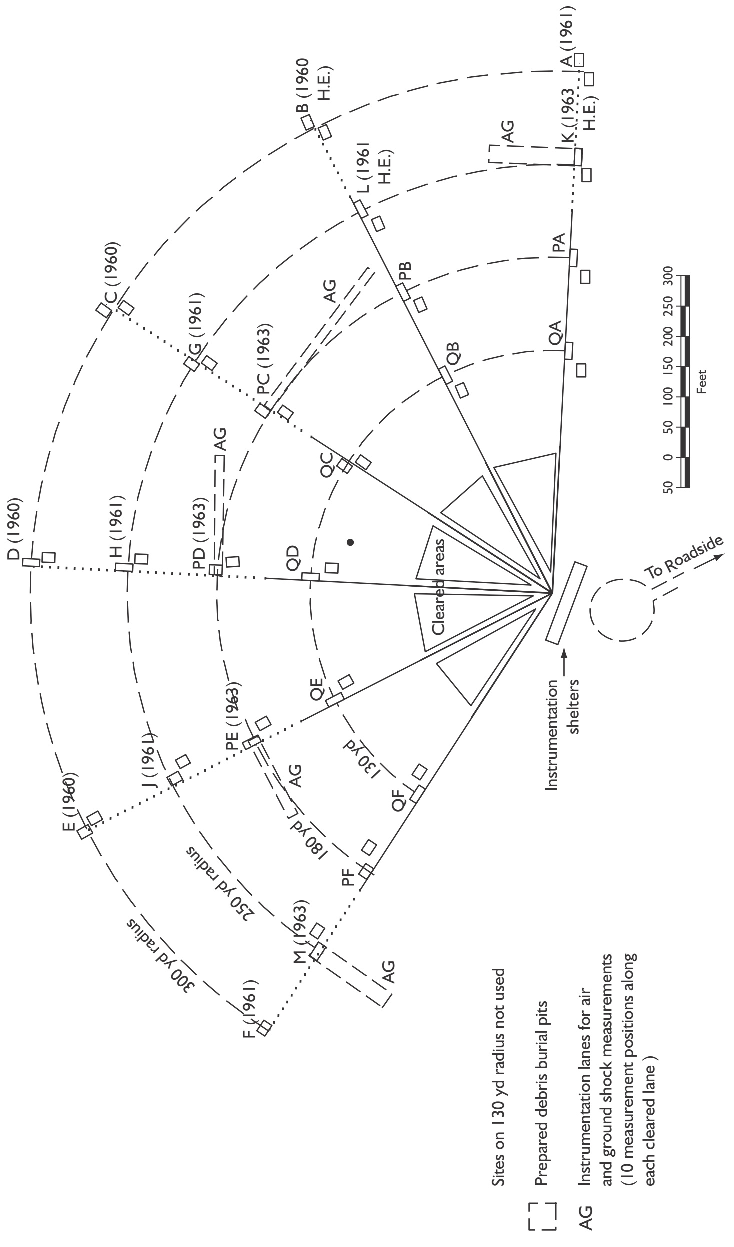


Figure 3.13 Location map showing *Vixen B* pad and pit layout by Jones (no date).



3.4.4 MARTAC'S DELIBERATIONS ON THE APPLICATION OF ISV TO THE TARANAKI PITS

3.4.4.1 To ISV or not to ISV?

Despite the specification of ISV treatment at Taranaki in the selected Option 6(c), alternative treatment by exhumation and reburial of the contents of the Taranaki pits was revisited as a fall-back situation in the event of ISV not proving technically suitable. Earlier estimates during the TAG studies for exhumation of the pits at Taranaki had ranged from $15.8 million to $21.8 million.

The Project Manager was tasked to prepare a draft operational procedure and cost estimate for excavating the small Taranaki pit 15. A total estimated cost of $204 000 for a simple monitoring operation (Option 1) involved:

> *Establishment of a clean access road to and around the pit, surveying and cutting of the concrete cap, excavation of the pit contents onto an area prepared for measurement of the level of contamination on debris and fill, loading the pit contents into a skip and transference and unloading in a burial trench. An alternative operation (Option 2) involving more complex monitoring of debris on a conveyer belt, was estimated to cost $423 000.*
>
> ACS 1995

The Project Manager extrapolated these costs to the remainder of 19 Taranaki pits that were believed not to be grouted substantially to yield overall costs of $3.9 million and $6.2 million for exhumation Options 1 and 2 respectively (ACS 1995). The initial cost estimate of $423 000 for exhumation of pit 15 had escalated to $488 000 a year later. A later reworking of the Project Manager costings, using TAG estimates of the time requirements (*Attachment 1.3* , Part 2) indicated an increase in exhumation costs to between $8.3 million and $8.9 million in 1996 with additional costs of digging the burial trench, monitoring the excavated pits and re-filling them.

These costs were sensitive to assumptions on rates of progress, equipment required and numbers of personnel. The former estimates assumed a fourteen-month exhumation period. Recalculation by MARTAC, assuming an exhumation period of 24 months and increased numbers of personnel with additional equipment, led to an increase in total exhumation costs for exhuming pits 1 to 19, 19A and 19B to some $16.2 million.

Estimates of comparative costs for ISV and exhumation indicated that exhumation might involve a lower cost (possibly $16.8 million) compared with a probable $25 million for ISV. However, the economics of exhumation involved a wider band of costs owing to the inherent engineering uncertainty (period of excavation, number of personnel involved and additional equipment required) in the exhumation operation[10].

On the evidence produced at the MARTAC meeting of 1 March 1996, it was not clear that exhumation offered a definite cost advantage over the ISV process, as was being offered by the ISV Contractor. ISV was assumed to have the further advantage of being non-intrusive, whereas exhumation involved potential risks of contamination of personnel by plutonium during intrusion into and removal of highly contaminated, massive, pit debris.

After considerable discussion of the advantages and disadvantages of the available data on ISV, and in the face of the uncertainties, MARTAC in 1996 decided to recommend ISV as the most feasible, certain (both financially and technically) and reliable method of rehabilitating the debris pits in central Taranaki.

The recommendation was as follows:

> *MARTAC recommends acceptance of the ISV proposal as defined by Geosafe's documents GSC-2602 (Remedial Design Plan) and GA-96-001-A (Phase 3 proposal) and in particular Option 10 of table 4.1 (Summary of Phase 3 and 4 Scenarios) of the last mentioned document, provided that DPI&E could negotiate either a fixed price contract for Phase 3 and 4, or alternatively a fixed price contract for Phase 3 and a cost plus fixed fee contract for Phase 4 such that there is no upside risk on a total of $25 million to the project other than gross error in pit depths as listed in historic documents and $A/$US conversions.*

Although the ISV Contractor's *Remedial Design Plan* (RDP), referenced in this recommendation, did not list explicitly any acceptance criteria for the ISV process, it described a series of operational activities and outcomes expected in the melting (see boxed text, p. 137).

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[10] In the event, 10 of the *Taranaki* pits (total volume 3680 m^3) were excavated over a seven-week period.

3.4.4.2 MARTAC criteria for the ISV process

In August 1995, MARTAC listed its basic requirements for the outcome of the ISV process and for the characteristics of the product. Outcome requirements were described by the following acceptance criteria:

- there should be a high degree of confidence that contaminated soils and debris within the pits are completely vitrified and all materials either melted or encased in the vitrified product;
- temperatures of the melt at the base of the pit would reach a specified level, to be advised following the *Report of Phase II trials at Intermediate Scale*; and
- most of the plutonium should be distributed within the vitreous/ceramic component of the ISV product.

EXPECTED OUTCOMES

ISV Contractor's *Remedial Design Plan*

- Ensuring that melt temperatures are adequate to melt steel, silica will need to be added (p. 5).
- Added 1.5% Na_2O to the red (silica) sand to provide the highest possible melt temperature (1950–2000°C) in the sand (p. 5).
- Expectation that the probing will identify the pit boundaries (p. 8).
- Electrodes to be held above the molten metal at the base of the melt (p. 10).
- Thickness of the molten metal pool, which is on the melt bottom, to be less than 100 mm (4 in.) in all cases (p. 10).
- Cooled melt to end up sub-grade (not in these words, but reference is made to a 'subsidence void').
- Use of an average melt temperature of 1600°C for the modelling reported in this appendix.
- Target melt depth to be 100 mm (4 in.) deeper than the stated bottom of the pit (p. 8).

Criteria to determine if an adequate melt depth has been achieved are that:

- each of the four electrodes must be inserted to a depth that is equal to, or below, the bottom of the pit; and
- the average insertion depths of all four electrodes must be greater than or equal to 100 mm deeper than the identified pit bottom (pp. 8–10).

Appendix A 'Model Outputs' show average power to be used is 2.3–4.0 MW for small, shallow pits and 3.8–4.2 MW for large pits.

3.4.4.3 MARTAC's review of operational ISV experience in the pits

Section 4.6 and *Attachment 4.8* provide a detailed assessment on the outcomes of the ISV Contractor's process for 11 pits at Taranaki including a comparison of the outcomes with the MARTAC acceptance criteria and the outcomes discussed in the ISV Contractor's RDP.

From early in the ISV program, following the partial excavation of the first melt, (considered to be satisfactory by the ISV Contractor (pit 3—non-radioactive)) a growing body of evidence indicated that all steel waste was not being melted and that all waste would not be incorporated or that some plutonium may not be incorporated. At the same time, it had become apparent that the volume of material to be treated in the outer pits was approximately five times greater than had been anticipated on the basis of the description at the time of *Operation Brumby*. This led MARTAC to discuss with the MCG an option in which the pits would be excavated, the contents sorted into debris and contaminated soil, with the latter going to reburial and the former being staged into a tailored excavation prior to applying the ISV process. This option was discussed in terms of the eight outer pits where the demands on an ISV process were greater than in the case of the inner pits. It was variously called the hybrid option or *ex-situ* vitrification (ESV). The discussions on ISV performance at a MCG meeting would be followed chronologically by the preparation of an information paper for the next MCG meeting.

The first paper proposing an alternative to ISV was prepared by the Project Manager for the June 1998 meetings of MARTAC and the MCG. It was motivated by the changed scale of the ISV program resulting from a re-assessment of the cross-sectional area (and hence volume) of the Taranaki pits that followed the removal of soil from around the concrete pit caps. This re-assessment suggested that now 41 melts would be required rather than the 26 that formed the basis of the Stage 4 proposal from the ISV Contractor. The Project Manager's paper reviewed the option of excavation and reburial of all wastes from the large pits: 1, 2, 5, 8, 11, 10 and 14 (i.e. the outer pits, but omitting pit 7). The estimated saving was $5.1 million. Pit 10 is the extreme example of the change brought about by substituting field estimate of cross-sectional area for the values in the British reporting—the ISV Contractor's Stage 4 proposal involved one melt for pit 10 whereas in reality five would have been applied.

This paper was prepared prior to the occurrence of the transients (i.e. melt displacements) experienced during the first ISV melt (pit 19) that led the ISV Contractor to prematurely terminate that melt in order to take remedial measures.

The hybrid option was initiated by MARTAC out of session with an email, from the MARTAC convener on 18 June 1998, proposing the concept (excavation, sort waste into contaminated soil and debris, rebury the soil and treat the debris by vitrification in specially prepared pods) that was a process of ESV.

By the time the information paper on the hybrid option was prepared for the MCG (10 July 1998) the methods employed by the ISV Contractor to overcome the transient problems experienced in the first melt were known. One consequence of this, evident at the second melt (pit 3), was that the extra overburden placed over the pit was leading to melts that ended up proud of ground surface. As a consequence the hybrid option was identified in this paper as having cost savings ($5 million) and providing a better treatment than the modified ISV Contractor's process. Four specific advantages were listed:

- superior waste form (because of the optimum design of the pods);
- ISV treatment of supergrade part of the ISV blocks from the inner pits;
- time saving (eight months); and
- a superior situation for accidental intrusion.

This paper proposed that the hybrid option be applied to all the outer pits (i.e. including pit 7).

Subsequently MARTAC identified a further advantage—the ability to place thermocouples and chemical tracers below the pods to confirm that the melt had satisfactorily reached the required depth.

MARTAC held a teleconference about the rehabilitation options for the Taranaki pits on 30 July 1998. During the teleconference all MARTAC members agreed that the indicators used by the ISV Contractor to determine when a melt should be stopped were inconsistent and had proved to be inadequate[11]. Concern was generally expressed that problems with the measurement of temperature in the melts and a lack of information from high temperature thermocouples placed around the melts acted to severely limit MARTAC's ability to be assured that for the melts to date:

- the content in a pit was completely vitrified and all materials either melted or encased in the vitrified product;
- the temperature at the bottom of the pit was sufficiently high; and
- most of the plutonium was distributed within the ISV product.

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[11] During the teleconference with the ISV Contractor's staff during December 1998, Geosafe (Australia) and Geosafe (USA) acknowledged the same problem (paragraphs 5(c), 5(d) and 6 of the teleconference minutes [see *Appendix 3.3*]).

It was noted that determining actual pit depth and consequently, the appropriate depth to melt to, was problematic, and that the assumption that the historical pit depth was an approximate level at which the melt could be terminated was misplaced.

It was considered that the result of increasing the lateral melt too much would be a lower temperature of the melt (and possibly a slower melt rate).

It was also noted that if the melt temperature was not high enough, then the quality of the melt product may be adversely affected, and the melt might not extend vertically enough to melt/encase the steel at the bottom of a pit.

The next information paper for the MCG—*Explanation of MARTAC's recommendation for the rehabilitation of the outer Taranaki pits using the hybrid option*—was circulated on 1 October 1998. It discussed the advantages of the hybrid option under the subheadings:

- technically consistent with Option 6(c);
- saves some time and money;
- combines the best possible waste form for specific wastes, with an ability to bury contaminated soil in trenches consistent with previous practice;
- using ideal ISV pods, allows for predictable melt characteristics and verification of ISV modelling;
- has at least an intermediate level of intrusion resistance post rehabilitation;
- allows for operational flexibility;
- allows for plutonium determinations on significant debris; and
- allows for a potential reduction in sulphur dioxide emissions from the treatment.

Among the disadvantages listed was a discussion of the hybrid option requiring a continued major reliance on ISV, with its associated technical uncertainties, and increased occupational radiological exposure.

A further information paper from the MARTAC convener, dated 27 October 1998 was circulated to the MCG. By this time analytical results for samples from the early melts were trickling in and randomness in many of them was evident. The information paper—*Difficulties associated with the ISV process*—dealt with the consequences stemming from the changes introduced into the operating procedures to reduce the frequency of the transient class of events as experienced in the first melt. Undesirable consequences were discussed including:

- lowering of melt temperature;
- dilution of tracer concentration;

- sampling difficulties;
- on frequent occasions, the prevention of dipped thermocouple entry, by the thickness of the cold cap; and
- the difficulty of obtaining melt temperature within the melt.

The new operating procedures also complicated the interpretation of the low temperature thermocouples; and led to some melts ending up above grade.

The paper then discussed the uncertainties in the outcomes achieved in the early melts (pit 3 block had been partially excavated by this time). This discussion was under the headings:

- uncertainties associated with temperature measurements;
- uncertainties in the encapsulation of the contents of the pits; and
- uncertainties in the required melt temperature to ensure all pit debris is melted or encapsulated in the melt.

The discussion finished with the observation that

> *... as a consequence, the average melt temperature cannot be inferred and no opinion can be expressed on the likelihood or otherwise of the plutonium contamination being incorporated in the melt.*

The information paper concluded with a discussion of the further potential ISV complications associated with the outer pits.

During November 1998, when there were further data from draft melt reports, partial excavation of the pit 19A block had occurred and chemical analyses on block material were available, it was established via email exchanges that half the MARTAC members were in favour of recommending terminating the in situ treatments of all further pits after the Christmas break. The remaining members favoured a wait-and-see approach with a range of end points in mind—including treating all pits in situ irrespective of the early results.

MARTAC's growing uncertainty with the ISV product led to a teleconference with the senior staff of Geosafe (US), Geosafe (Australia) and a consultant to them early in December 1998. Agreed minutes for that teleconference are at *Appendix 3.3* and were circulated to members of the MCG. The first part of this conference concentrated on the shortcomings in ISV outcomes, as perceived by MARTAC members, and what the ISV Contractor could or would do in an attempt to overcome these shortcomings.

It became clear during that discussion that, as a result of the uncertainties inherent in the vitrification process when applied to mixed debris, the ISV Contractor could provide no assurances on expected outcomes for a staged pod containing the mixed debris in the hybrid option. This led MARTAC to propose an arrangement whereby the steel would go to a pod where the ISV Contractor would completely specify the staging of the steel items and the composition of the soil backfill, and a separate pod for the general debris for which some items were known to have an adverse effect on the ISV temperature performance. It was agreed this general debris pod need not reach the melting point of steel since, at worst, only smaller pieces of steel scrap would be present.

The ISV Contractor developed the hybrid proposal to this extent and put the detail to MARTAC who expressed concern at the risk (radiological and operational) to which the people involved in staging the pods would be exposed, should they be required to construct the pods in such a fashion. MARTAC decided to hold in abeyance a recommendation for either complete excavation and reburial of the outer pits, or the application of the hybrid option to them until after the remaining melts on the inner pits had been completed (to be done in the order pits 18, 17, 16, 19B). The second of the melts, on pit 17, was the closest approach to what was planned in the hybrid option, in so far as the in situ geology was favourable. Further, the pit had been modelled using adequate samples of the in situ geology, the fractured limestone region had been narrowed to 500 mm and the cut-off trench was 600 mm below probed depth, and it had been partially backfilled with fluxed sand.

In the meantime the MCG had endorsed the hybrid approach, subject to conditions specified by Maralinga Tjarutja. The technical component of these conditions was agreed at a meeting in December 1998, but the administrative aspects were still under negotiation when an explosion occurred during the application of the ISV process to pit 17 (21/3/1999). Subsequently the ISV Contractor notified the Project Manager (facsimile from L Thompson [Geosafe Australia] to G Chamberlain [GHD], 29 March 1999) that it was no longer prepared to undertake ISV treatment of any pit at Taranaki.

Based on the concerns expressed on the ISV process, MARTAC recommended that a meeting be held to discuss:

- the pit 17 incident;
- status of operations at the site;
- approach to further ISV treatment; and
- the design of the hybrid pods.

This meeting took place in Canberra on 31 March 1999. Representatives from MARTAC, the Department, the ISV Contractor, the Project Manager and the Environmental Monitor were in attendance. As a result of the 31 March 1999 meeting, an assessment paper was prepared by MARTAC at the request of the Department.

Consequently MARTAC reviewed all past recommendations by TAG and itself on ISV, the ISV performance to that date, what was known about the pit 17 explosion and the detail of what was then proposed for ESV with respect to uncertainties in outcome and risk to operators during preparation and implementation. *Chapter 4* provides discussion of the performance of the ISV process with the detailed assessment being referenced in the many documents listed in *Attachment 4.8*.

MARTAC recommended abandonment of the vitrification process and subsequently developed a paper on the radiological acceptability for reburial of the waste remaining in half of the Taranaki pits. This paper is reproduced as *Appendix 3.4*. The analytical data that had become available progressively from successive melts showed that the plutonium content of the pits being treated by ISV was at the lower end of prior estimates (see Table 3.9).

The MARTAC paper reviewing the origin of recommendations on ISV and the ISV performance was discussed with the MCG at a special meeting on 8 May 1999. It contained an appendix where each member stated the reasons why he recommended as he did. The role the pit 17 explosion played in reaching a decision varied from member to member, and ranged from full support of the hybrid option, provided all operations could be executed remotely, through to a view that ESV was non-viable under the set of operational changes proposed by the ISV Contractor in order to reduce the operational risks.

The MARTAC paper dealing with the radiological acceptability of the reburial option was put in draft form to a second special meeting of the MCG meeting at the end of the same week (12 May 1999) after the MARTAC meeting. It concluded that:

> *... the contaminated materials that would arise from the exhumation of the contents of the 10 Taranaki pits are appropriate for burial in a manner consistent with the NHMRC Code and additional depth of burial for the contaminated steel would reduce further the likelihood of intrusion.*

3.5 REHABILITATION OF THE FORMAL DEBRIS PITS OUTSIDE TARANAKI

3.5.1 THE FORMAL DEBRIS PITS OUTSIDE TARANAKI UNDER TAG OPTION 6(C)

As already mentioned in *Section 3.2*, other than decontamination and radiobiology (DC/RB) pit 30, for which exhumation and reburial of contents was proposed, Option 6(c) proposed the ISV treatment of all the formal debris pits that had been defined by the British. In the event, none of these formal disposals pits (i.e. the radioactive waste disposal pits at TM101, Kuli, TM50 and airfield cemetery) were treated with the ISV process.

For the Taranaki pits, given the upper bound for the amount of plutonium claimed to be present in them and to be used in conservative assessments (20 kg), the potential radiological hazard following inadvertent intrusion or large-scale subsidence demanded treatment to stabilise the waste. As far as MARTAC was concerned, ISV remained the preferred option at those pits, subject to confirmation of the feasibility of the technique. Because of the unit cost figures for ISV available at the time, TAG regarded ISV as the default option for the treatment of any area involving radioactive waste disposal pits. However, by the time MARTAC came to consider the treatment of the pits as part of the Project, there had been a large escalation in the cost for ISV. This prompted MARTAC to revisit the question of what should be done with the formal pits outside of Taranaki, by first reviewing how much plutonium was expected to be in them. Further, it was known that much of the plutonium waste buried at TM101 was in the form of depositions on malthoid that had been rolled up and stuffed into 44 gallon drums. MARTAC believed this to be an inappropriate waste form for ISV treatment.

MARTAC concluded that the ISV treatment of the formal debris pits outside of Taranaki was neither appropriate nor cost-effective, given the relatively small quantities of plutonium they were believed to contain:

- airfield, 18 pits (approximately 1 g);
- TM 101-22 (approximately 70 g);
- Tietkens Plain-23 and parallel pit (approximately 26 g);
- TM 50-26 (0);
- Kuli-27 (0); and
- DC/RB (0).

The excavated volumes of pits 22 and 23 were 400 m^3 and approximately 2500 m^3 respectively.

MARTAC recommended exhumation of the pits' contents and burial of the debris in appropriate trenches.

A range of treatments was proposed by MARTAC for the different pits to suit their various circumstances. The following is a case-by-case development of the reasons for these changes.

3.5.2 TMS/TIETKENS PLAIN

3.5.2.1 Pit 23 (Tietkens Plain cemetery)

The term 'Tietkens Plain' was coined by the Senior Health Physicist (Mr OH [Harry] Turner) during the tests. He had intended to consolidate all contaminated debris from the TM100, TM101 and Wewak sites into one 'cemetery' that he called Tietkens Plain. This did not, however, prove to be feasible.

Tietkens Plain cemetery is within the TM101 site but well separated from pit 1 of the three TM101 burials. The Tietkens Plain cemetery was located next to pit 2 of the original TM101 burials. Pit 3 of the original burials was excavated and the contents placed in the Tietkens Plain cemetery (Turner 1985 [May 1964 report]).

Tietkens Plain cemetery was believed to contain approximately 26 g of plutonium in a designated part of the long pit containing contaminated debris and soil from TM100, TM101 and Wewak. Unlike the pits at Taranaki, the pit contained no RSJs or bulky steel plates.

Because of ambiguity in the record of the burial, MARTAC in 1994 reconsidered a former recommendation by TAG for removal of the cap and applying ISV to the underlying contents in that part of the pit believed to contain plutonium, in favour of exhumation of the pit in entirety. Pit 23 was excavated over 14 days and the contents transferred to and buried in the TM area trench. The second pit (pit 2 TM101 burials), 5 m square and 1.5 m in depth, was not listed as a separate formal pit in the Pearce Report and contained contaminated bitumen and other debris. It was also reburied in the TM trench (see *Chapter 4*).

3.5.2.2 Pit 22 (TM 101 burial pit 1)

Two factors mitigated against applying the ISV process to pit 22.

- For the reasons stated above ISV was not a viable option for pit 23 and the cost of relocating the large amount of infrastructure associated with the ISV process made consideration of applying the ISV process just to pit 22 a very costly option.
- MARTAC took the view that the waste in pit 22 could include drums of bitumen heavily contaminated with plutonium. Subsequent experience (melt 10, pit 9, 9–21/11/1998) where a drum of hydrocarbon-type waste floated

to the top of the melt, and where the contents burned, demonstrated the significance of that concern.

MARTAC took the decision to excavate pit 22 and rebury it in the TM area trench (see *Chapter 4* for detail).

3.5.3 AIRFIELD CEMETERY

The airfield cemetery is an area relatively close to the village area at which a variety of radioactive debris was stored. During the tests, the airfield cemetery was under the control of the Senior Australian Health Physicist at Maralinga, Mr OH Turner.

Mr Turner designed the storage at the airfield cemetery to allow for the retrieval of the wastes (other than that which was of a very low level). The operation involved waste conditioning, rigid packaging and good record keeping (letter from OH Turner to J Richardson, CXRL files NAA R29/105).

The retrievability of the higher activity wastes was achieved by having well-separated packages within a concrete-lined bunker and using concrete or steel tops to the concrete bunkers. Figure 3.14 illustrates the layout of the airfield cemetery.

The airfield cemetery was arranged in three categories of waste. Historical records (Pearce 1968) stated that the airfield cemetery consisted of 18 pits:

- 11 'Category 1' pits (labelled 'A' to 'K') high level activity;
- three 'Category 2' pits (labelled 'A' to 'C') medium level activity); and
- four 'Category 3' pits (labelled 'A' to 'D') low level activity.

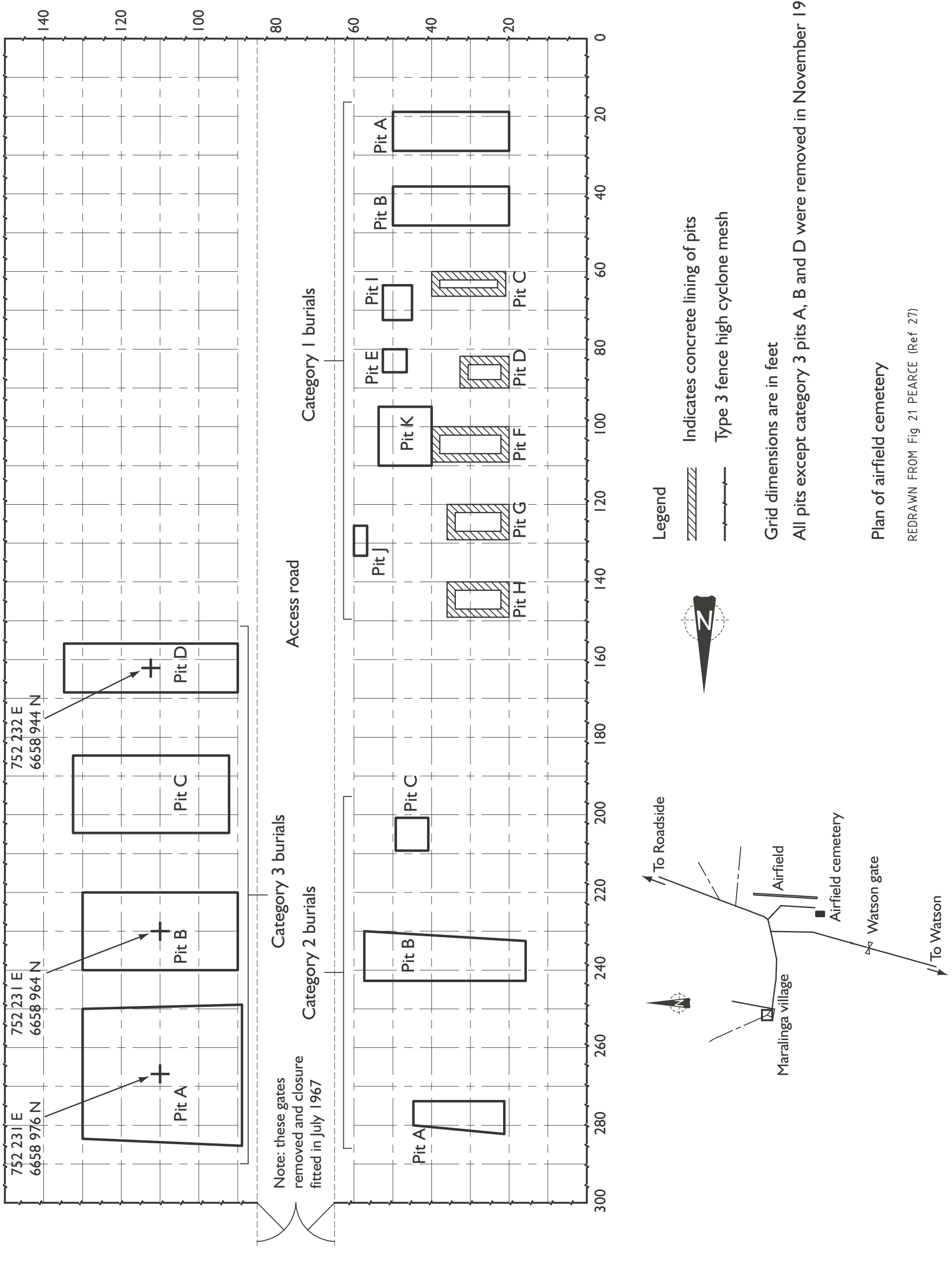
The total inventory is provided in Tables 3.10, 3.11 and 3.12.

3.5.3.1 Category 1 wastes

Category 1 was the most active waste. The wastes were predominantly the short-lived Th^{228} (half-life: 1.9 years) and Co^{60} (half-life: 5.3 years). The Co^{60} sources were the scavenged pellets found in the fallout from the major *Tadje* trial. They had been encased in lead in a 'Milo' tin before being set in concrete in a 100 L drum (Table 3.10).

An initial waste burial in Category 1 consisted of approximately 500 g of Pu^{239}. This plutonium arose from experiments conducted at site TM100 during the period September to November 1961 when 600 g of plutonium was used. The experiments were arranged so that at approximately 80% of the plutonium was captured in steel drums and the remaining 20% escaped to the local environment (Coppard 1961). These drums were subsequently disposed of at the airfield cemetery but were repatriated to the UK in 1979 (DNDE 1980).

Figure 3.14 Layout of airfield cemetery with pit numbers as of 28 July 1999 superimposed.



Grid dimensions are in feet

All pits except category 3 pits A, B and D were removed in November 1997

Plan of airfield cemetery

REDRAWN FROM Fig 21 PEARCE (Ref 27)

Table 3.10 Schedule of burials in airfield cemetery—Category 1 (high level activity).

Serial number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Date of burial		May 4 1959	May 4 1959	May 4 1959	May 4 1959	May 15 1959	Jul 6 1959	Jul 6 1959	Jul 15 1959	Feb 16 1960	Feb 16 1960	Jan 28 1961	Mar 25 1961
Isotope		Th^{228}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232}
Quantity Ci		0.2	0.3	0.6	0.1	0.43	5	1.4	0.9	0.5	0.7	20	0.7
Description		a	b	a	c	c	a	b	b	d	a/e	f	d
Outer container		w	x	w	x	w	w	w	w	nil	nil	nil	w
Surface dose rate (r/h)		0.04	0.2	1	0.22	0.18	5	0.7	0.5	–	–	1	2
Outer shielding material		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	M	M	M	M
Thickness in										12	12	12	12–24
Depth (ft)		3.5	4	4	4	4	3	4	4	3	4	2.5	2
Location	E (ft)	25	32	45	31.5	38	26	34	44	30	26.5	46	36
	N (ft)	24	21.5	25	26	24	43	43	43	64	86	83	104.5
Pit number		1A	!A	1A	1A	!A	1B	1B	1B	1C	1D	1E	1F

a	contaminated Vokes filter	FP	fission products
b	isotopes in metal containers	w	wood
c	contaminated waste	x	steel drum or box
d	steel or fibre glass & perspex hot box	y	concrete coffin with lid
e	contaminated valves, piping, etc.	z	lead castle
f	contaminated plastic pre-filter	M	concrete
g	miscellaneous experimental samples	L	lead

Table 3.10 Schedule of burials in airfield cemetery—Category 1 (high level activity) continued.

Serial number		**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Date of burial		Mar 25 1961	Mar 27 1961	Mar 27 1961	Mar 28 1961	Mar 31 1961	May 14 1962	Apr 27 1963	Oct 19 1964	Oct 28 1964	Oct 28 1964	Oct 28 1964	Oct 28 1964	Oct 28 1964
Isotope		Th^{232}	Th^{232}	Th^{232}	Th^{232}	Th^{232} Sc^{46}	Pu^{239}	Th^{228}	Th^{228}	Co^{60}	Co^{60}	Co^{60}	Co^{60}	Co^{60}
Quantity Ci		10	8	1.4	5.5	0.75 1.5	30	0.05	70	0.5	0.4	0.008	0.018	0.1
Description		e	d	e	a/e	b	b	d	b	b	b	b	b	g
Outer container		w	w	w	w	x	x	w	x	z	z	x	x	x
Surface dose rate (r/h)		12	20	4	23	18	–	–	0.05	1.5	1.5	0.05	0.02	0.02
Outer shielding material		M	M	M	M	M	M	M	M	L	L	L	L	Nil
Thickness in		12–24	12–24	12–24	12–24	24	42	4	12–36	1.5	1.5	1.5	3	–
Depth (ft)		2	2	2	2	2	3	2	1.5–2	8	1.5	8	8	8
Location	E (ft)	28	25	31	26	37	48	129	48.5	48.5	50	48.5	47.5	48.5
	N (ft)	104.5	124.5	124.5	144.5	141.5	68	59	103	106.5	106.5	109	109	108
Pit number		1F	1G	1G	1H	1H	1I	1J	1K	1K	1K	1K	1K	1K

a	contaminated Vokes filter
b	isotopes in metal containers
c	contaminated waste
d	steel or fibre glass & perspex hot box
e	contaminated valves, piping, etc.
f	contaminated plastic pre-filter
g	miscellaneous experimental samples
FP	fission products
w	wood
x	steel drum or box
y	concrete coffin with lid
z	lead castle
M	concrete
L	lead

3.5.3.2 Category 2 wastes

Category 2 wastes (intermediate level waste) were lesser activities of Co^{60} and Th^{228} and with some burials involving milligram quantities of Pu^{239}. The wastes were conditioned with concrete in steel drums (see Table 3.11).

Pits A and B in Category 2 were reported each to contain approximately 40 mCi (1.4 GBq) of unspecified radioactive waste from the University of Adelaide.

3.5.3.3 Category 3 wastes

From health physics reports of the time (Turner 1985 [December 1963, January and June 1964 reports]), the Category 3 'D' waste was identified with the low level waste associated with the chemical treatment of wastes arising from radiochemical work on samples from the *Vixen B* trials. The bulk (98%) of this waste (2.5 millicuries) was treated as Category 2 wastes, the remainder in a series of 100 L drums as Category 3 wastes. Category 3A and 3B wastes were drums of soil dug up from the wash down

Table 3.11 Schedule of burials in airfield cemetery—Category 2 (medium activity) (from Pearce 1968).

Pit label	Serial number	Date of burial	Container	Isotope	Quantity (mCi)
pit 2A	1–3	4/5/59	Steel drum	Th^{228}	65
	4	19/6/59	Vokes filter	Th^{228}	< 1
	5	15/7/59	Steel drum	Th^{228}	5
	6–21	29/10/60	Steel drum	*	9
	23–25	29/10/60	Steel drum	*	8
	34–38	29/10/60	Steel drum	*	5
pit 2B	22	29/10/60	Steel drum	*	1
	26–33	29/10/60	Steel drum	*	19
	39–40	5/6/61	Steel drum	Th^{228}/Pu^{239}	30
	41	5/6/61	Steel drum	Th^{228}	20
	42	5/6/61	Steel drum	Pu^{239}	10
	43–44	23/5/63	a	Th^{228}	1
	45–46	29/6/64	Steel drum	Pu^{239}	mCi level
	47–49	29/6/64	Steel drum	Th^{228}	mCi level
	50	28/10/64	Steel drum	Miscellaneous sources & experimental samples	3
	51	30/10/64	GI cylinder		2
	52	3/11/64	Wood box		1
pit 2C	53	10/7/67	Lead pot	Co^{60}	290
	54	10/7/67	Lead pot	Co^{60}	74
	55	10/7/67	Lead pot	Co^{60}	56
	56	10/7/67	Lead pot	U-natural	15

a Internally contaminated apparatus.

* Radioactive waste from University of Adelaide; isotope(s) not recorded.

area of Edinburgh airfield, plus the low level waste from the University of Adelaide. The most active at the time of disposal contained 1 microcurie of gamma activity (letter from OH Turner to J Richardson, 21 May 1959).

It was observed that the record for two drums of waste from a British laboratory was inconsistent by a factor of 1000 between the claimed weight and activity of contained Pu^{239} waste (see waste disposal record sheet reproduced as *Attachment 3.3*) since 3 mg of Pu^{239} would be somewhat less than 200 microcuries. For the higher value, 3 g, disposal in the Category 3 area was inappropriate and they at least would have to be exhumed.

Accordingly only the specific drums with ambiguous levels for the plutonium contained within them were removed from the Category 3 wastes (see Table 3.12).

Table 3.12 Schedule of burials in airfield cemetery—Category 3 (low level activity) (Pearce 1968).

Pit label	Date of burial	Container	Contents
pit 3A	19/6/59	Polythene bags & 1 wood crate	Fission products (FP)—active waste from Operation Antler, Maralinga
	21/1/60	282 steel drums	FP—active waste from aircraft
	12/2/60	2 steel drums	Decontamination at Edinburgh Field Th^{228} on cleaning materials
pit 3B	9/4/60	50 steel drums	FP—active waste from aircraft decontamination at Edinburgh Field
	9/4/60	11 steel drums laundry, Maralinga	FP—contaminated waste from DC
	23/6/60	14 steel drums	FP—active waste from Edinburgh Field
	29/10/60	14 steel drums	FP—active waste from Edinburgh Field
	29/10/60	7 steel drums	Active waste from University of Adelaide (Isotope(s) not recorded)
	14/11/60	Nil	FP—3 tons miscellaneous active waste from major trial sites Th^{228}—1 contaminated filter duct
pit 3C	13/12/60	2 steel drums	Pu^{239}—laboratory waste
	5/6/61	4 steel drums	Pu^{239}—contaminated lead bricks
	23/5/63	Nil	Th^{228}—apparatus and laboratory waste Th^{228}—contaminated extract system components
pit 3D	29/6/64	8 steel drums	Pu^{239}—FP laboratory waste

3.5.3.4 MARTAC's deliberations

The TAG report effectively considered the airfield as a 'formal' disposal pit so that under Option 6(c) all classes of waste would be treated with the Geosafe ISV process.

Consistency with national waste disposal code

Initially MARTAC considered leaving the airfield cemetery as a formal, enclosed, waste disposal site and reviewed the disposal records in that light. It was quickly realised that the depth of cover over the buried waste and the design of the pits was intended to simplify intrusion and retrieval (e.g. in Category 1 wastes of the 25 burials, none were below 5 m of cover, only four were below 2 m of cover [Pearce 1968] and many were held within concrete walled enclosures). This depth of burial and the employment of a specific design to simplify retrieval are inconsistent with national and international waste disposal codes for shallow ground disposal of low level radioactive waste (NHMRC 1992).

MARTAC recommendations for treatment of pits

Category 1 and 2 pits

Accordingly MARTAC required the exhumation of the entire Category 1 and 2 waste inventory, and its relocation in the forward area and that it be disposed of in a way that provided several metres of sub-grade clean soil as fill. Figure 3.15 illustrates the retrievability that was designed into the disposal pits for Category 1 and 2 wastes.

Figure 3.15 Exhumation of a Category 1 pit at airfield cemetery.

Category 3 pits

Only the waste with ambiguous levels of contamination (pit 3C) was excavated and reburied. The remainder was left in situ since it contained near background levels of radioactivity.

3.5.4 TM50—PIT 26

No action was taken at the TM50 site—the rationale is given in *Appendix 3.1*. Essentially there is nothing known about pit 26 that provides justification for classifying it as a formal rather than as an informal disposal pit.

3.5.5 DECOMMISSIONING RADIATION BIOLOGY AREA—PIT 30

Option 6(c) had assumed exhumation and reburial for the contents of pit 30 because of possible attempts at salvage of ‘Yellow Fleet’ vehicles containing some contamination. At the time of disposal, vehicles destined for pit 30 were in poor mechanical condition, and had been decontaminated on a number of occasions (CXRL file, NAA R29.110) but might have had residual plutonium in their oil sumps. During *Operation Brumby* the vehicles driven into pit 30 had their oil plugs removed, the oil drained and the engines run until seizure occurred. The vehicles were then burnt in situ. Intrusion into the pit for salvage of the vehicles did not appear worthwhile or probable and would not involve any radiological consequence.

Treatment of pit 30 involved promotion of further subsidence by driving heavy equipment over this pit followed by filling subsided areas and revegetating (see *Chapter 4*).

During *Operation Hercules*, other items, such as a disc plough, were added to the ‘Yellow Fleet’. Ultimately, these would have been disposed of, but not necessarily all to the DC/RB pit 30. The early TAG work suggests that some items ended up in pit 35U but their fate is not known.

3.6 REHABILITATION OF ‘FORMAL’ (NUMBERED) PITS AND AREAS AT KULI

This topic is considered in detail in *Appendix 3.5*. The following is a precis of that appendix.

Maps of the area as it was in 1961 and 1964 are shown as Figures 3.16 and 3.17.

3.6.1 BRITISH USE OF THE KULI SITE

Kuli was the location used for one series of development trials called *Tims*. They were designed to study the behaviour of materials in an assembly under shock from detonated chemical explosive. Of interest was the timing of compression of the tamper.

In preparing for any trial an arc was defined within which it was required all debris would fall. The defined arc would lie outside other locations where Maralinga Range personnel might be working.

In the *Tims* trials, natural or depleted uranium was used in lieu of plutonium or enriched uranium. Beryllium was also present in some trials but there was no alpha emitter (e.g. Po^{210}), the other component of an initiator. Thus detonation and its aftermath gave rise to three hazards—the chemical explosion itself, particulate beryllium (chemically toxic) and particulate uranium (chemically toxic and radioactive). A safety circle for these three hazards had a radius of 2300 yards (approximately 2120 m) and the safety arc was all directions other than those that included Maralinga village and its infrastrcture (240° to 286° centred on Kuli) (AWRE 1958a).

In all, some 340 *Tims* trials were conducted at Kuli and involved approximately 7000 kg of uranium and at least 28 kg of beryllium. These trials were conducted from 1957 to 1961 inclusive and again in 1963. Generally there were two series of trials each year (Symonds 1985).

3.6.2 NATURE OF THE *TIMS* FIRING AND WASTE MANAGEMENT

The trials conducted during any one day were at the same spot. After each firing of the larger assemblies (i.e. more than 100 kg uranium) and, for some series on a daily basis (Classified report by Carter handed to R Jeffree [Australian High Commission] and faxed to DISR, 9 December 1994), the ground was levelled and the crater filled in. The craters formed were small. In and near them was a considerable deposit of grey pulverised rock dust and around the crater was a blackened scorched surface approximately 5 to 10 m in radius.

Figure 3.16 Map of Kuli area in 1961 (from Schofield 1985).

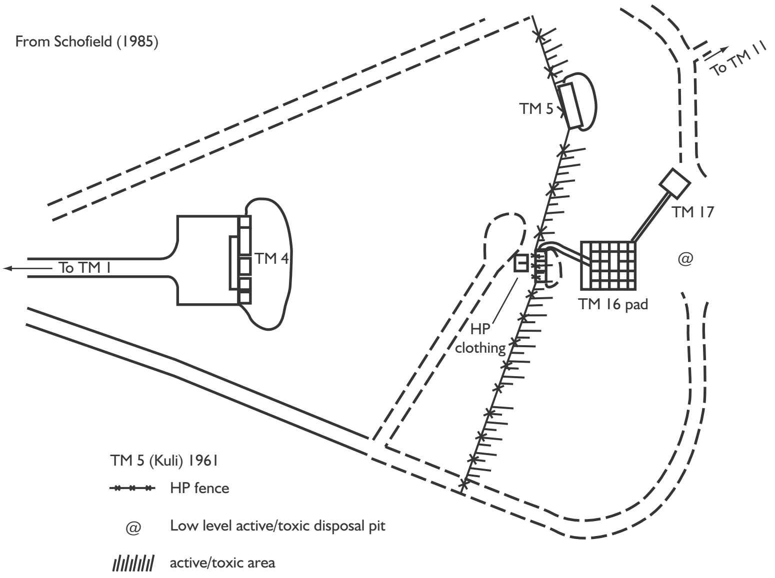
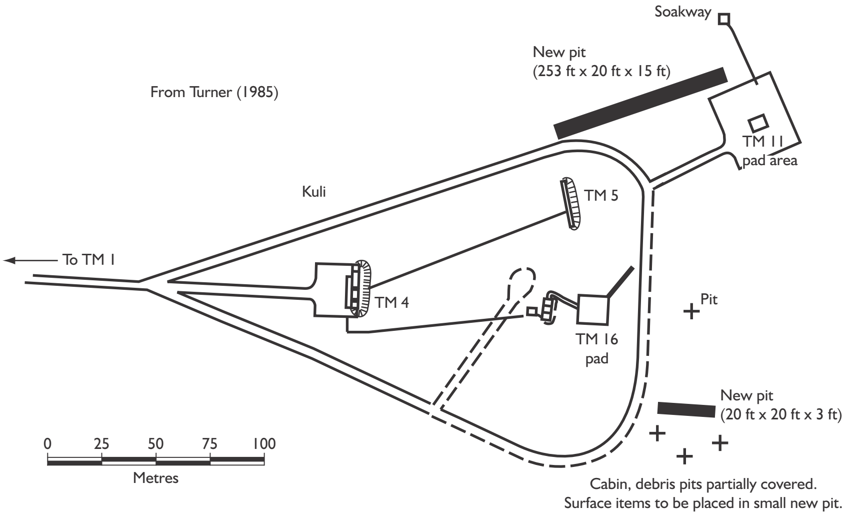


Figure 3.17 Map of Kuli area in 1964 (from Turner 1985 [May 1964 report]).



During the explosion the tamper is subject to rapid heating and undergoes fragmentation. Normally the explosive force is such that the tamper material is finely divided and is dispersed considerable distances as fine particulate oxide. However in charges where the mass of the explosive material is comparable to the tamper mass, fragmentation may not result in all the material being finely divided. Under these circumstances the fragments of uranium are blasted out to a distance of some 300 m as lumps of uranium. On landing most of these fragments continue to burn (sometimes for days) and leave behind a heap of uranium oxide (AWRE 1958c, 1958d).

At the end of each series plant was used to level the site (AWRE 1957, 1958a). The process seems to have been to scrape in one direction (away from the control room and shelters). Thus over time the scraped material accumulated into what was described at the time as ‘bulky and abundant’ (Turner 1985).

Sometime during 1958 to 1961 firing conditions were changed from being over bare ground (TM5) to being over a formal concrete firing pad (TM16). By then a small disposal pit (subsequently to be named pit 28) had also been set aside for disposal of low level, toxic, active waste described as ‘cables, metal debris, wood, strawboard, etc.’ having ‘very low’ levels of natural uranium and beryllium. Presumably this class of debris had in earlier times been included in the general scrapings from the site. It was stated that this waste could not be considered hazardous (Coppard 1961). Examination of historical map and drawing records indicate that this pit probably lies under what is now the road system loop around this part of Kuli.

The 1961 report assesses the hazard then at Kuli as being limited to the surface of the firing pad and its immediate surrounds. It acknowledges that outside the area there will be some active/toxic fragments which cannot constitute a hazard but should not be removed from the area. No mention is made of the mounds resulting from the daily scrapings.

A large pit (subsequently named pit 27) was dug as a receptor for the ‘bulky and abundant’ material that had resulted from the scrapings (Pearce 1964, Turner 1985). The two maps of the area shown in Figures 3.16 and 3.17 indicate the significant number of informal disposal pits that must exist at Kuli.

At the start of *Operation Brumby,* Kuli was described as:

> *A concrete firing pad (Pit No. 29) and two debris pits (No. 27 and 28) existed at Kuli. The firing pad had been sealed with concrete to cover fixed beryllium contamination and the pits contained debris contaminated to low levels with natural uranium and beryllium. Appropriate fences, signs and markers were in place.*
>
> Pearce 1968

Operation Brumby removed the fences, signs and pit markers, covered the firing pad with soil and levelled the whole area.

3.6.3 KULI SURVEY

ARL surveyed the Kuli area as part of its study into residual contamination at Maralinga (Lokan 1985). It reported that although uranium fragments were found over the entire site, their abundance was relatively light, except in one area of a wash away over the TM16 firing pad where a continuum of uranium activity was encountered. They also reported a cluster of uranium fragments approximately 750 m north-east of the firing sites.

All results for beryllium levels in the soil were within the naturally occurring limits (1 ppm) but one small piece of metal subsequently confirmed to be beryllium was found approximately 500 m east of the firing pads.

3.6.4 TAG STUDIES AND RECOMMENDATIONS

The Kuli site was included in the aerial survey conducted by the Remote Sensing Laboratory (EG&G 1990) on behalf of TAG. They reported that the uranium activity appeared to be largely confined to the area around the firing site (see *Attachment 1.3*).

During the TAG period misinformation developed on the question of the quantity of uranium at Kuli. This is reflected in the Remote Sensing Laboratory (EG&G) and TAG reports where it is stated:

> *Much of the uranium and beryllium was scavenged at the time of the trials and is presumed to be buried in the large pit on the N side of the Kuli site.*

TAG's consideration of the burial pits at Kuli was joined to the consideration of all 'formal' (numbered) pits (i.e. 'formal' British disposal pits, recognised as such and numbered during *Operation Brumby*) other than those at Central Taranaki.

With cost estimates available to TAG, the cost of treatment of burial pits decreased as excavation, grouting and ISV were in turn considered. Reality was the reverse of this.

TAG's Options 6(a), (b) and (c) differed only in the method of dealing with the 'formal' (numbered) pits with Option 6(c) using ISV. Consequently Option 6(c) was reported as the lowest price of the three options. As reported, it was a case of seemingly the best for the least, so the acceptance of Option 6(c) as the preferred option is not surprising.

As each option involved treatment of the firing pad (as pit 29) there was no need for TAG to separately consider uranium fragments on the surface, since all background information suggested they were predominantly on or near the firing pads.

3.6.5 MARTAC DELIBERATIONS

MARTAC recommended the hand scavenging at the Kuli site. It concluded, from the outcomes of the first attempt to do so, that the presence of uranium fragments was more general than one might believe from the ARL and aerial survey results. Consequently, the scope of the TAG recommendation was broadened to include formal scavenging operations over the Kuli site.

The retrieval of uranium fragments at Kuli was undertaken by the Health Physics Provider (see *Attachment 3.4*) intermittently over the period 28 March through 4 October 1998. The total effort involved 775 person hours and the portion cleared had a 600 m diameter centred about the air sampling location (approximately 45 m south-east of the southerly end of pit 27).

The low energy gamma detectors used to detect the uranium were type PG-2. The following were retrieved:

- uranium metal fragments with any dimension greater than 10 mm;
- uranium contaminated metal fragments; and
- uranium metal pieces that were possibly once greater than 10 mm but had since broken up and, being on the surface, were easily recoverable.

Five grid areas, totalling an area of 40 m by 60 m, due west of a line joining pit 29 with the southerly end of pit 27 were found to have such a high density of fragments as to make retrieval by hand too difficult.

At MARTAC's request, the Environmental Monitor surveyed the Kuli area using the high-resolution detector on the OKA vehicle and with the multi-detector arrangement fitted to the Nissan vehicle. These measurements confirmed a high level of particulate contamination (up to 200 kBq/m^2) in the area not scavenged by the Health Physics Provider. The Environmental Monitor separately staked out an area of approximately 1.5 ha in which the surface layer of finely divided uranium exceeded 15 kBq/m^2.

MARTAC reviewed the results of the fragment retrieval program and the Environmental Monitor survey results with Maralinga Tjarutja community members. The remaining contamination was discussed with emphasis on the chemical toxicity of soluble uranium compounds, the uncertainty in an appropriate value for the gut transfer factor for infants and the possibility that an infant, while crawling on the ground, might selectively ingest brightly coloured, weathered uranium compounds.

The proposal was to strip the surface of the more heavily contaminated area, bury the contaminated soil in an existing excavated area approximately 1.5 km west of Kuli and replace the contaminated soil with clean fill. It was further proposed to surround the central area with boundary markers to exclude the possibility of family units camping there. The boundary markers would follow the 5 kBq/m^2 defined in the Environmental Monitor's survey[12]. This recommendation was accepted by the community.

MARTAC also recognised that, by the very nature of the daily scraping operation during the operational phase, some fragments of uranium would have been forced under the surface. Thus to reduce the risk of such fragments reaching the surface, the program for Kuli was extended to include the reduction of rainwater run-on to central Kuli through recontouring and re-seeding.

At its fifth meeting, MARTAC focused on the high cost of transporting 2600 m^3 of material from pit 27 to the forward area for reburial in order to include something less than 7 tonnes of uranium metal of low radiological importance. Suggestions of pre-sorting seemed not to be viable because of the friable nature of any oxidised uranium and the needle-in-the-haystack nature of the problem (one part uranium in six thousand parts of soil). The exhumation detail was therefore considered in terms of reburial at depth at the Kuli site. MARTAC elected to form an opinion on the likely content of pit 27 by backhoeing it longitudinally and transversely.

Inspection of the spoil from the excavation at the time of backhoeing, and at a night session under UV, revealed a few small fragments of uranium from a depth of at least 2 m. From these inspections, MARTAC concluded that any uranium disposed of in the pit was so widely dispersed, and/or deeply disposed, that no further action was required.

This position was supported by a review of British reports (AWRE 1957, 1958a, 1958b, 1958c, 1958d; and see *Appendix 3.5* of this report) on minor trials for some of the years. For those years at least, a high percentage of the uranium consumed was widely dispersed in the atmosphere so that aircraft sampling of the resulting cloud plume was a viable experiment. The Kuli program for part of 1957 consumed 2696 kg of uranium. This amount was spread over approximately 30 shots. Of these 30, 12 were followed for plume sampling by Canberra aircraft; nine of these had indicated that practically all of the uranium consumed was present in the cloud. These nine included two credited with 'slight' fragmentation. The remaining three of the 12 were credited with 'much' fragmentation. The nine consumed 1600 kg of natural uranium; the other three, 570 kg of natural uranium. Thus, this one series carried out in one year would have widely dispersed about two of the approximately 7 tonnes of uranium consumed over the 12 series of trials during the six years of testing.

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[12] A surface density of 1 kBq/m^2 corresponds to uranium found in typical soils around Australia.

POTENTIAL RISKS/HEALTH EFFECTS OF URANIUM AT KULI

The potential risks/health effects of uranium at Kuli is discussed in detail in *Appendix 3.5*. The following is a selective precis of that information. References are given in the appendix.

The uranium at Kuli is a mixture of natural and depleted material that had been chemically separated from all non-uranium daughters at an earlier time. Consequently any comparison with reported health effects arising in uranium mines and mills must recognise that radium, radon and its decay product are not elevated above natural levels at Kuli.

The post-detonation uranium at Kuli was present as the metal or the oxide, but subsequent conversion to carbonates and other corrosion products is evident on some samples. Inspection of the Kuli area under UV light indicates that some solubilisation has occurred, with limestone chips and other rock minerals showing a superficial sorbed layer of uranium.

The low specific activities of natural and depleted uranium mean that no non-cancerous radiological health effect is expected from exposure to natural and depleted uranium. The US National Academy of Science Report *Biological Effects of Ionising Radiation IV* concluded that:

> *... exposure to natural uranium is unlikely to be a significant health risk in the population and may well have no measurable effect.*

Epidemiological studies

General animal evidence suggests that the more water soluble uranium compounds are primarily renal and systemic toxicants, the less water soluble are of moderate to low toxicity while the insoluble compounds (e.g. uranium dioxide) are primarily pulmonary toxicants. The kidneys have been identified as the most sensitive target of uranium toxicosis, consistent with the metallotoxic action of a heavy metal.

No unequivocal evidence has been found, in epidemiological studies, which link human deaths to uranium exposure. In uranium miners, deaths from diseases of the cardiovascular system and the urogenital system are low compared to other populations. Uranium miners have higher than expected rates of death from lung cancer, but this finding is attributable to the radiological effects of radon and its decay products.

One study of workers from three uranium mills exposed for more than a year to uranium concentrations exceeding the occupational standard by up to eight times (i.e. exposure to levels up to 30 Bq/m^3 [1.2 mg/m^3] found a dose response for nephrotoxicity).

Several epidemiological studies have reported respiratory diseases in uranium mine and mill workers who are also exposed to significant amounts of dust and other pulmonary irritants but not in uranium processing workers who are not exposed to these potential aggravants. No clinical signs of pulmonary toxicity were found in about 100 uranium-processing workers exposed to insoluble uranium dust at levels of 0.5–2.5 mg U/m^3 for approximately five years. Other studies have supported this general conclusion with respect to uranium processing workers.

3.6.6 MARTAC RECOMMENDATIONS

In conclusion, MARTAC recommended:

- hand scavenging with the aid of gamma detectors;
- exhumation of soil with local reburial over a region of approximately 100 x 200 m near the firing pads where the density of fragments was high and depth of soil through which they were distributed deeper;
- recontouring and reseeding; and
- enclosing an area of 28 ha with a notional fence comprising warning signs (see Figure 3.18).

REGULATORY STANDARDS

Solely for radiological effects, the ICRP has set a guide line for the individual chronic exposure of 1 mSv/yr (i.e. approximately equal to an intake of 100–400 Bq/yr, depending on the chemical form).

Of much greater importance are recommendations from regulatory authorities concerned with occupational health that take account of the chemical toxicity.

In the US, the National Institute for Occupational Safety and Health and the American Conference of Governmental Industrial Hygienists have set the permissible exposure to dust limit at 0.2 mg/m^3 for insoluble uranium (8 hr/day per 40 hr/week). Given that continuous exposure for members of the general public is about one-quarter of this value, the standard for the public would be about 50 µg/m^3. A more conservative group in the US, the Agency for Toxic Substances and Disease Registry, has derived a chronic inhalation minimal risk level of 1 µg/m^3.

For Australia, the inferred National Occupational Health and Safety Commission general public continuous exposure standard would also be 50 µg/m^3 for insoluble and soluble uranium compounds.

POTENTIAL EXPOSURE AT KULI

Inhalation

From Tables 4.1 and 4.2, the time-averaged respirable dust loading for an adult male living and carrying out all activities at Kuli would be almost 0.9 mg/m^3. Using an adult respiration rate of 8400 m^3/yr, the respirable dust intake per year would be approximately 7.6 g.

The average surface concentration of uranium in central Kuli soil can be taken as 20 kBq/m^2. If it is assumed that this uranium is distributed through 20 mm of soil, then the specific activity of the surface soil is 0.6 Bq/g, as the relative bulk density of the soil is about 1.7. At Kuli most of the remaining uranium is depleted and this can conservatively be assumed to be true for all of it. The specific activity of U^{238} in equilibrium with its daughter U^{234} is 24 kBq/g. Hence the mass concentration of uranium in the surface soil is 0.6 Bq/g of soil divided by 24 kBq/g of uranium (i.e. 0.6/24000 = 0.025 mg of uranium per gram of soil).

As the daily weighted average dust intake for a male Aboriginal is 0.9 mg/m^3 the uranium concentration of the air inhaled at Kuli is less than 0.025 µg/m^3; a value well within recommended limits expressed in mass concentration in air.

The air intake per year is about 8400 m^3.

Thus the activity of the uranium inhaled per year is:

0.6 Bq/g of soil x 0.9 mg soil/m^3 x 8400 m^3 of inhaled air per year = 4.5 Bq

This also is well within recommended limits based on annual intakes of activity.

Ingestion

Soil ingestion by community members is set at 10 g/day (TAG studies). This corresponds to the ingestion of 0.25 mg of uranium per day for a uranium concentration of 0.025 mg/g. This total quantity would marginally exceed the recommended intake of uranium in drinking water for a 70 kg adult contained in the World Health Organization (WHO) *Guidelines for Drinking Water Quality* (WHO 1993). This recommendation is 3 µg/day/kg of body weight. For this limit to be exceeded, the uranium ingested with the soil would have to be almost completely soluble in the gut, an extremely unlikely circumstance.

3.7 REHABILITATION OF THE INFORMAL PITS

3.7.1 THE INFORMAL PITS UNDER TAG OPTION 6(C)

Under Option 6(c), TAG recommended the excavation of all informal pits, sorting of the contents and removal of any components contaminated with radioactivity, followed by reburial at the initial location of the remaining debris. The collected contaminated items would be reburied in the forward area in a specially prepared trench.

3.7.2 MARTAC DELIBERATIONS

Excluding *Marcoo* (see *Section 3.9*), the treatment of the informal pits involved:

- removal of any debris exposed during the TAG studies and its reburial using the reburial method determined by the level of detected radioactive contamination (if any); and
- determining the extent of compaction on a case by case basis (see *Chapter 4*).

MARTAC deliberations leading to the recommendation of different approaches are presented as *Appendix 3.2*.

Figure 3.19 shows the location of each of the pits.

Figure 3.18 Warning signs at Kuli.

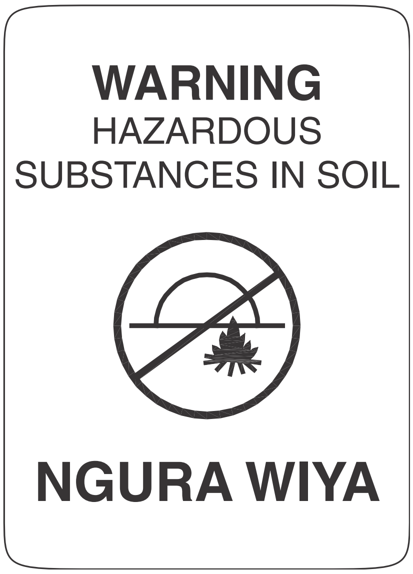
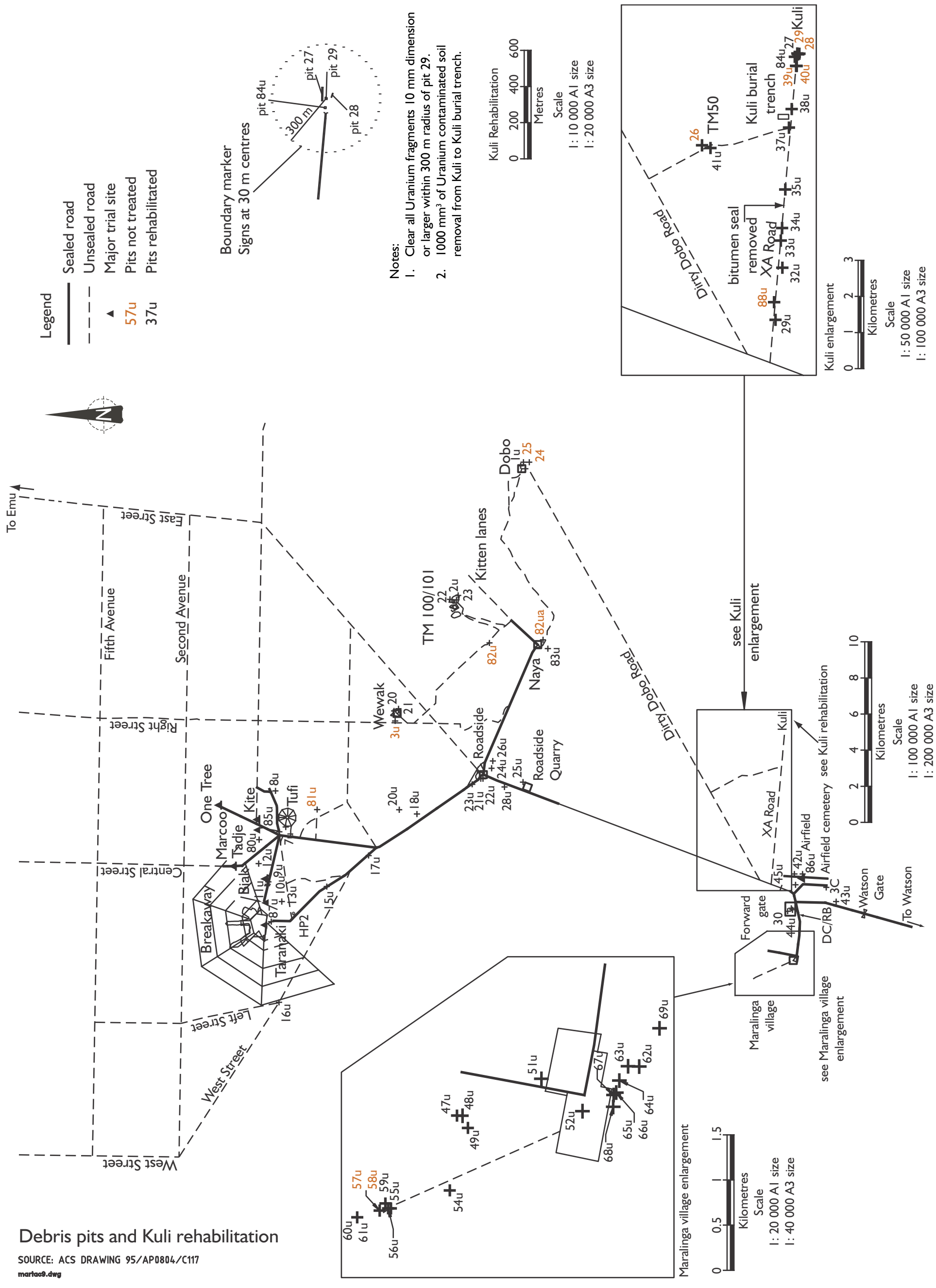


Figure 3.19 Location of the ‘informal’ pits.



Debris pits and Kuli rehabilitation

SOURCE: ACS DRAWING 95/AP0804/C117

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3.8 REHABILITATION AT EMU

3.8.1 MARTAC'S CONSIDERATION OF IMPLEMENTATION OF OPTION 9 AT EMU

Emu, some 200 km northeast of Maralinga was used for two nuclear weapon detonations, *Totem 1* (10 kT) and *Totem 2* (8 kT). Both detonations were on 30 m steel towers and used plutonium that had a high Pu^{239}:Am^{241} ratio. Currently these ratios are approximately 40 for *Totem 1* and 50 for *Totem 2* in contrast to approximately eight for the NW plume from the minor trials at Taranaki. This factor, together with the higher gamma radiation backgrounds resulting from nuclear detonations (e.g. Cs^{137}) causes the estimates of levels of Pu^{239} surface contamination, by measurement of Am^{241}, to be a much less sensitive technique at Emu than it is at the minor trial sites (i.e. at Taranaki and TMs). This made it difficult to derive from the aerial survey a plutonium dose contour corresponding to an upper limit exposure of 5 mSv/yr for children practising an outstation life style.

Other than a few *Kitten* trials, all of which involved only short-lived radioisotopes, Emu was a major trial site. Accordingly, as for the major trial sites at Maralinga, little was required in the way of rehabilitation but, in contrast to the major trial sites at Maralinga, the *Totem* ground zeros were not within areas with restrictions on land use. Further consideration of plutonium fallout and the glaze present at ground zero was therefore required.

Neither of the *Totem* trials was carried out in anything approaching ideal meteorological conditions. The *Totem 1* plume developed under low dispersive conditions that led to a pencil beam profile. *Totem 2* suffered a wind shift at low altitude so that stem fallout occurred initially to the south (over the road system and other services) before doubling back on itself. The consequence of these factors is still evident today (see *Chapter 1* Figures 1.13 and 1.14).

The surface soil at the *Totem* sites is sandy, with some outcropping limestone. The outcrops are more in evidence at *Totem 2*. Glaze was produced symmetrically about the ground zeros. At *Totem 2*, the stem fallout contained 'beads' (teardrop-shaped, solidified material derived from initially liquefied soil/limestone). The distribution of these beads follows the stem fallout footprint, with the highest density and largest particles being closer to ground zero and trailing away to the south.

Fallout beads were studied quite extensively in association with the *Breakaway* detonation (10 kT) at Maralinga that produced the most marked distribution of fallout beads and any potential inhalation or ingestion risk had been assessed (Turner 1985).

3.8.2 BASIS FOR TAG'S RECOMMENDATIONS AT EMU

Partly as a result of the higher Pu:Am ratio, the 'A' contour of Am^{241} measured by the aerial survey corresponded to doses estimated by TAG to be higher than 5 mSv (see Table 13; *Attachment 1.3*, p. 110). At the same time the Am^{241} 'A' contour covered extremely little area (see Figure 1.14).

In order to be conservative, TAG defined the area needing control in terms of the Cs^{137} 'A' contour. TAG calculated that the Cs^{137} 'A' contour corresponded to a dose of 0.5 mSv/yr for *Totem 1*, and 1.0 mSv for *Totem 2* (Haywood & Smith 1990). These calculations were based on the Pu^{239}:Cs^{137} ratio reported by ARL for glaze samples collected near ground zeros (4:1 at time of detonation). TAG then erroneously credited some doses (6.3 and 7.8 mSv per year for *Totems 1* and *2* respectively) to the Cs^{137} 'A' contour instead of specific situations for the Am^{241} 'A' contour, when calculating the scope of soil removal required at Emu (see *Attachment 1.3*, p. 108).

TAG recommended that surface soil within the Cs^{137} 'A' contour at Emu be scraped and mounded over the ground zeros.

3.8.3 ABORIGINAL COMMUNITY VIEW OF TAG OPTION 9

The community was not enthusiastic about the proposed mounding of soil at Emu because the soil mound would be unsightly.

3.8.4 DOSE ASSESSMENT

MARTAC returned to basics and asked ARL to review the tapes of the Remote Sensing Laboratory (EG&G) aerial survey (EG&G 1990) and to calculate doses associated with the area inside the Am^{241} contour using the criteria specified by MARTAC for soil removal at Maralinga.

ARL reported back in a minute dated 28 February 1995 that using the MARTAC/TAG criteria for clean-up and dosimetry, the average Am^{241} surface activity concentration (mid-1987 values), equivalent to an annual dose of 5 mSv, was 4.9 and 4.0 kBq/m^2 for *Totem 1* and *2* respectively. In contrast, the average activity for the areas containing the Am^{241} 'A' contour (averaged over 3 km^2) was 1.2 and 2.7 kBq/m^2 respectively. Consequently there was no need for any soil removal at Emu.

There was a need, however, to consider the radiological aspects of the glaze and beads since, without soil removal, they would be exposed. Scenarios involving glaze and beads had to consider all possible exposure routes.

3.8.4.1 Inhalation

TAG did not need to consider scenarios involving glaze or close-in bead fallout since the immediate ground zero areas would have been under the mound of soil if TAG's recommendation was accepted.

MARTAC arranged for ANSTO to determine the particle size distribution for the material produced by drilling and snipping samples of glaze and beads (ANSTO 1995). On the assumptions that the inhalable fraction corresponds to particles of less than 10 µm, and that the glaze would be worked on with pliers and similar tools close to the nose so that 1% of the fines were inhaled, then approximately 50 hours would have to be spent breaking up glaze in order to inhale sufficient plutonium to lead to a dose of 5 mSv.

Credible reasons for spending even a moderate amount of time in random breaking of glazing with pliers are difficult to imagine.

Whereas approximately 10% of the fines (< 75 µm) produced in breaking up glaze were inhalable, this figure rises to approximately 50% for abrasion of the beads. The percentages for particles of size less than 1 µm are 1% and 7% for glaze and beads respectively.

Since the beads are not particularly noticeable and are sparsely distributed it is again hard to imagine any realistic scenario that would lead to inhaling material abraded from them for hours on end.

3.8.4.2 Ingestion

MARTAC did not carry out any dissolution trials on the glaze or beads. During the late 1950s, digestion trials were carried out using water and N/20 hydrochloric acid[13] (as mock digestive fluids). At that time the beads were quite radioactive with short-lived fission products (Zr^{95}, Nb^{75}, Ce^{144}) so dissolution could be determined with high sensitivity. No significant dissolution of the glaze or beads was found (Turner 1985).

3.8.4.3 Bulk handling

As a final consideration, MARTAC needed to consider an entrepreneur who expended considerable effort in collecting sackfuls of glaze material presumably for resale to tourists as souvenirs. The surface dose rates from a sackful of glaze collected at the *Totem* sites are 0.7 mSv/yr (*Totem 1*) and 0.6 mSv/yr (*Totem 2*) and therefore bulk handling does not lead to a significant dose in any realistic assumptions.

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[13] N/20 hydrochloric acid is 5% of molecular weight gram equivalent dissolved in a litre of water.

3.8.5 MARTAC'S RECOMMENDATIONS

Acting as a scavenger around the ground zeros leads to some exposure to radiation, whether as a result of handling glaze or beads from the neutron induced radioactivity in the soil, or from soil ingestion. Occupancy of these sites should be discouraged.

MARTAC therefore recommended that the track entrance to them should be ripped up and seeded with local vegetation, and that the existing English language radiation warning signs near the ground zeros that warned against collecting souvenirs be duplicated with the standard Maralinga boundary marker signs.

MARTAC'S objective was shared by the community who wished to minimise attraction of the area for tourists.

The Emu lands (Section 1486 [500 km^2]) and that strip of land immediately due west of West Street (Section 1487 [200 km^2]) were returned to the traditional owners by the South Australian Government in 1998 (see discussion of these areas in *Chapter 1*).

3.9 REHABILITATION AT *MARCOO* CRATER

Marcoo was a ground surface detonation of a weapon with approximately 1.5 kT yield. The test was part of the 1956 *Buffalo* series and was conducted on 4 October 1956. The crater formed by the detonation had a volume of approximately 6000 cubic yards (4600 m^3; Cook 1967). Its diameter was approximately 50 m and depth was 12 m. It was surrounded by a rim formed by the ejection of earth from the crater as a result of the explosion. The rim was between 1 to 3 m high (Arnold 1987). During *Operation Brumby* the *Marcoo* crater was used as a general debris pit. The inventory of material deposited there is not known but would be expected to include fences, gates, warning signs and target response waste, as well as small quantities of contaminated soil. A known specific source of contaminated soil was from small areas adjacent to two used firing pads at Wewak (Pearce 1968). An indication of the quantity of plutonium involved is provided by the British report on *Operation Hercules* (UKAEA 1966). It infers that the contaminated soil was from the site of the plutonium burning experiment (VK 33) where the contamination was very heavy at the very centre (> 110 MBq/m^2) but decreased to near zero over a distance of a few metres (drawing H5HP/6/64 from UKAEA 1966). An upper estimate would be 100 m^2 at say 50 MBq/m^2 (i.e. approximately 2 g of plutonium). This is consistent with the reported recovery of 98% of the 100 g of plutonium that was used in the burning experiment (Stuart 1960).

In calculating where target response debris was deposited, we need to take account of:

- the closeness of the *Marcoo* crater to the target response trials associated with the other major test sites;
- the size of the *Marcoo* crater cross-section;
- the relative smallness of the cross-section of the ‘informal’ debris pits and their distances from the major test sites; and
- the list of classes of items disposed of in the debris pits.

It seems reasonable to assume that at least the more bulky of the target response debris were placed in the *Marcoo* crater and, in particular, up to three caravans, five swift aircraft, eight aircraft wing sections and up to six 100-foot towers.

Pearce, in his final report, claims that there is now a 5 m depth of uncontaminated soil at the top of the *Marcoo* crater and the concentrations and depth of cover seem to fit the requirements for categories of waste under the National Health and Medical Research Council (NHMRC) Code (NHMRC 1992) related to shallow ground burial. To be otherwise would require a quantity of plutonium that grossly exceeds the quantity used at Wewak.

TAG (1990, p. 12) regarded the *Marcoo* crater as a special case in its consideration of the debris pits. It concluded that while provision had been made (in its costing exercise) to grout the contents and to provide a concrete cap, further investigations may show that the contents should be exhumed and transferred to a prepared disposal site. TAG did not mention its basis for this statement[14].

MARTAC noted that:

- if deliberate intrusion was being considered, then the items of plant required to exhume the target items would have no difficulty in handling the concrete cap and even less in exhuming through the grout material;
- if the purpose of the concrete slab was to reduce the probability of inadvertent intrusion, then the same could be achieved with a pit marker as envisaged for the other debris pits; and
- there was a large amount of inactive metal scrap in the general vicinity of the crater.

Accordingly, MARTAC decided to reduce the scope of works for *Marcoo* to the removal of scrap from the surface and the installation of appropriate signs/markers.

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[14] The NHMRC code had not been developed by the time the TAG report was published.

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APPENDICES

3.1 TM50

3.2 The ‘informal’ pits

3.3 Teleconference minutes, 18 December 1998 meeting

3.4 MARTAC paper ‘Burial Option’ 11 May 1999

3.5 Kuli

ATTACHMENTS

3.1 Ordnance information

3.2 Project Manager’s removal of asbestos report

3.3 Record sheet for category ‘3C’ waste

3.4 Health Physics Provider’s report on retrieval of uranium fragments at Kuli

3.5 Treatment of debris pits, November 1994

CHAPTER 4

REHABILITATION OPERATIONS, EARTHWORKS AND END-STATES

4.1 REHABILITATION OF GROUND SURFACE CONTAMINATION

This chapter describes remedial operations as they were carried out in the field. It covers the major operations from:

- initial planning and establishment of infrastructure for the removal and disposal of contaminated soil; to
- verification that the specified end-states had been achieved; and
- rehabilitation of the formal (contaminated) and informal (uncontaminated) burial pits.

The areas which required the removal of contaminated surface soil are listed in Table 4.1 and illustrated in Figure 4.1. These were located at Taranaki, TM100/101 and Wewak, which were contaminated with plutonium, and Kuli where there was substantial contamination with uranium and possibly beryllium.

4.1.1 PLANNING, PRELIMINARY STUDIES, SKILLS AND ENGINEERING DESIGN

4.1.1.1 Planning and studies

The largest single rehabilitation operation to be undertaken at the site was the collection and burial of contaminated surface soil at Taranaki. For this reason, most of the planning and procedures were developed first for Taranaki and later applied with appropriate changes at Wewak and the TM sites.

Major elements of the planning involved:

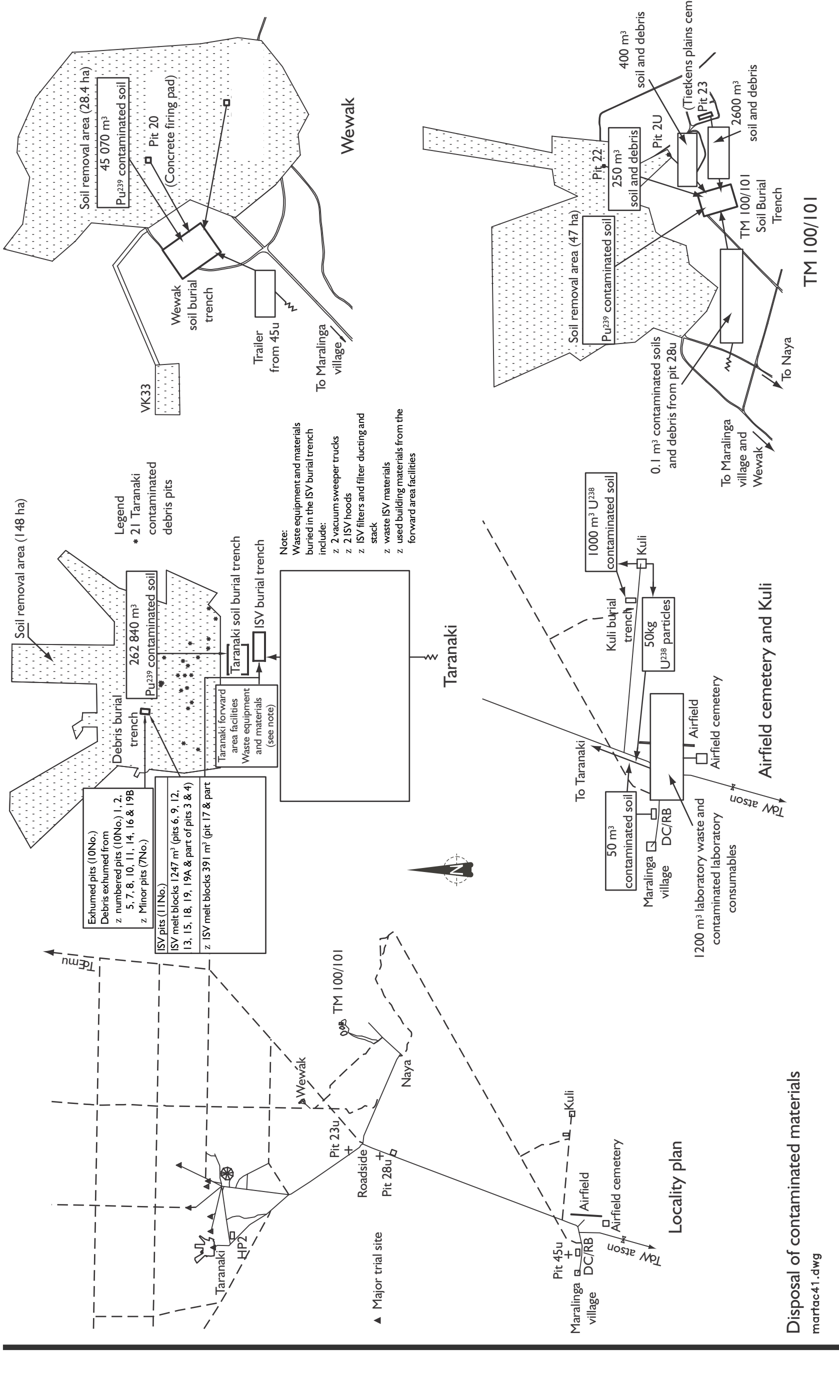
- installation of the forward area facilities;
- preparation of the modified or Class II plant;
- performance of trial rehabilitation operations;

Table 4.1 The areas on which initial planning was based.

Trial site	Area of soil removed (km^2)	
	Planned	Actual[1]
Taranaki	1.39	1.50
TMs	0.18	0.47
Wewak	0.04	0.29
Total	1.61	2.25

1 The actual values of the areas finally cleared are shown in the third column for comparison.

Figure 4.1 Areas from which contaminated soil and debris was removed and disposal locations.



- excavation of the soil burial trenches;
- stripping of vegetation cover;
- setting out of soil removal lots and construction of haul roads;
- stripping of the contaminated soil and its burial in the trenches;
- verification that residual radioactivity after soil stripping met specifications;
- removal and burial of debris and obstacles within the soil removal areas; and
- closure of the burial trench.

A range of soil removal options were assessed by the Project Manager and its subconsultants to determine their suitability. They were based on consideration of several criteria including effectiveness of contamination removal, safety (both conventional and radiological), cost and demands placed on the workers. The report *Contaminated soil removal methodology* (ACS 1994) presents the assessment of these options in detail.

A large number of factors had to be taken into account in formulating the options. They included:

- the presence of rock close to the surface in some areas;
- the presence of concrete capped debris pits in some soil removal areas;
- a range of vegetation, from scrub to small trees, that needed to be removed;
- high temperatures, low rainfall and occasional strong winds;
- limited availability of easily accessible water;
- the need to prevent contamination spread by dust and spillage;
- the constraints placed on operations by health physics and decontamination requirements; and
- the need for ARPANSA to monitor and approve treated areas.

The contamination in the soil removal areas was associated with three distinct types of material including fine dust, sub-millimetre particles and larger fragments with contamination on surfaces.

The boundaries within which soil was to be collected at Taranaki were defined through a number of surveys by ARPANSA.

Locations needed to be found for construction of trenches in which to bury the contaminated soil within close proximity to the soil removal areas and in locations where the geology was suitable for deep excavation. At Taranaki a further constraint was that low level contamination was present in the plumes to the north of the soil removal areas.

Based on a review of all available data, it was assumed for design purposes that the average depth that would need to be removed to achieve the clearance levels was 150 mm. The factors that influenced the assessment of the expected soil volume during this review included:

- depth of windrows in the ploughed areas;
- estimated depth of plutonium contamination;
- depth to rock;
- presence of previously imported clean soil; and
- precision of depth of cut during soil removal.

These quantities influenced the burial trench capacities, the capacity of the earthmoving plant and the time for completing the work.

A key consideration in determining the approach to be adopted for soil removal was to determine whether dust formation was a significant problem and, if it was, to decide which methods should be used for its control.

Water is normally used to control dust in conventional earthmoving operations to ensure that adequate visibility is maintained for plant operators and to prevent migration of material to surrounding properties.

Using a ‘dry approach’ for soil collection with only limited use of water to ensure that visibility is adequate for plant operators has several disadvantages, including:

- the risk of airborne contamination spreading on to clean areas;
- the high standard of personal protection required to combat the risk of worker contamination from airborne dust;
- the high demand placed on filters for vehicle air intakes and personal air filters;
- limitations on simultaneous operations in adjacent areas;
- concerns of workers because of their perception of risk at working in an environment of contaminated dust;
- limitations on vehicle speeds to limit dust generation; and
- difficulty of compacting dry soil in the burial trench.

The 'wet approach' would to a significant degree overcome the above disadvantages of the dry approach. However, it has several significant disadvantages including the:

- significant time and costs associated with sourcing and applying the large quantities of water necessary to ensure that the soil is thoroughly wet;
- difficulties of decontaminating the plant used to handle the wet soil as it would adhere strongly to the plant; and
- difficulty of achieving full wetting of the soil to be removed and the resulting risk of encountering dry soil pockets.

The conclusion reached after assessment of the advantages and disadvantages of both of these options was that the dry approach could be managed to limit the impact of the disadvantages of that system and result in a more practicable and cost-effective system. Key factors in this decision were confidence in the level of protection that would be provided to the workers by the planned plant modifications and the low probability that the dust would result in significant contamination of areas adjacent to areas being worked.

This still involved the use of some sprayed water in advance of soil removal to at least maintain limited control on dust raising and thus to reduce the hazards resulting from reduced visibility. As experience was gained, more water was used for dust suppression.

4.1.1.2 Skills

It was a requirement of the earthworks contract that prior to commencement of full scale operations, trials were to be undertaken involving all of the plant and personnel to be used in the vegetation removal and soil collection operations.

This was to demonstrate the suitability of the equipment, the capability of the operators and the practicability of the associated health physics procedures. In addition it was to serve as a training operation for all involved personnel.

The 'blue' (uncontaminated) area trials of soil removal were undertaken in two locations. The first location was to the west of the soil removal area at Taranaki where the land was relatively flat. The second was beyond the end of the north-west plume in an area which contained windrows left by the British from their ploughing operations. The purpose in trialling soil removal in both areas was to see if the proposed methods could handle the different ground conditions.

The blue area trials familiarised all persons with the special requirements of dealing with contaminated materials and the likely impacts of health physics practices on what were relatively standard soil removal operations. Overall these trials went well and confirmed that the equipment and personnel were capable of satisfactorily undertaking the soil removal operations.

SOIL-REMOVAL TRIALS

Appropriateness of shears

Vegetation was removed to confirm that the shears on the excavator were suitable for cutting off or extracting the shrubs prevalent at the site without significant soil disturbance. The alternative of using a small excavator bucket to remove the vegetation proved to cause more disturbance to the soil.

Soil removal depth

Soil was removed to a specified depth to see if there was adequate control on the depth of cut. Sensors were fitted to the scrapers to provide an indication to the operator within the cabin as to whether they were cutting at the required depth. Trial cuts, targeting a range of cutting depths, were made and the depths achieved were measured to check performance. This operation, while initially not highly accurate, was expected to improve once the operators became more experienced with the use of the sensor equipment.

Scraper effectiveness

The effectiveness of the scrapers to remove soil cleanly without spillage and without dropping residual windrows was trialled. It had been intended by the Earthworks Contractor that the grader be used to consolidate residual windrows to make them easier to pick up with the scrapers. However this did not prove to be necessary as the scrapers were able to remove small windrows quite effectively.

Plant breakdown and recovery operations

Simulation of plant breakdown and recovery operations and emergency operator evacuation procedures assuming the vehicle was on contaminated soil. This included removal of a wheel.

Decontamination

Decontamination operations were trialled in the vehicle decontamination facility.

4.1.1.3 Plant design

An important part of designing the approach and methods for the soil removal operation was to allow the work to be done using plant or machinery driven by operators in a controlled environment without the need for them to have any personal protective equipment in order to ensure their safety against the radiation hazard. Thus, vehicles used in contaminated areas were fitted with heavy 'submarine' style doors with 'O' ring seals and separate supplies of high efficiency particulate air (HEPA) filtered air both to cabin and engine. Figure 4.2 shows a modified excavator with its cabin entry door and roof-mounted air filtration plant.

Plant and vehicles used on the project were classified into:

- *Class I*—conventional earthmoving plant and support vehicles not modified for use in contaminated areas; and
- *Class II*—earthmoving plant and support vehicles modified for use in contaminated areas.

The design exercise involved:

- an evaluation of the radiological hazards, assessment of contamination risks, exploration of methods of radiological control and development of performance criteria; and
- concept development, protective systems design, operational/maintenance assessment, design development and contract documentation.

The Project Manager used the ALARA criterion as the overriding design philosophy for hazard and risk control to limit the potential for human exposure to ionising radiation to 'as low as reasonably achievable'. This criterion sought to achieve lower levels of exposure than the limits imposed by statutory authorities and applicable standards and code requirements.

Nuclear engineering

The first or nuclear engineering design phase addressed issues such as:

- dust burden in site operations;
- dose restriction;
- plant/vehicle operator protection;
- operating protocols;
- plant/vehicle maintenance; and
- plant/vehicle decontamination.

These issues are covered in detail in a number of reports, which are provided at *Attachment 4.1*.

Mechanical engineering

The second or mechanical engineering phase of the design resolved the overall conceptual design issues, and settled particular issues, such as:

- choice of two-stage HEPA filtration for control of contamination in cabin ventilation/pressurising systems;
- provision of HEPA engine filtration to control hazards in engine maintenance; and
- provision of in-cab monitoring.

The mechanical engineering design was developed around four primary elements:

- protection of plant operators;
- protection of maintenance personnel;
- facilitating plant/vehicle servicing and decontamination; and
- preservation of the functionality of plant.

Figure 4.2 Class II modified excavator.

Protection of operators from dust in contaminated areas

The focus of plant operator protection was protection of operators from exposure to dust in the contaminated areas. From a systems design perspective this involved elements including:

- barrier controls for entry to, and exit from, contaminated site operations;
- controlled vehicle entry and exit procedures;
- maintenance of clean conditions in vehicle cabins;
- modification of vehicle cabins to preclude the entry of dust;
- modification of vehicles to reduce dust generation;
- provision of personal safety equipment for emergency situations; and
- radiological monitoring.

Protection of maintenance personnel

The systems design for protection of maintenance personnel included:

- operational planning and modifications to vehicles to minimise the requirement for servicing and maintenance;
- modification of components and servicing systems to minimise contact with vehicle surfaces during servicing or maintenance operations;
- minimisation of servicing and maintenance procedures undertaken within contaminated sites;
- decontamination of localised or total vehicle surfaces, as appropriate, before commencing servicing operations;
- servicing procedures that protected personnel from exposure to radioactive material;
- provision of appropriate personnel protection for service operations; and
- radiological monitoring.

Experience quickly dictated the need to operate high pressure surface cleaning jets at the lowest effective pressure in order to minimise the dispersion of possibly contaminated grease and to minimise reliance on rear-entry suits that in themselves can raise the risks of industrial accidents, particularly when working on large plant items.

Modification of Class II fleet

The boxed text details the modifications carried out for the Class II fleet. Experience with the use of the modified plant in the field led to some changes to that set of initial modifications. Thus, under *impact protection*, stone guards for windscreens were omitted as the associated reduction in visibility was considered a greater hazard than that presented by the risk of impacts. Also, under *engine filtration*, HEPA filters were omitted from the engine air intakes for the major pit exhumation plant on the basis of experience gained earlier in soil removal operations.

Validation requirements were developed for critical protective systems. These included inspection, testing and formal certification of elements such as cabin integrity, cabin ventilation/pressurisation systems and safety instrumentation.

The drawings demonstrating the plant modification are in *Attachment 4.4*, *Appendix B*.

4.1.1.4 Quality assurance program

The Earthworks Contractor delivered the rehabilitation works under its certified quality system to AS/NZS ISO 9002. It conducted regular employee training in safety and the approved methodology for each task, and maintained records of this training.

Process control

Control of the work process was managed using a series of work procedures (WPs) developed by the Earthworks Contractor for various aspects of the rehabilitation work. The WPs identified the various separate activities involved to complete the work described in each task as well as listing the construction safety and surveillance and verification requirements.

These activities were referenced to a ‘method of work statement’ (MOWS) that detailed the sequence of steps and the access restrictions for undertaking a particular activity.

All MOWSs developed by the Earthworks Contractor were submitted to the Project Manager for review to ensure that Project requirements were being met. If the particular activity involved work that potentially exposed personnel to contamination, the Project Manager would prepare a ‘radiological work permit’ (RWP) which described the health physics controls to be implemented to accompany that activity. For each WP, the Earthworks Contractor performed a risk analysis to address construction safety. The documented outcome was the *Job Safety Analysis*. The analysis was a process of assessment of the physical risks of each task using a standard methodology that resulted in a set of recommendations or procedures designed to minimise the risk of an accident or personal injury during the performance of a particular site operation. Each operator received training in the recommended action or procedure resulting from the analysis and this was verified by their signature on the ‘job safety analysis’ form.

OVERVIEW OF MAJOR DESIGN ELEMENTS INCORPORATED IN CLASS II FLEET MODIFICATIONS

Plant/vehicle attributes: A number of basic attributes were developed for acceptable plant. Tracked vehicles were prohibited for contaminated area operations because of their tendency to disturb and trample in the soil-borne contamination. Vehicles needed to be relatively new or newly overhauled to maximise reliability and limit the need for servicing. Diesel power was required to rationalise fuel handling.

Colour coding: Class II vehicles were discriminated on site by a distinctive colour coding of vehicle entry doors.

Entry/exit provisions: Vehicles were required to be fitted out to assist manoeuvring into position and facilitate personnel transfers.

Dust suppression: Performance requirements for dust suppression and soil load security were designed to limit the dust burden and the dispersion of contaminated soil.

Sealing vehicle cabins: Stringent sealing requirements and a range of modifications to facilitate housekeeping were developed for vehicle cabins.

Cabin pressurisation: Systems for cabin pressurisation were required, including instrumentation and alarm systems to indicate loss of pressurisation.

Cabin filtration: Inlet air to cabins needed to be filtered to absolute standards using pre-filters and two stage HEPA filters (i.e. two HEPA filters in series). Each HEPA filter stage provides an minimum overall particle arrestance efficiency of 99.99% (for the most penetrating 0.3 micron particles). High-efficiency filters were also required on the cabin air relief to prevent dust infiltration by backflow when vehicles were idle.

Air intake: Cabin air inlets needed to be ducted from above cabins where the dust burden was lowest.

Cabin air sampling: Cabin air samplers were needed for monitoring the particulate levels and presence of radiological contamination in vehicle cabins.

Impact protection: Impact protection measures focused on prevention of stones or debris penetrating cabins. Where practical, cabin skins were made of 2.0 mm thick steel and impact resisting materials were used for viewing panels. Stone guards were required for windscreens.

Engine filtration: Vehicle engines needed to have absolute (i.e. HEPA) filtration to avoid the intake of radioactive particles and reduce the risk of exposure in the event of an engine needing to be overhauled. Crankcase breathers and oil and fuel vents were also filtered to preclude the intake of radioactive particles.

Maintenance facilitation: Measures were required to reduce the need for vehicle servicing, make vehicles easy to decontaminate (i.e. easy to clean) and permit servicing with minimum physical contact with vehicles.

The quality records for site surveillance and verification were the ‘inspection and test plans’ (ITPs), ‘procedural checklists’ and ‘verification checklists’. The ITPs were supported by the procedural and verification checklists. The verification checklists were signed off by the Earthworks Contractor’s Quality Assurance Engineer to verify that the works were performed in accordance with the specification and standard procedures.

Plant operation

The Earthworks Contractor implemented its own procedures to ensure the safe and reliable operation of plant. This included a requirement for the plant operators to complete daily check sheets. These check sheets were signed off by the Earthworks Contractor’s Site Superintendent to verify the plant operator’s compliance with the procedure.

Records of the soil removal progress

The Earthworks Contractor was required to maintain records of the soil removal operations including:

- the quantity of soil removed;
- where it was removed from; and
- where it was placed in the burial trench.

This was achieved by:

- dividing the soil removal area into lots;
- measuring the depth of cut by the soil removal plant;
- logging the number of loads delivered to the burial trench; and
- undertaking regular engineering surveys of the surface of the contaminated soil placed in the burial trench.

The Earthworks Contractor maintained these records for the entire soil removal operation.

Earthworks Contractor’s corrective and preventative action procedures

The Earthworks Contractor maintained a register of observations or events that had the potential to cause injury or lead to a radiological contamination incident. The register recorded incidents such as contamination on fitters’ hands and fractures of the brackets on the HEPA filter units.

Fractures in the filter brackets observed by the Earthworks Contractor’s maintenance fitters were corrected before the filter failed, thus removing the potential for a contamination incident.

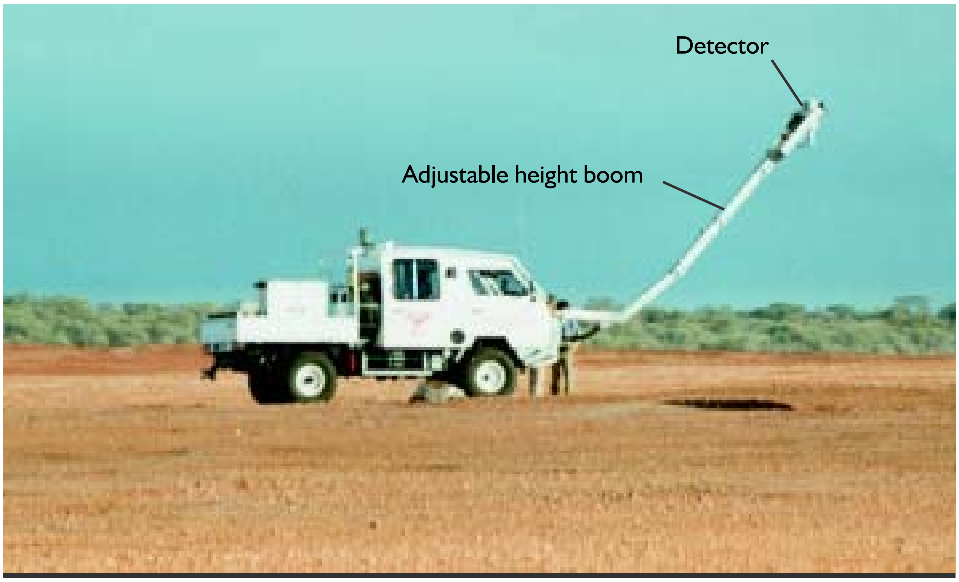
Audits

During the course of the project, internal audits were conducted by the Earthworks Contractor's Site Quality Coordinator and its Quality and Environmental Manager VIC/SA/TAS. The Project Manager also conducted three external audits of the Earthworks Contractor. No significant non-conformances with the Earthworks Contractor's quality system were identified in these audits and all recommendations of the audits were satisfied (see *Attachment 4.4*, *Section 17.2.3*).

4.1.2 ISSUES IN THE PRACTICAL ESTABLISHMENT OF SOIL REMOVAL BOUNDARIES

In order for the Environmental Monitor to define the boundaries of the soil removal areas, on the basis of the MARTAC criteria given in *Section 3.3.4*, both the surface activity concentration and the abundance and activity of particles and fragments were assessed. The surface activity concentration was measured with a closed end coaxial intrinsic gamma-ray detector, held at 4 m above the ground level on a boom mounted on an OKA all-terrain light truck (the OKA measurement system). A single measurement effectively averaged over an area of approximately 1000 m^2, and the detector resolution allowed easy separation of the 59.5 keV Am^{241} gamma-ray from the background contributions of natural radionuclides. Measurement times of 600 to 1000 seconds allowed a minimum detectable Am^{241} activity of 0.3 to 0.5 kBq/m^2, depending on the background at the location. The OKA high resolution measurement system is shown in Figure 4.3.

Figure 4.3 The OKA measurement system—an all-terrain OKA vehicle, adjustable boom and sensitive gamma ray detector.



Once a preliminary soil removal boundary had been determined in terms of the surface activity concentration, the boundary region was searched on foot, using hand-held gamma survey instruments. Using data obtained in earlier Environmental Monitor surveys, manual searching was started in the areas most likely to contain contaminated fragments and particles. Random walks and straight-line traverses between stakes outlining the boundary were conducted and as contaminated fragments or particles were detected, their position was marked and the search zone was moved 20 m outwards. On reaching an outer limit, where no further items were detected, more quantitative scanning was carried out. Ten by ten, or twenty by twenty metre grids were pegged out, outside the new soil removal boundary, and a 100% scan carried out to determine the concentration and activity of all fragments or particles within the grids. The final soil removal boundary was set at least 30 m outside the last detected visible fragment or particle exceeding MARTAC criteria. It was envisaged that small areas of contamination, amenable to small-scale removal by hand or machinery without special safety modification, might well have existed outside this boundary and would need to be remediated individually.

When the final soil removal boundary had been determined, the soil removal area was divided into lots, varying in size from 2 to 5 ha, to facilitate the orderly removal of soil and the verification at the end that the remaining level of surface contamination met the clearance criteria.

4.1.3 ENVIRONMENTAL MONITOR VERIFICATION

The Environmental Monitor deployed two separate vehicle-mounted systems to assess completed lots for compliance. Both vehicles were fitted with a differential global positioning system (GPS), with a precision of approximately 1 m.

4.1.3.1 Scanning for particles and fragments

For the determination of discrete particulate contamination or contaminated fragments, an array of four 12.5 cm diameter by approximately 2 mm thick sodium-iodide detectors was mounted on the bullbar of a four-wheel drive utility vehicle (Nissan). These detectors were each connected to a single-channel analyser set to count the approximately 59.5 keV gamma rays from Am^{241}. The four detectors were spaced at 0.5 m intervals, 25 to 30 cm above the ground and scanned a 2 m wide track. They were able to reliably detect all particles or fragments of activity greater than 100 kBq, and 50% of particles with an activity of 20 kBq. The Nissan vehicle-mounted particle detection system is shown in Figure 4.4.

Measurements by the Nissan system were conducted on each lot to determine the number and activity of discrete particles, above the soil-removal criteria, remaining after soil removal. Starting at one of the lot corners, the vehicle was driven anticlockwise around the lot along a path which spiralled inwards in increments equal to its slightly less than 2 m wheel track to ensure that as close to 100% coverage as possible was achieved. The data collected each day was analysed by purpose-written software. This software provided a map indicating the fraction of the area actually monitored, together with the position of every particle detected whose estimated activity exceeded a predefined threshold, usually set at 80 kBq. The software also provided estimates of the number of particles in the scanned area whose activity exceeded 20 kBq. Subsequently, the position of each recorded particle was revisited, and the particle's location determined with a hand held monitor and marked for removal at a later stage. A particle-removal request form was completed and handed to the Health Physics Provider.

Removal of contaminated particles was conducted by the Health Physics Provider, on completion of which documentation was passed back to the Environmental Monitor. Each area was then scanned again to verify that the particle and any surrounding contamination had been removed and that the soil-removal criteria had been met. The marker was then removed.

Figure 4.4 The Nissan measurement system—a Nissan vehicle with four sodium iodide detectors for particle detection.

4.1.3.2 OKA scanning

On completion of the Nissan scanning and particle removal and verification elements of lot clearance, residual surface radioactivity was measured using the OKA vehicle system.

Generally, at least nine measurements were made, where possible on a uniform 30 to 40 m grid within each hectare, to determine the average over a hectare of the surface concentration of Am^{241} (kBq/m^2).

Each set of nine points, forming a square within the lot, was averaged. If any of these sets was found to exceed the clearance criterion when averaged, remedial action was usually requested. This involved either extra bulk soil removal, vacuuming of the rocky ground surface or removing individual high-activity particles. The type of rehabilitation carried out depended on the type and degree of residual contamination and was determined by the Health Physics Provider. In extreme cases, (in particular at Taranaki) when it was impractical to reduce the contamination further, the Environmental Monitor had the flexibility, recommended by MARTAC, to pass lots with localised areas of contamination up to 10 kBq/m^2.

Count times of 1000 seconds were used for these measurements as the contamination levels were expected to be very low ($<$ 1.4 kBq/m^2). Count times of this length allow for a minimum detectable activity (MDA) of 0.3 to 0.5 kBq/m^2 to be achieved. A full description of ARPANSA's field monitoring at Taranaki is provided at *Attachment 4.3*.

4.1.4 LOT CLEARANCE

On completion of the above measurements, a 'lot clearance certificate' was issued by the Environmental Monitor. These certificates indicated that the lots met all criteria and were to be classed as cleared. Access to cleared lots was restricted thereafter to limit the potential for recontamination.

A sample lot clearance certificate is provided at *Attachment 4.2*.

4.1.5 SOIL BURIAL TRENCHES

In the initial considerations of the geotechnical investigation work required for burial trench location and design, the options considered were to have:

- one large trench at Taranaki and haul all contaminated materials from other sites; or
- three trenches, one each at Taranaki, Wewak and the TM sites.

Centralisation was not an issue in itself, since other components of the rehabilitation program called for continuing administrative control over substantial parts of the forward area. It was decided that the one trench solution would result in large volumes of contaminated materials being transported tens of kilometres and that this, apart from the cost, could result in a considerable dissipation of contaminated materials within the general area by wind blown spoil losses and contaminated soil dropping from vehicles. These general considerations were discussed on site with some MARTAC members in July 1994 and it was agreed that geotechnical investigations should be planned to provide data for construction of three burial trenches—one each at Taranaki, Wewak and TM 100/101.

TAG recognised that not all radiological waste material could be accommodated by ISV treatment, that some contaminated material would inevitably require burying, and that this would influence trench size and cover specifications. MARTAC recommended through further deliberations at the September 1994 MARTAC meeting the following cover requirements:

- all contaminated soils must have a minimum cover of 5 m thickness of clean soil or rock;
- at least 3 m of the clean soil or rock should be below existing ground level;
- the surface of the clean soil and rock should be sloped to minimise the ingress of water; and
- the clean soils and rock should be placed in an appropriate sequence to give the best natural barrier to water ingress to the trench.

The trenches were designed to contain the estimated volume of removed soil and debris, with allowance for soil bulking on excavation, as well as an allowance for contingencies. The design also needed to allow adequate space for movement of the earthmoving plant operating in the trench. Trench capacities needed to consider the:

- likely depth of contamination;
- expected depth to rock; and
- minimum practical thickness that could be removed by earthmoving plant.

A design assumption was that soil would be removed to a depth of 150 mm, with a bulking factor of 10%, and a further 10% was allowed for contingencies. This conservative approach was important, as the quantity of soil for disposal was larger than had been estimated (see *Appendix 4.1* for a more complete account of all earthwork operations).

4.1.6 SOIL REMOVAL OPERATIONS

The process of soil removal and disposal was complex. The primary plant units for soil removal operation were three open bowl scrapers and a push dozer. The scrapers were able to pick up part loads under their own power but then required pushing by the dozer to load an adequate load of soil in the bowl. The dozer and the three scrapers worked as a team with the scrapers cycling between the work area, where they took a soil load on board, and the burial trench where they dumped the material.

A pair of conventional road-type sweepers with rotating brushes and vacuum suction was used in a follow-up operation to the scrapers where necessary to remove thin layers of soil, particularly from rocky and uneven ground.

4.1.6.1 Dust control operations

As an important element of occupational safety, the Earthworks Contractor was required to adopt dust suppression strategies to ensure that the soil handling operations were carried out in a low dust environment. This requirement to suppress dust was mainly for operator perception and for visibility and plant movement safety reasons. The protection provided to the operators in the Class II vehicles and the required separation distances (200 m) between soil movement operations and unprotected workers ensured that raised dust did not present a radiation hazard to workers at the site.

It was left to the Earthworks Contractor to propose an appropriate approach to this operation. Typically this was expected to include the contractor's methodology for soil removal and transport (e.g. control of equipment operating speeds) and the use of a dust reduction agent such as water. Supply of water was itself an issue if it was to be used in quantity for dust suppression.

The Earthworks Contractor initially proposed that the supply of water for dust suppression be sourced from the existing Roadside bore with a pump to be installed down the bore and a plastic pipeline laid between Roadside and Taranaki where several above-ground plastic tanks were installed for storage.

It was planned that the line would then be relocated to feed TMs and Wewak when the soil removal operations moved to those sites.

The Earthworks Contractor had originally planned to use a single water trailer towed by a tool carrier to spread water for dust settling operations and this was all that the original bore water storage at Taranaki could support. The water trailer had a capacity of 15 000 L which was close to the output per hour of the Roadside bore.

Early soil removal operations clearly demonstrated that the level of dust generation was unacceptable with significant dust being raised at the trench when the loads were deposited and at the soil loading area during the loading operation.

The Earthworks Contractor thus agreed that it was necessary to both increase its ability to apply water in the field with additional tanker capacity as well as to increase the storage capacity at Taranaki which would allow for the pump at Roadside bore to pump continuously if required. The Earthworks Contractor also agreed to assess the practicability of installing a spray irrigation system at the trench to reduce the dust generated at that location.

The Earthworks Contractor brought a further water tank and spray system to site which was installed on the roll-on/roll-off truck. In addition, the Earthworks Contractor installed a plastic lined water dam in the blue (uncontaminated) area near the forward area facilities at Taranaki connected to the water loading standpipe within the red (contaminated) area.

While these measures improved the level of dust control, the water supply from the Roadside bore was a major limitation on the operation. Accordingly, a new bore was installed to the east of the forward area facilities at Taranaki. While there had been some uncertainty about the ability to obtain a constant supply from this location, the bore proved to be very successful and supplied water continuously from January 1997 until the completion of the work at Taranaki. This added water capacity became available at Taranaki at a stage when almost half of the Taranaki lots had been at least partly cleared of contaminated soil but work had not started on clearing soil from the central Taranaki lots.

The Earthworks Contractor then put further effort into watering of lots before soil removal and at the burial trench and overall the dust levels were kept under more effective control from that point. In addition, the extra water in the soil being delivered to the trench improved the level of compaction being achieved in the burial trench.

For a period, the Earthworks Contractor tried starting the watering crew several hours in advance of the soil removal operations. While this did allow for more penetration of the water into the soil to be cleared, it tied up considerable resources including health physics personnel and proved a difficult operation to sustain.

Water was not the only way of assisting to control dust generation and the Earthworks Contractor was regularly requested to reduce the speed of travel of its scrapers to the burial trench as excessive speed led to spillage of soil and considerable dust generation.

To a degree, the success of dust control was dependent on the weather conditions with it being difficult to maintain low dust levels in times of high temperatures and persistent strong winds. On a number of occasions (approximately 15 during the life of the Project) soil removal had to be suspended because of high winds, leading to approximately seven days of lost work time in total (*Attachment 4.4*, *Section 8.4.4.8*).

4.2 REHABILITATION OF GROUND SURFACE AT TARANAKI

4.2.1 THE TARANAKI SOIL BURIAL TRENCH

Taranaki is on the northern margin of the Tietkens Plain. A thin veneer of Quaternary age red-brown, loose, silty sand blankets most of the area. A widespread calcrete horizon has formed over the underlying Tertiary sediments in top down order of Garford Formation, Hampton Sandstone, Wilson Bluff Limestone and Pidinga Formation. Basement to the region is the Murnaroo Formation, and the depths of 23 to 26 m were investigated immediately to the south of Taranaki, where it is approximately 10 m below the maximum planned trench depth. These formations are described elsewhere in this report (see *Appendix 1.1* and Morris, Read & Beal 1989) Excavation of a trench to approximately 15 m below ground surface anywhere in the Taranaki region would have involved removal of materials from all or most of the Tertiary units.

The calcrete was the principal rock strength material that was encountered during excavation at the favoured site (Site 4, see below), to a depth of 15 m. As had been anticipated, some of the calcrete required blasting, although some zones where there was a reduced degree of cementing were amenable to heavy ripping prior to removal. The remainder of the excavated material ranged from of high soil strength to very weak rock strength. It had been noted that the lithologies to be excavated were generally unsuited for re-use in a zoned cap structure (Geoprojects 1995)[15].

4.2.1.1 Burial trench location

The trench location should ideally be chosen to minimise haulage distances from the soil removal area to the burial trench. Four potential trench sites were identified from earlier drilling programs (Morris, Read & Beal 1989, Morris & Walker 1993) but only one was investigated in detail.

Options for trench location at Taranaki as presented were:

- Site 1—north of the Taranaki site, between the north and north-west plumes;
- Site 2—north of Taranaki, between the north and north-east plumes;
- Site 3—north-west of Taranaki on the topographic high; and
- Site 4—approximately 200 m south of Taranaki, on the flank of the Taranaki basin.

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[15] The other burial trenches for contaminated surface soils from Wewak and the TM sites were located in areas of essentially similar geology. However, there was no opportunity at either to avoid excavation through the very high strength dolomite rock that, with the calcrete, totalled 4–6 m thickness at Wewak and 8–10 m at Taranaki. Blasting was employed at both sites.

The site immediately south of the soil removal area (Site 4) was selected as the most suitable. This site had several advantages. It was in an uncontaminated area and it could be excavated with minimal health physics impact. Since it was topographically low, the high strength Garford dolomite was missing from the stratigraphy and the strength of the Wilson Bluff Limestone in this region was low. The first of these characteristics led to the geotechnical investigations (Geoprojects 1995) focusing on this site and when the other characteristics were confirmed, the Project Manager (ACS) decided that no further sites needed to be investigated.

4.2.1.2 Burial trench volume estimate

Separate assessments were made of the ploughed and unploughed areas in determining proposed soil removal depth. Various reports were consulted to estimate the likely depth of contamination for both (see *Attachment 4.4*, *Section 6.3.4.5*). For the unploughed area the reports suggested excavation depths from 20 to 100 mm to remove all contamination. For the ploughed area the depth varied between 50 mm between windrows to more than 100 mm taking into account the soil volume in the crests. The design soil removal depth to be allowed for in the trench was proposed as 150 mm for the whole soil removal area. Additionally a further 150 mm depth was estimated from the area within the manproof fence at Taranaki where it was understood that additional soil had been introduced by the British. The total volume estimated for the Taranaki soil burial trench was 285 000 m^3. In fact the final volume turned out to be 262 840 m^3.

4.2.1.3 Excavation

The trench excavation was undertaken over a period of three months from June to September 1996, prior to the start of soil removal. The dimensions of the trench were approximately 140 m x 200 m and depth of 15 m.

The Earthworks Contractor elected to incorporate separate entry and exit ramps in the trench for ease of operation. The spoil excavated from the trench was stockpiled adjacent to the trench for later use. Separation was maintained between the different types of material removed from the trench so that selected materials could be used in the trench capping operation.

4.2.1.4 Filling the trench

Sequence for soil removal on a lot

- Installation of haul roads.
- Setting out of the lots.
- Advice from the Project Manager to the Earthworks Contractor on the appropriate depth of soil cut for the lot. This was based on the likely soil depth over rock and the likely depth of contamination. Experience on adjacent lots provided guidance in the depth selection.
- Watering of the lot to maintain a level of dust control.
- Removal of the nominated depth of soil from the lot and disposal in the burial trench.
- Monitoring by the Project Manager of the depth of cut from observations and from the quantities of soil placed in the trench.
- On completion of the first soil removal pass for that lot, measurement of the residual soil contamination by the Health Physics Provider.
- Nomination by the Health Physics Provider of any areas within the lot over which additional soil removal was required to achieve specified contamination criteria.
- Repeat of soil removal and monitoring operations using scrapers or vacuum units as appropriate until it was assessed that the clearance criteria for the lot had been met.
- Once the lot met the clearance criteria according to the Health Physics Provider, the Earthworks Contractor was advised that work on that lot was completed and it was passed to the Environmental Monitor for final clearance monitoring.

As soil was progressively introduced into the trench, it was spread uniformly over the trench surface, with each incremental layer being limited to 30 cm. This allowed each layer to be surveyed to determine its average plutonium (americium) concentration, so that a final estimate could be made of the trench's plutonium content. The estimate obtained from these measurements was subject to considerable uncertainty, because of the difficulty in allowing for self absorption in the soil layers. The result of 2.6 kg for the mass of the contained plutonium that was obtained had an estimated uncertainty of ±50%. A second retrospective estimate made later (see *Section 4.3.2.3*) of 3.0 kg was consistent with this value.

A more complete description of all earthworks from which the above summary has been drawn can be found at *Appendix 4.1*.

4.2.1.5 Criteria for soil removal and final clearance

As has been discussed earlier (*Chapter 3*), the final soil removal boundary at Taranaki was set to satisfy the following criteria:

- the averaged concentration over a hectare would not exceed 40 kBq/m^2 Am^{241};
- no particle or fragment exceeding 100 kBq Am^{241} would be present; and
- particles of activity greater than 20 kBq Am^{241} would not exceed a surface density of 0.1 per square metre.

After soil removal, the residual Am^{241} surface activity concentration, averaged over a hectare, was not to exceed the value of 3 kBq/m^2 (1998 Pu:Am ratio). Experience with the north and north-west plumes showed that the equipment was not always competent to fulfil the stated criteria (see *Section 4.2.4*).

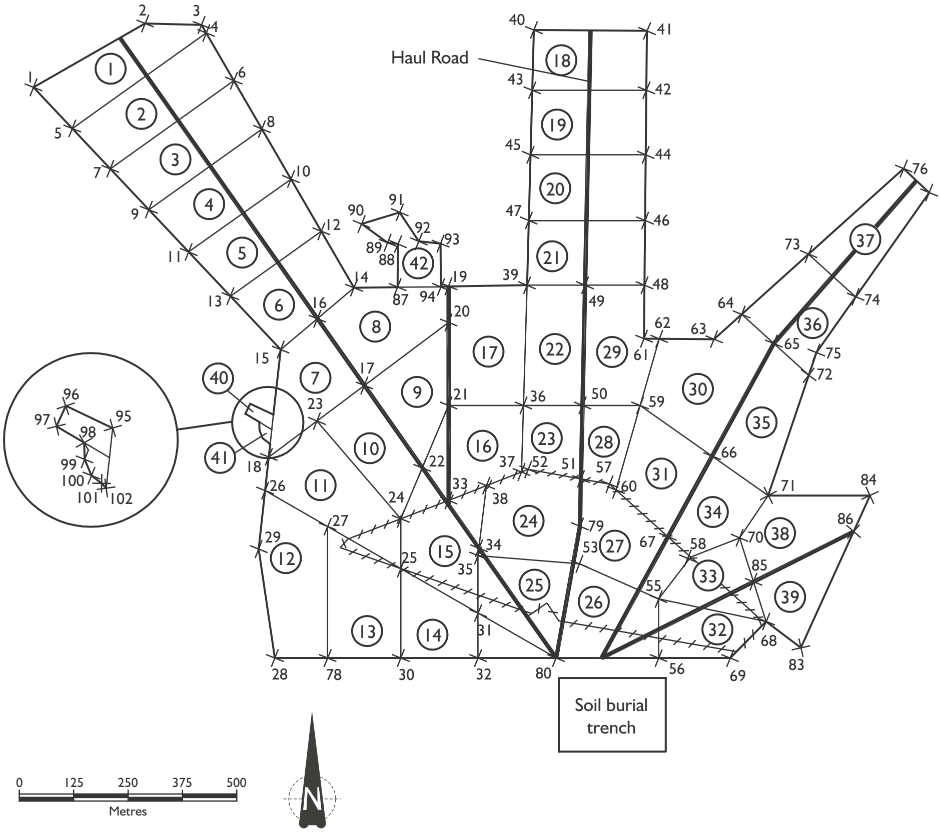
4.2.2 TARANAKI LOTS

Taranaki initially had 37 lots but, during the early stages of soil removal, further contaminated debris was found in a ploughed area to the east and particulate contamination was found in a small area to the west. Additional lots 38, 39 and 40 were added bringing the total area to 147.3 ha. Much later, during final clearance, two further areas were found to contain high levels of dispersed contamination and, although they strictly met criteria, soil removal was recommended and carried out (see Figure 4.5). These increased the final cleared area to 149 ha (see later discussion *Section 4.2.4*). Approximately 250 000 m^3 of contaminated soil was collected and buried at Taranaki.

The GPS coordinates of the Taranaki lots are given in *Appendix 6.1*, Table 6.1.1.

Each of the lots was treated individually during soil removal and verification. Soil was removed from each to a depth of at least 100 mm and transported to the Taranaki soil burial trench, located on the south side of the Taranaki soil removal area (see Figure 4.5). Once soil removal was completed on each lot, the Health Physics Provider scanned it for contamination and assessed it for compliance with the end-state criteria. If these appeared to have been attained, often only after several treatment passes, access to the lot was granted to the Environmental Monitor for final verification monitoring. Handover documentation including details of the lot coordinates, how the lot is accessed and any other relevant information were given to the Environmental Monitor.

Figure 4.5 Layout of Taranaki lots.



SOURCE: THIESS CONTRACTORS DRAWING No. TCV-1360-QUC-DR01 A7

4.2.3 END-STATE OF TARANAKI SOIL REMOVAL

4.2.3.1 Residual radioactivity

Figure 4.6 shows the area at Taranaki that is covered by this end-state description. *Appendix 6.1*, Table 6.1.2 summarises the condition of each of the Taranaki lots at the end of the soil removal operation. While several occurrences of individual hectares exceeding the criterion of 3 kBq/m^2 occur within a lot, all lots met the criterion satisfactorily.

4.2.3.2 Introduction of uncontaminated soil

Following the completion of the soil removal, some fresh soil was re-introduced in the form of windrows to serve as seed traps, and the windrows were themselves seeded with local native vegetation. While all lots had met the clearance criterion of 3 kBq/m^2, further soil was re-introduced to provide some soil cover in that part of the central region (see Figure 4.6), which to achieve the required criterion had been completely denuded to the underlying bedrock.

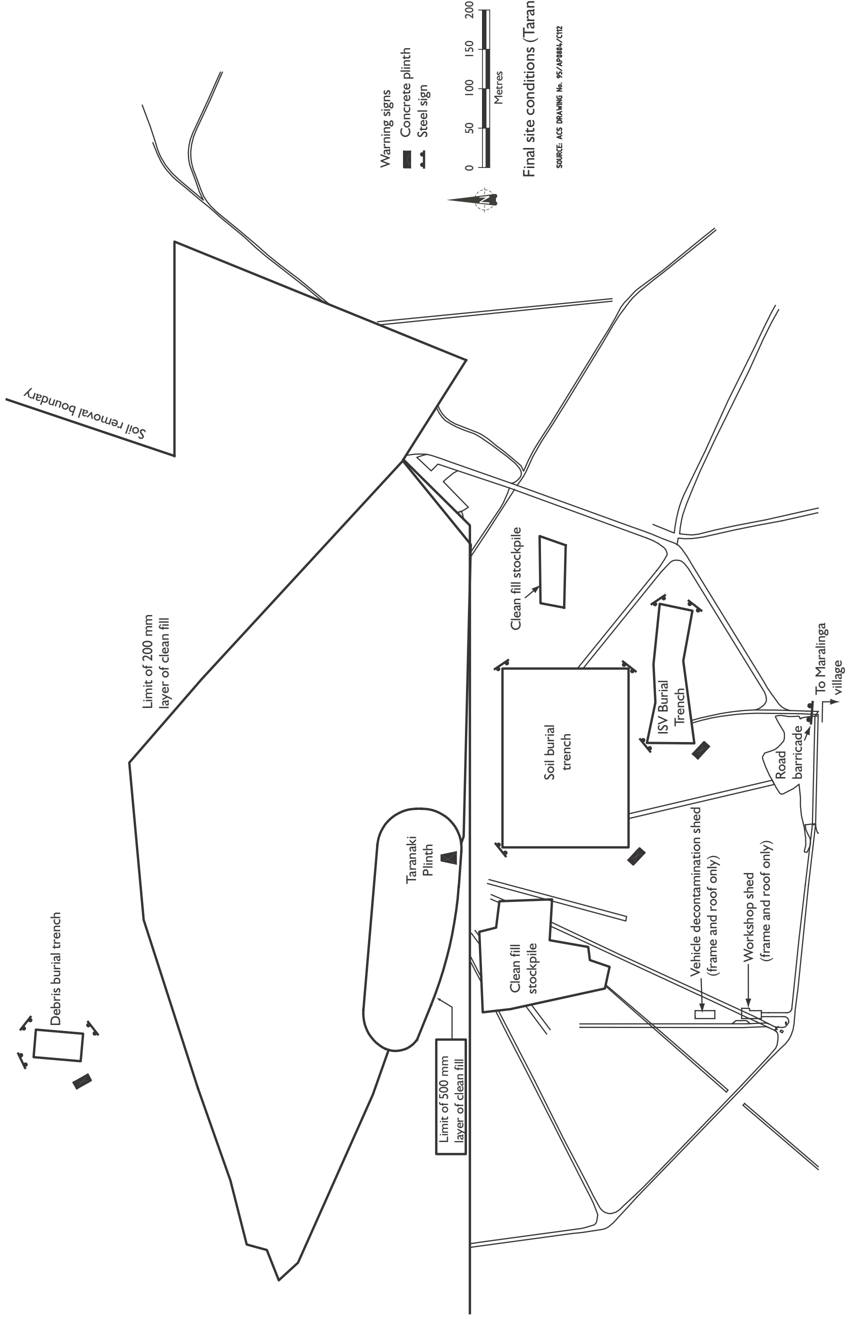
4.2.3.3 Discovery of pit L

During soil removal operations, a pit containing debris was uncovered when soil was being removed from what appeared to be a contaminated sand lens on the southern boundary of lot 27, approximately 50 m east of pit 18. As soil layers were removed contamination levels increased until contaminated debris was uncovered. The pit was fully excavated to remove the soil and debris, which consisted of star pickets, pipe, wire cable, chain link fencing, concrete and other small debris. Contamination on the debris was not high and the debris from this pit was placed in the soil burial trench.

The exhumed pit was approximately 5 m x 5 m in area and 2 m deep with vertical walls. The location of the pit was reviewed in relation to the AWRE layout drawing of the *Vixen B* firing pads and pits, which showed that this was pit L adjacent to the firing pad of the same designation.

The Earthworks Contractor had been instructed to place in the trench any debris found in the course of soil removal. However, when it was realised that significant quantities of debris pit material were present on or close to the surface, the Earthworks Contractor was instructed to leave a featherbed and other pieces of the test structures in place for later incorporation into the ISV melt at that pit. Some steel plates and RSJs had already been moved to the trench and the decision was made to leave them there. This decision, made in the field by the Project Manager and agreed by the Department's representative ... *took into account estimates of levels of contamination on those items that indicated they were no more contaminated than the surrounding soils* (see *Attachment 4.4*, *Section 8.4.4.7*).

Figure 4.6 The end-state at Taranaki at the completion of operations.



4.2.3.4 Closure of the Taranaki soil burial trench

The final contaminated soil surface contours in the burial trench are shown in Figure 4.7. This shows that the soil at the western end of the trench is at the maximum elevation of 3.0 m below grade whereas at the eastern end of the trench it is approximately 4.5 m below grade.

Class II plant was used to place at least the first 0.5 m layer of clean fill over the contaminated soil in the trench. Following monitoring of the surface of this layer and the trench walls to confirm that all contamination had been covered, Class I plant was then used for the remaining trench capping work.

Forming up the cap of the trench to the required profile, which ensured a minimum of 5 m of clean cover above the contaminated soil, was completed with Class I plant. The material was built up in layers to match the design profile to the best extent possible. Sandstone was the final capping layer with topsoil at the next level that was exposed for revegetation purposes by surface ripping.

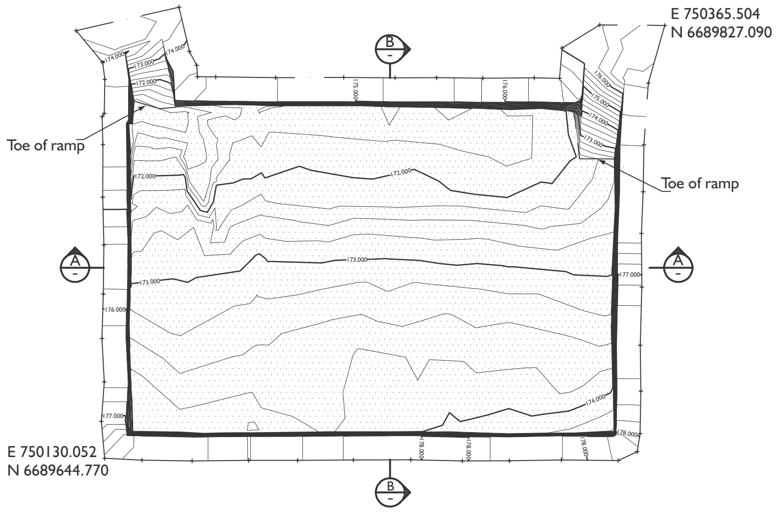
The lack of vehicle access to the top of the cover meant that the Environmental Monitor made a limited number of hand-held measurements there to confirm the absence of contamination.

Figure 4.7 also shows a section through the completed soil burial trench. Its GPS coordinates are given in *Appendix 6.1*, Table 6.1.3. A photograph typical of this end-state trench is shown in *Chapter 6*.

4.2.3.5 Re-measurement of points within Taranaki soil-removal areas

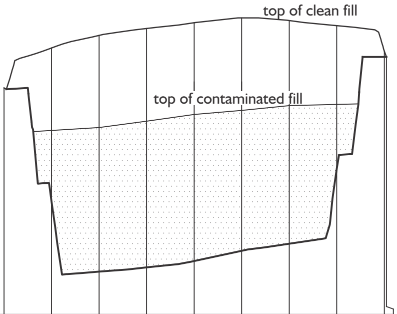
The removal of soil at the Taranaki site reduced the average surface activity of the cleared area to 1.5 kBq/m^2 of Am^{241}, well below the 3 kBq/m^2 clearance criterion. This was a consequence of the particle criteria being more restrictive than the criterion dealing with surface contamination. The subsequent windrowing of the cleared area with additional clean topsoil covered part of the area responsible for this surface activity and consequently the amount of contamination available for resuspension was also reduced. The Environmental Monitor, as part of its site closure program, made further measurements after the windrows were laid. It was not possible to re-measure the entire area but the areas which were re-measured support the view that the total area now has an overall lower surface activity. Results typically show a surface activity one-half to one-third of those measured previously. Further details are to be found in *Attachment 4.3*.

Figure 4.7 Layout of the Taranaki soil burial trench.



Plan top of contaminated fill
Scale 1: 1000

0 10 20 30 40 50
Metres
(1:1000 for A1 size plot)



Datum R.L.155.0

Final surface	175.312	178.669	179.724	180.308	180.784	181.200	180.971	180.545	178.414	177.919
Top of fill surface	175.312	171.743	171.993	172.517	173.080	173.429	173.826	173.925	177.919	177.919
base of trench		165.789	159.875	160.234	160.767	161.626	162.222	168.495		
chainage	0.00	20.00	40.00	60.00	80.00	100.00	120.00	140.00	160.00	160.90

Section B

Vertical
0 2 4 6 8 10
Metres
(1:200 for A1 size plot)

Horizontal
0 10 20 30 40 50
Metres
(1:1000 for A1 size plot)

Soil burial trench as constructed (Taranaki)

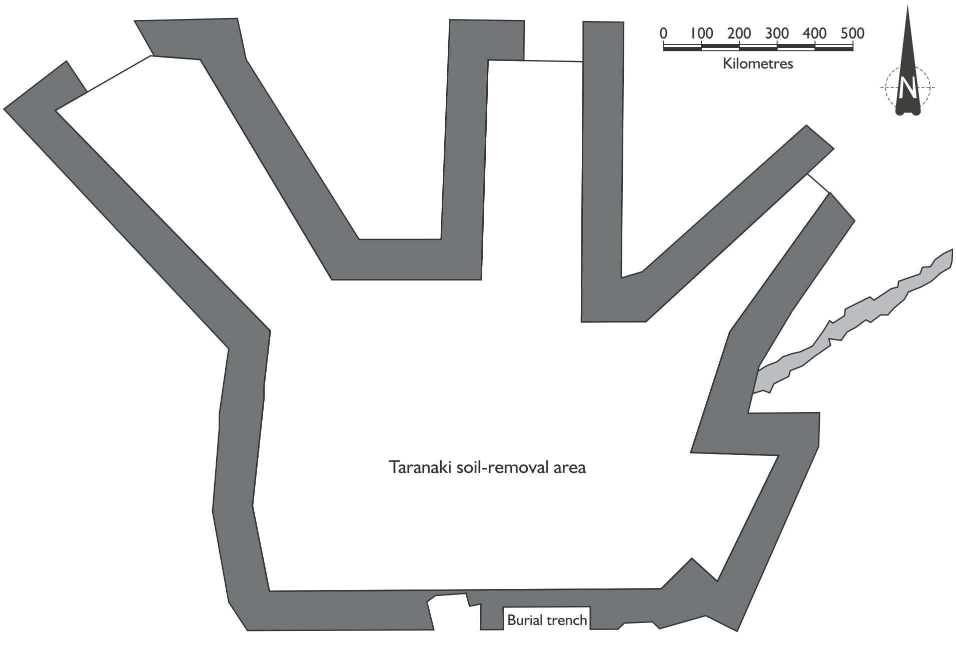
4.2.4 VERIFICATION OF SOIL-REMOVAL BOUNDARY

Following completion of the soil removal program at Taranaki, the Environmental Monitor undertook a final series of measurements to confirm that the overall requirements criteria had been satisfied.

Particle detection

The perimeter of the Taranaki site was divided into 85 ‘plots’ of 100 m x 100 m. Scanning with the Nissan-mounted detection system was performed on these plots around almost the entire soil-removal area (Figure 4.8). The plots at the end of the north-east, north and north-west plumes (a total of six) were not scanned as high-continuum activity (approximately 20–30 kBq/m^2) made it impossible to differentiate discrete particles with the equipment available. All particles of 80 kBq or greater recorded by the Nissan system were manually investigated. Any particles exceeding 80 kBq, or any visible, contaminated fragments were removed. In total, 23 particles exceeding 80 kBq were detected and individually removed from outside the soil-removal area. A 2 m x 2 m area surrounding each of the removed particles was again scanned with hand-held sodium iodide detectors to ensure that no further particulate

Figure 4.8 Map showing the area scanned by the vehicle-mounted particle detection system during the verification of the soil-removal boundary at Taranaki. The sparsely covered section in the east is a very narrow plume of dispersed contamination, which was monitored to ensure that this area met the MARTAC criteria.



contamination remained. In scanning these plots, two further areas were found to contain generally high levels of particulate contamination and further bulk soil removal was requested. An area of 0.1 ha south of lot 40, labelled lot 41 (Figure 4.5), contained some particles with activities greater than 100 kBq of Am^{241} and therefore exceeded the criterion for residual particulate contamination. This area had been inadvertently omitted from the definition of lot 40. Soil was removed from this lot in the usual way. It was then scanned and verified by the Environmental Monitor using the usual scanning protocol for lot clearance. Coordinates of this lot are included in *Appendix 6.1*, Table 6.1.1.

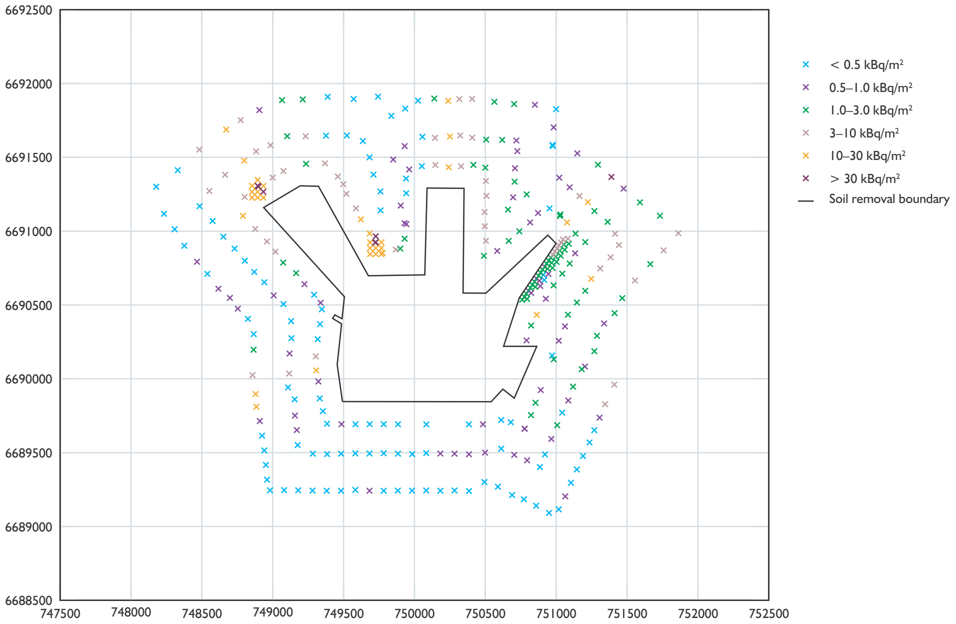
The second area where bulk rehabilitation was requested was Plot 31 (subsequently relabelled lot 42; Figure 4.5) and an area north of it. Surface soil was removed from this 1.5 ha area, which was then checked with the Nissan measurement system (see Figure 4.4) to verify that all particulate contamination was reduced to below MARTAC criteria. There was no evidence that this area exceeded criteria, but the high level of dispersed contamination and low activity particles made it impossible to ensure that the windrows did not contain high activity particles. Given the proximity to the disposal trench being constructed for the pit debris, it was considered worthwhile to remove this soil.

In each of these areas, and in regions where the occasional particle or fragment was detected and removed from outside the main soil-removal area, additional Nissan measurement system scanning was carried out to a substantial distance beyond the outermost particle or fragment located. Any particles and fragments encountered were removed by qualified environmental monitoring personnel and passed to the Health Physics Provider for disposal or placed in the ISV burial trench.

Average levels of surface contamination

OKA measurements were conducted around the perimeter of the soil-removal boundary (SRB) at distances of 100, 350 and 600 m from the soil-removal area (Figure 4.9). These clearly show that the dispersed activity in the area directly surrounding the Taranaki SRB is well below the 40 kBq/m^2 criterion for Am^{241} activity. When conducting these measurements, two areas were located in which measurement points had values of greater than 30 kBq/m^2. In each of these areas a grid of measurements was conducted and the results averaged over a hectare. Figure 4.9 indicates that when averaged over a hectare, neither of these two areas exceed the removal criterion for dispersed activity.

Figure 4.9 Location of OKA measurements around perimeter of soil removal area.



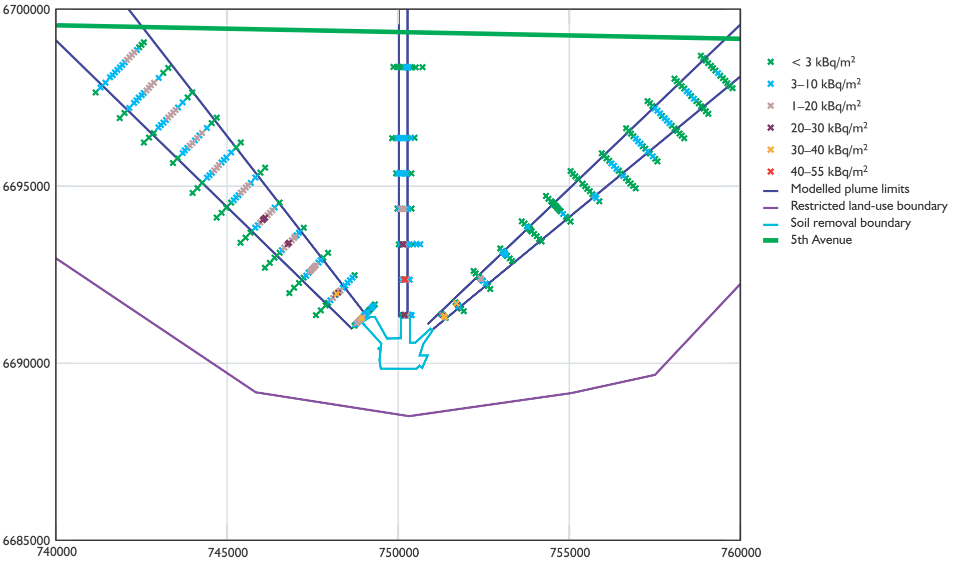
Operational lessons learnt

Many improvements to the documentation, pre-stripping operations, stripping operations, soil movement and disposal and to plant maintenance were made during the soil-removal operation at Taranaki. These issues were discussed at a post-operational workshop. The minutes of those discussions are at *Attachment 4.14*.

Residual contamination at Taranaki

The OKA measuring system was used to determine residual contamination at Taranaki by traverses across the plume at regular spacings down the plume footprint away from the cleared area. The results are illustrated in Figure 4.10. As would be expected from the boundaries of the 'C' contour in the results from the aerial survey (see Figure 1.8), there were individual readings above 30 kBq/m^2 Am^{241} along the centre line of the plumes. None of these locations breach the soil clearance criteria specified by MARTAC.

Figure 4.10 OKA measurement system traverses across Taranaki plumes after soil removal.



4.3 REHABILITATION OF GROUND SURFACE AT WEWAK AND AT TM100/101

As part of planning for soil stripping at Wewak and TM 100/101, a meeting of all involved parties was held to discuss the lessons leant from the Taranaki operations. The minutes of that meeting are reproduced as *Attachment 4.14* and the results from the meeting are discussed in *Attachment 4.4*, *Section 8.4.7*.

The methodology applied for the removal of soil at Wewak and TM100/TM101 was similar to that adopted at Taranaki, but adjusted to take into account the different Pu:Am ratios, different enhancement factors and the absence of any restrictions on land use.

4.3.1 CRITERIA FOR SOIL REMOVAL AND FINAL CLEARANCE

The criteria applied by the Environmental Monitor to determine the area to include within the SRB at TM100, TM101 and Wewak were:

- the average level of residual contamination over a 3 km^2 area was not to exceed 4.0 kBq/m^2 Am^{241} at TM101, 1.8 kBq/m^2 Am^{241} at the main Wewak site and at TM100, and 0.7 kBq/m^2 Am^{241} at lot 8 (a de facto limit on individual hectares was also applied, see below);
- no particles of activity greater than 100 kBq Am^{241} were to remain;
- particles of activity greater than 20 kBq Am^{241} would not exceed a surface density of 0.1 per square metre; and
- no visible, contaminated fragments to remain.

MARTAC specified ‘0.1 per square metre’ (or 1 per 10 square metres) rather than an average criterion for particles greater than 20 kBq. The Environmental Monitor interpreted this as requiring that there be fewer than 1000 particles per hectare greater than 20 kBq.

Similarly, MARTAC did not place a specific limit on the one-hectare average that was to determine the placement of the SRB at TMs and Wewak. However, areas where the contamination exceeded the assessed dose (taking isotopic ratios and enhancement factors into account) corresponding to 40 kBq/m^2 over a single hectare at Taranaki (approximately 12 kBq/m^2) were included in the soil removal contour. This included lot 8 where the activity at the centre of the ploughed circle was found to be greater than 100 kBq/m^2 of Am^{241} and sections of the north plume at TM101 where the peak activity was around 16 kBq/m^2 Am^{241}.

Due to the difference in isotopic ratios between the contamination at Taranaki and that at TMs and Wewak a more appropriate upper limit for particulate contamination for these sites is 30 kBq. For this reason, the Environmental Monitor attempted to investigate and remove all particles of activity 30 kBq of Am^{241} and above.

To the north-east of the main Wewak site, several individual areas of a few metres diameter were also found to be contaminated with another radionuclide, actinium-227 (Ac^{227}). A quantity of 5.6 MBq of Ac^{227} was known to have been used during the *Vixen A* trials at Wewak.

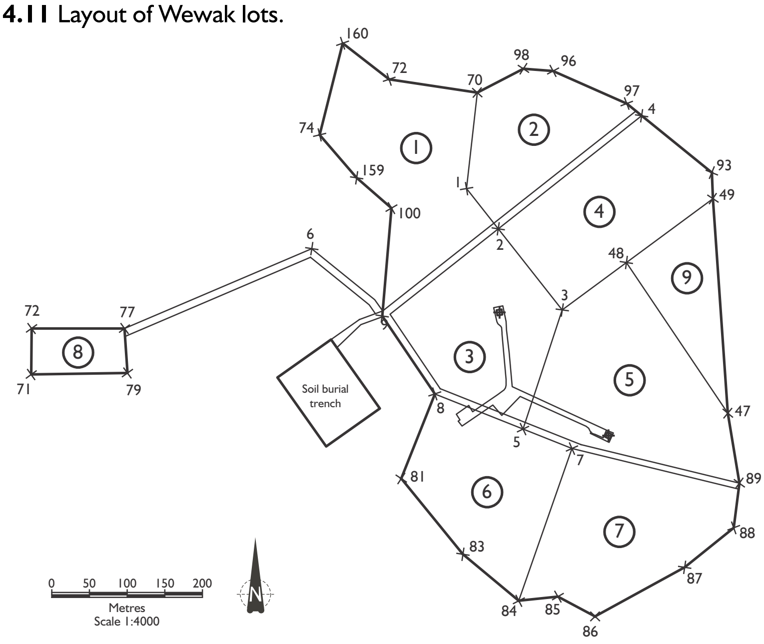
4.3.2 SOIL REMOVAL, DISPOSAL AND ENVIRONMENTAL MONITOR CLEARANCE

4.3.2.1 Layout of Wewak and TM100/101 lots

The layout of the lots at the Wewak and TM sites are shown in Figures 4.11 and 4.12 and the GPS coordinates of the lots are given in *Appendix 6.1* Tables 6.1.14 and 6.1.8. respectively. The figures also indicate the positions of the burial trenches at the Wewak and TM sites and the GPS coordinates of the burial trenches are given in *Appendix 6.1* Tables 6.1.15 and 6.1.13 respectively. Approximately 65 500 m^3 of contaminated soil was collected and buried at TMs from an area of 46.7 ha.

Soil was removed from within the soil-removal areas, including lot 8 (lot 8 [VK33] was the site of a 1959 British plutonium burning study) and transported to the relevant soil burial trench. Unfortunately, progressive measurements of the concentration of americium as the pit filled were not undertaken. This meant that it was not possible to make a direct assessment of the plutonium content of these trenches, as had been done for Taranaki. However, it was possible to make retrospective assessments, based on the field data collected by ARL in 1985 (see *Section 4.3.2.3* for discussion).

Figure 4.11 Layout of Wewak lots.

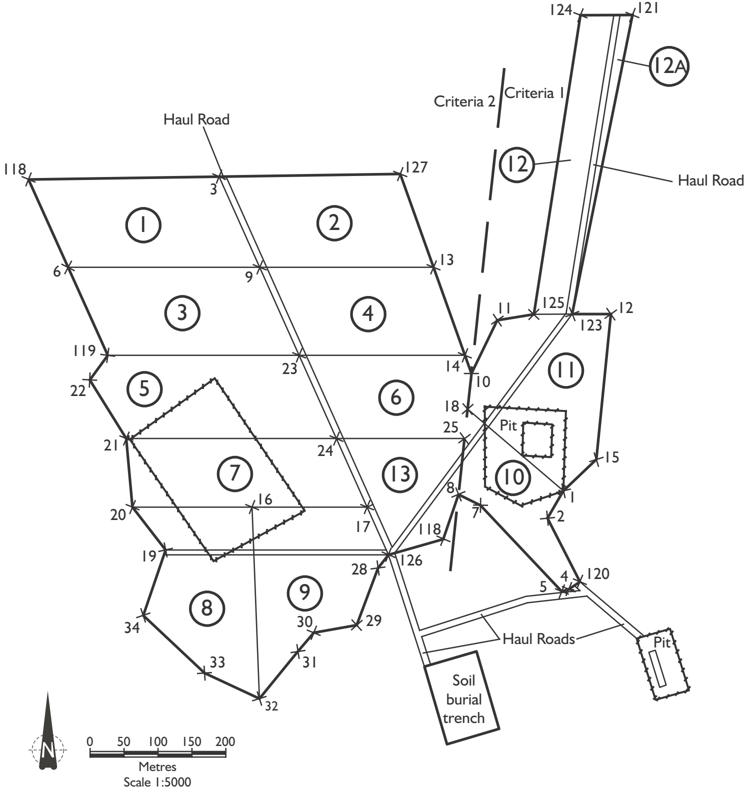


SOURCE: THIESS CONTRACTORS DRAWING No. TCV-1360-QUC-DR03 A3

All of the known actinium sites were included in the soil-removal area at Wewak. After soil was removed each of these was scanned with the Nissan measurement system as well as manually to ensure no residual contamination remained. Approximately 44 500 m^3 of contaminated soil was collected and buried at Wewak from an area of 29.1 ha.

South-east of Wewak, it was known that a plume had crossed the Emu Road. This area where the plume was found to cross the road was scraped aside and spread out into low piles leaving a large cleared area surrounded by very low heaps of dirt. The total area of this section of road was 2.65 ha. The scraped area and the piles were treated by the Environmental Monitor as a lot and scanned with the Nissan measurement system for particulate contamination. Twenty metres of the untreated road on either side was also scanned. No particulate contamination was detected. Nine OKA measurements were conducted over the cleared area to measure residual background Am^{241} contamination. The average Am^{241} level over the cleared section of road was found to be 0.56 kBq/m^2, well within the acceptable limit.

Figure 4.12 Layout of lots at TM100/101.



SOURCE: THIESS CONTRACTORS DRAWING No. TCV-1360-QUC-DR02 A5

Numerous fragments of contaminated bitumen were detected during lot clearance verification by the Environmental Monitor on TM100/101 lots 10 and 11. The Environmental Monitor's field team halted scanning with the Nissan measurement system and conducted systematic manual searching of the area. In doing this, an area was marked out in which further rehabilitation was requested.

Mechanical ways of removing these fragments of bitumen were not practical as the remaining soil and loose rock was present in between small rocky outcrops. The bitumen was therefore removed manually by the Health Physics Provider in an emu parade. Two hundred fragments were found and removed. The area was then rescanned by the Environmental Monitor and found to meet criteria.

4.3.2.2 Environmental Monitor's verification and clearance

The outcome of the soil removal operations, both at Wewak and TM100/101 was that all lots comfortably met the clearance criteria. Lot clearance summaries are given in Tables 6.16 and 6.9 of *Appendix 6.1*.

4.3.2.3 Retrospective assessment of plutonium in trenches

In 1985, ARL had made extensive measurements of surface americium count rates at Taranaki, Wewak and the TM sites (Lokan 1985). These measurements were made on a 20 m x 20 m grid, except at TM101 where the grid scale was 10 m x 10 m. They covered all of the areas of higher activity at each site and embraced all of the areas from which soil was removed.

Taking these data, together with the well determined Pu:Am activity ratios (Johnston et al. 1988), and integrating over the grids in each case, the estimates in Table 4.2 were obtained (Lokan 2000, unpublished data). The methods used an empirical conversion factor developed by ARL from americium count rates to activity concentrations in the soil (*Attachment 4.4*, *Appendix F9*).

Overall, these estimates are quite reasonable, and in the case of Taranaki, compare well with the estimate of 2.6 kg (± 50%) based on progressive measurements as soil was placed in the trench. It is not possible, however, to estimate the uncertainty of the estimates in Table 4.2 because of the possibility of variations in the depth of ploughing in the 1967 *Brumby* clean-up.

Table 4.2 Retrospective assessment of plutonium in soil burial trenches.

Soil burial trench	Amount of plutonium (g)
Taranaki	3 000
TM100	220
TM101	31
Wewak	59

4.4 REHABILITATION OF GROUND SURFACE AT KULI

4.4.1 INTRODUCTION

Kuli was the site, situated closer to the Maralinga village (see Figure 4.1), where approximately 8 tonnes of natural and depleted uranium was dispersed. It was cleaned up during *Operation Brumby*, by hand scavenging of the larger visible items of debris, and by introducing fresh soil to cover the central area around the firing pads. Over time, movement of the surface sand had revealed many items lying on the surface.

4.4.1.1 MARTAC recommendations

With a reappraisal of the unit cost of ISV treatment and an appreciation of the volume involved in pit 27, MARTAC recommended that, following the execution of a scavenging operation for the removal of uranium at or near the surface, the area be contoured and re-seeded in order to reduce the potential for erosion. Pit 27 was to be left undisturbed.

4.4.1.2 Retrieval of uranium and uranium-contaminated metal

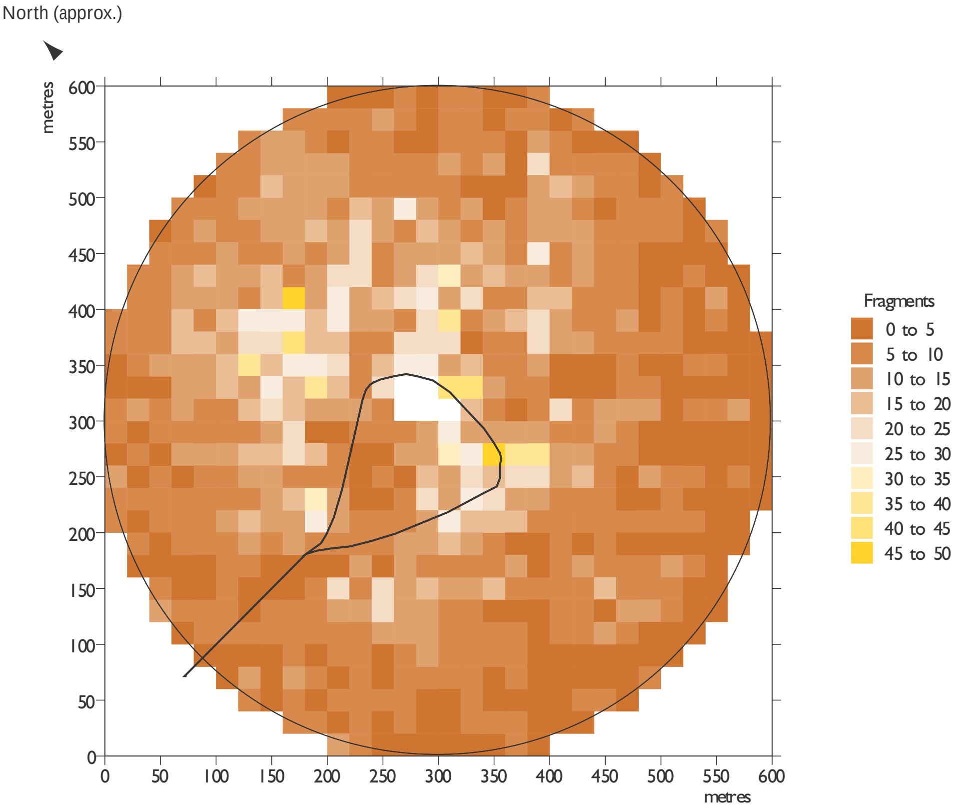
The retrieval of pieces of uranium and uranium-contaminated metal at Kuli was undertaken by the Health Physics Provider (see *Attachment 4.7*) intermittently between March and October 1998. The total effort involved was 775 person hours. The portion cleared had a 600 m diameter centred about the air sampling location (approximately 45 m south-east of the southerly end of pit 27) and the material retrieved (approximately 50 kg) was disposed of in the ISV burial trench in the Taranaki forward area.

PG-2 low energy gamma detectors were used to detect the uranium. The following were retrieved:

- uranium metal fragments with any dimension greater than 10 mm;
- uranium contaminated metal fragments; and
- uranium metal pieces that were possibly once greater than 10 mm but had since broken up and, being on the surface, were easily recoverable.

Figure 4.13 illustrates the distribution of discrete uranium items retrieved from Kuli. In one central region, however, their density was too high for individual items to be identified and retrieved.

Figure 4.13 Distribution of uranium fragments retrieved at Kuli. The numbers in the legend refer to the number of fragments within a 40 m x 40 m area.



At MARTAC's request, the Environmental Monitor surveyed the Kuli area using the high-resolution detector on the OKA vehicle and with the multi-detector arrangement fitted to the Nissan vehicle. The central area at Kuli (approximately 1.5 ha in area), which was not scavenged by the Health Physics Provider because the high concentration of fragments made hand scavenging impractical, was confirmed to be heavily contaminated. A partial scan using the Nissan vehicle confirmed high levels of particulate contamination and a generally high overall level, up to 200 kBq/m^2. The boundary of this area was staked out and included, to a good approximation, the area in which the surface layer of finely divided uranium exceeded 15 kBq/m2.

4.4.1.3 Soil removal and disposal

MARTAC reviewed the results of the above retrieval program and the Environmental Monitor's survey results with Maralinga Tjarutja. The remaining contamination was discussed with emphasis on the chemical toxicity of soluble uranium compounds, the uncertainty in an appropriate value for the gut transfer factor for infants and the possibility that an infant, while crawling on the ground, might selectively ingest brightly coloured weathered uranium compounds.

The proposal was to strip the surface of the more heavily contaminated area and to bury the contaminated soil in an existing, excavated area approximately 1.5 km west of Kuli. It was further proposed to surround the central area with boundary markers to exclude the possibility of family units camping in the area. The boundary markers would follow the 5 kBq/m^2 contour defined in the ARPANSA survey[16]. This recommendation was accepted by the community and the above treatment was subsequently carried out.

The soil stripping operation was undertaken during the first two weeks of July 1999. The area for soil stripping was defined by the Health Physics Provider and agreed to by the Environmental Monitor. The Environmental Monitor also requested some five areas that it had marked be treated at the same time.

In an area designated as an old firing pad (TM16) and marked as pit 29, buried 150 mm thick concrete walls and steel extending 11 m to the north-east were found but not removed. It is suspected that this debris arose from demolition of the concrete shelter at TM4 and/or the structures west of the TM16 pad (see Figure 3.17). The loader had difficulties exhuming this material, and rising contamination levels and the discovery of large amounts of debris resulted in the Health Physics technician ceasing operations in the area. Only soils outside the walls were removed to 500 mm below grade as directed by the Environmental Monitor. Since the completion of the Project, MARTAC recommended the removal and reburial of this material the next time suitable plant is on site.

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[16] A surface density of 1 kBq/m^2 corresponds to uranium found in typical soils around Australia.

After the total area in central Kuli had been scraped, additional surveys were performed, resulting in the requirement for further soil removal and retrieval of approximately 40 further discrete fragments. These materials were disposed of in the burial trench (see below).

An existing scrape approximately 1.8 km from Kuli on the north side of XA Road was prepared and used as a burial trench. On completion, 2.0 m of clean fill was placed over the contaminated material and signs erected on the four corners of the trench. Approximately 1000 m^3 of contaminated soil was removed from Kuli during this operation.

Clean fill was located north-west of Kuli and used to restore the stripped soil area. The central area was finally recontoured and seeded with native seeds to promote revegetation. The bitumen surface to the road leading to the Kuli experimental area was removed at the same time. An aerial view of Kuli, following rehabilitation, is shown in Figure 6.22.

Appendix 6.1, Table 6.1.17 presents the GPS coordinates of the Kuli soil burial trench.

4.4.2 REMOVAL OF URANIUM AT ‘HORSESHOE’ SITE

The British undertook small-scale tests with uranium in a horseshoe shaped area[17] on the north side of XA-Kuli Road, 1.25 km from the east or Kuli end of the road. Uranium fragments could easily be seen on the surface of the area. MARTAC requested that the area be treated by removal and burial locally of soil contaminated with uranium.

The area was inspected by Health Physics technicians and monitored to establish the extent of clean-up required. From this initial survey it was found that the uranium was confined to the excavated horseshoe and the highest density of contamination was located on the northern rim and slope of the horseshoe.

A clean-up with a tyred loader, which pushed the ‘U’ shaped mounded area inwards to restore the original land contours, was undertaken on 8 October 1999 and completed in one day.

Health Physics personnel monitored the work continuously. A few fragments of uranium were found below the surface and final scanning demonstrated that all uranium fragments had been buried.

Trees that had been removed were replaced over the area to prevent wind erosion and promote growth. Further detail is provided in *Attachment 4.4*, *Section 12.5*.

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[17] Recorded on an early UK map of the area as ‘small firing site’ and described as such in Lokan (1985).

4.5 EXHUMATION OF BURIAL PITS AT WEWAK, TMS AND THE AIRFIELD

4.5.1 INTRODUCTION

Apart from the formal pits at Taranaki, which were known to contain indeterminate quantities of plutonium, further contaminated pits were located away from Taranaki which TAG had proposed for ISV treatment.

Initially MARTAC stayed with the intent of the TAG Option 6(c) but with the reappraisal of the unit cost of ISV treatment and appreciation of the volume involved, the detail switched to achieving the outcomes of Option 6(c) by employing some of the methodologies described in Option 6(a)—in particular the replacement of ISV by exhumation and reburial of pit contents.

The pits of concern were located at TM100/101, Wewak and at the airfield cemetery at the south-west corner of the landing strip. An abbreviated summary of this exhumation work is provided below. A detailed description may be found in *Attachment 4.4*, *Sections 9.3–9.5*.

4.5.1.1 Exhumations at TM101

Pits 2U and 22 were located within the soil removal boundary while pit 23, known as the Tietken's Plain Cemetery, lay some 150 m south-east of the soil removal area.

As pit 2U was expected to contain much lower levels of contamination than the other two, it was exhumed first to allow for the development and refinement of techniques to ensure that exposures would be well controlled. Watering was a key part of the exhumation operation. This involved pre-soaking before exhumation and after the removal of the concrete caps (where they existed). Water sprays were continued during the exhumation, as often as was needed to keep dust levels essentially at zero. Pit contents were transported by truck in removable bins with tight fitting covers for burial in the TM soil burial trench. Class II plant was used throughout, with all plant kept upwind when handling pit contents.

Following the successful exhumation and disposal of the contents of pit 2U, pits 22 and 23 and a further pit to the north of pit 23 (labelled accordingly as pit 23A) were exhumed without incident.

4.5.1.2 Exhumation of Wewak firing pads

The two pits at Wewak were in fact concrete firing pads, approximately 0.75 m thick that had been subsequently covered with 150 mm of concrete and 300 mm of soil during *Operation Hercules* in 1964 (UKAEA 1966). They were broken up and removed to the Wewak soil burial trench for disposal. Water was again used to control dust, and following their removal, a 1 m deep hole that was later filled with clean fill remained.

The contents of pits 2U, 22, 23 and 23A were reburied in the TM soil disposal trench and the Wewak firing pads in the Wewak soil disposal trench. The plutonium contamination on these wastes was not assayed during the reburial operation. Any estimate for these components of plutonium in the trenches has to be based on British records. These estimates were provided in *Section 3.5.1*.

4.5.1.3 Post-exhumation pit monitoring

Following the exhumations described above, the internal faces of the pits were monitored by the Environmental Monitor and clearance certificates issued when it was established that the surface activity concentration met the relevant residual activity for soil removal. The pits were then backfilled with uncontaminated material.

4.5.1.4 Exhumations at the airfield cemetery

The airfield cemetery contained a total of 18 pits in two rows. It is described in *Chapter 3* (see *Section 3.5.3*).

Initially it was planned that only pit 3C would be exhumed and the removed material be buried at Taranaki. However, after further consideration MARTAC determined that some of the burials at the cemetery did not conform to current national standards for burial of radioactive waste. There was also some uncertainty as to the contents of Category 2 pits and there was the possibility of an unauthorised exhumation by someone at a later date. These factors led to the decision to exhume all of the Category 1 and 2 pits and also pit 3C. Since pits 3A, 3B and 3D contained mainly fission product material and other low level short half-life material, it was decided that these did not need to be exhumed.

Generally, the procedures adopted followed those employed at Wewak and the TM sites, although more stringent sealing of the transport bins was provided as their contents had to transported to Taranaki in the forward area, for disposal in the ISV trench.

A list of debris exhumed from the airfield cemetery (letter from CH2M Hill to Works Australia, 12 December 1997) is contained in Tables 4.3, 4.4 and 4.5.

Table 4.3 Wastes excavated from the airfield cemetery for reburial at Taranaki—Category 1 pits.

Pit no.	Contents	Radiological status of pit after exhumation
1A	3 concrete blocks, 2 m x 2 m x 0.5 m 2 drums with concrete tops	Unlined burial pit was excavated and backfilled with clean soil Residual radiation levels were at background levels
1B	1 concrete block, 2 m x 2 m x 3 m 2 concrete blocks, 1 m x 1 m x 2 m	Unlined burial pit was excavated and backfilled with clean soil Residual radiation levels were at background levels
1C	Glove box, 1 m x 1 m x 5 m	Concrete lined pit was excavated, none of the concrete liner was removed Residual radiation levels were at background levels
1D	2 filter housings Miscellaneous duct work	Concrete lined pit was excavated, none of the concrete liner was removed Residual radiation levels were at background levels
1E	1 concrete block (1.5 m x 1.5 m x 1.5 m)	Unlined burial pit was excavated and backfilled (contained a valve) with clean soil Residual radiation levels were at background levels
1F	Glove box, 1 m x 1 m x 2 m Miscellaneous duct work	Concrete lined pit was excavated, a portion of the floor of the concrete liner was removed Residual radiation levels were at background levels
1G	Glove box, 1 m x 1 m x 2 m Miscellaneous debris	Concrete lined pit was excavated, a portion of the floor of the metal sheeting concrete liner was removed Residual radiation levels were at background levels
1H	2 glove boxes Miscellaneous debris	Concrete lined pit was excavated, a portion of the floor of the concrete liner was removed Residual radiation levels were at background levels
1I	12 drums (44 gal.) Canvas	Concrete lined pit was excavated, none of the concrete liner was removed Residual radiation levels were at background levels
1J	2 pieces of duct work Miscellaneous debris	Concrete lined pit was excavated, none of the concrete liner 1 m x 1 m x 0.4 m was removed Residual radiation levels were at background levels
1K	Steel box 2 m x 2 m x 2 m filled with concrete Small cylinder Small steel box Small concrete sphere Miscellaneous debris (4–5 items)	Unlined burial pit was excavated and backfilled with clean soil Residual radiation levels were at background levels

Table 4.4 Wastes excavated from the airfield cemetery for reburial at Taranaki—Category 2 pits.

Pit no.	Contents	Radiological status of pit after exhumation
2A	7 large 200 L drums Approx. 23 x 20 L drums, deterioration and close proximity of drums to each other made an exact count impossible	Unlined burial pit was excavated and backfilled with clean soil Residual radiation levels were at background levels
2B	Approximately 21 200 L drums reported to contain laboratory wastes. Deterioration of drums made an exact count impossible	Unlined burial pit was excavated and backfilled with clean soil, residual radiation Residual radiation levels were at background levels
2C	4 lead pots 0.3 m diameter x 1 m	Unlined burial pit was excavated and backfilled with clean soil, residual radiation Residual radiation levels were at background levels

Table 4.5 Wastes excavated from the airfield cemetery for reburial at Taranaki—Category 3 pits.

Pit no.	Contents	Radiological status of pit after exhumation
3A	Not excavated	–
3B	Not excavated	–
3C	2 cylindrical shaped objects, each 1 m diameter x 4 m, one with stabilising fins portions of a vertical exhaust plenum approximately 3 large 200 L drums—the number of drums was probably greater; deterioration of drums made an exact count impossible Pre-formed metal sheeting (approx. 40 pieces) Ducting Wire	Unlined burial pit was excavated and backfilled with clean soil Residual radiation levels were at background levels Approximately 80% of radiologically clean concrete caps were placed in pit 3C
3D	Not excavated	–

4.5.2 SUMMARY

A summary of the treatments proposed by MARTAC for the formal burial pits away from Taranaki and the outcomes is provided in Table 4.6.

Table 4.6 Treatment of formal burial pits.

Pit no.	Location	Treatment proposed by MARTAC	What was done
20 & 21	Wewak	Removal & burial	As proposed
22, 23 (23A)	TM101	Exhumation & reburial	As proposed
26	TM50	Ripping up road surface Recontouring & revegetation	Not done
27 28, 29	Kuli	Ripping up road surface Recontouring & revegetation	As proposed (bitumen surface of road removed)
	Airfield	Removal & burial, all Category 1 and 2 pits and pit 3C	As proposed

4.6 IN SITU VITRIFICATION

4.6.1 INTRODUCTION

ISV had been identified by TAG, on the basis of information provided at the time, as a non-intrusive and cost-effective way of stabilising and rendering permanently safe the Taranaki post *Vixen B* debris pits, known to be contaminated with plutonium. TAG noted that the ISV process would require further development and proving for use in the Maralinga situation and that there was considerable uncertainty about the cost data.

This section describes the development of the ISV process to adapt it for use at Maralinga and its application at Taranaki until its suspension in March 1999.

4.6.1.1 The ISV process

ISV is a process developed by the USA Department of Energy, which has been commercially applied by Geosafe Corporation. The process involves electrical (joule) heating to melt contaminated soil and/or other materials to destroy, remove and/or immobilise toxic and radioactive contaminants. Typical melt temperatures of 1400 to 2000°C can be developed by the passage of up to 4 MW of electrical power into the soil in the pit from a square array of four graphite electrodes. Off-gases are removed for treatment by a steel containment hood spanning the area being processed.

On ceasing the application of electrical power at the completion of the melt, the molten mass is claimed to solidify into a vitreous/ceramic monolith with outstanding physical, chemical and weathering properties, typically two to five times stronger in compressive strength and five to ten times stronger in tensile strength than unreinforced concrete, and superior to or comparable with alternative solidification/ stabilisation technologies (Geosafe Corporation 1994a).

Individual melts have been designed to be up to 7 m deep, 15 m in diameter and 1000 tonne in mass. The ISV process had been demonstrated at USA Chemical Superfund sites and the United States Environmental Protection Agency Site Program (USEPA 1994), where a total of approximately 3000 cubic yards of contaminated soil had been treated in nine pre-staged treatment cells at a location known as the Parsons site. One test cell vitrified approximately 600 tons of contaminated soil of volume estimated at 475 cubic yards (363 m^3) with approximately 613 MWh of energy. Outstanding treatment effectiveness data and positive safety information was stated by the ISV Contractor to have been obtained during a large-scale test on pit 1 at Oak Ridge National Laboratory, though the test was prematurely shut down by a melt disturbance and overheating event attributed to groundwater (Geosafe Corporation 1997).

The primary advantages advocated for application of ISV to the contents of the Taranaki pits (Geosafe Corporation 1997) were that:

- multiple contaminant types (heavy metals, radionuclides, organics) could be treated simultaneously;
- the process could accommodate the substantial amounts of debris in the pits;
- contaminated soil and debris could be treated in place and did not require excavation or handling;
- the plutonium and uranium were predominantly retained in the melt and were not volatilised to the off-gas; and
- the vitrified product was extremely durable, highly leach resistant, and resisted fracturing and intrusion.

The ISV Contractor (Geosafe Corporation 1994) stressed that for most ISV melts, the resulting viscosity is 100 poise or less. If the viscosity is high at high temperatures, the soil will not melt easily. Melts that have substantially higher viscosities are not sufficiently fluid to generate convection currents. Convective currents are the key factor in propagating the melts in terms of heat transfer. If there is no convection in the melt, the heat would have to be conducted from the interior of the melt where joule heating is occurring outward to the melt boundaries. Such heat transfer is not as efficient as the combination of convective and conductive heat transfer that exists in typical ISV melts. With convective currents, hot molten soil is circulated to within a few centimetres of the melt boundary. Near the melt boundary, conductive heat transfer dominates.

4.6.2 PHASE 1 AND PHASE 2 IN THE DEVELOPMENT OF ISV AT MARALINGA

The testing and demonstration of ISV took place in four sequential phases.

The first two phases tested the applicability of the ISV process to the geology and debris materials expected in the Taranaki pits over a size range increasing from laboratory (gram scale), through engineering (kilogram scale) to intermediate (tonne scale). The latter included the addition of cerium and uranium oxides as plutonium surrogates, and an actual test with a steel plate contaminated with 0.44 g of plutonium. The completion of these tests led to:

- a project review by the PWC (PWC 1995);
- an independent audit of the results of the ISV trials by competent experts not associated with the project (Harries 1996);
- estimates of comparative costs of ISV and exhumation operations (MARTAC meetings March and November 1996); and

Figure 4.14 Processes followed in relation to ISV.

Step	Body	Activity
1	MARTAC	Defined criteria for ISV performance
2	Geosafe (ISV Contractor)	Determined in a series of pre-operational level trials, that the ISV technology could meet the defined MARTAC criteria
3	ANSTO (independent reviewer)	Reviewed ISV trials Concluded criteria were met
4	ARL	Reviewed ANSTO's findings (without knowledge of the details of the prescribed criteria), and did not find reason to disagree with ANSTO's conclusions
5	PWC	Agreed that ISV work could be progressed
6	Geosafe	Further trials, and later, operational use of ISV at site
7	MARTAC	Reviewed melts against original criteria

- the awarding by the Department of a contract to Geosafe Australia for the manufacture and testing of full-scale ISV equipment (Phase 3) and operation of ISV on the Taranaki pits (Phase 4).

The progression of assessment, decisions and development steps for the application of ISV at Taranaki is shown in Figure 4.14.

4.6.2.1 Phase 1 testing and evaluation of Taranaki soils

Australian operations at Taranaki in support of Phase 1 commenced with the laying of a 'clean road' inside the Taranaki fenced enclosure with spurs near to pits 1, 2, 3, 4, 5, 7, 10, 13, 15 and 19A. The pit locations are shown in Figure 3.12. Diamond drill cores and reverse circulation samples of uncontaminated substrata were taken for evaluation of the geological and geochemical environments of the Taranaki pits (Morris & Walker 1993). These soil samples were tested in gram-scale laboratory trials by Geosafe Corporation at Richland, USA, for their applicability for ISV treatment.

Laboratory tests and preliminary modelling

Phase 1 included:

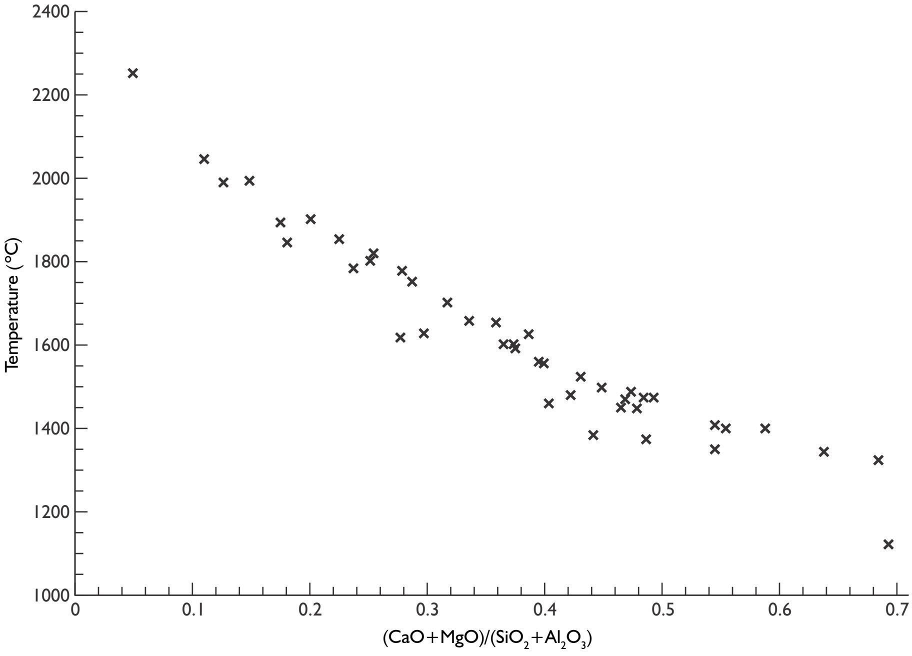
- characterisation of the near-surface samples of Taranaki soils;
- crucible melt tests to determine soil melting properties;
- geochemical modelling to evaluate and predict characteristics of different melt compositions and the resulting ISV product;
- two engineering (kilogram scale) melting tests to develop a baseline set of ISV operational data on representative soil and simulated waste arrangements; and
- structural integrity and leach resistance tests for product evaluation (Geosafe Corporation 1994).

A preliminary geochemical design analysis tailoring ISV to specific pits was conducted with the geochemical compositions of soil types found in the vicinity of the debris pits (see Geosafe Corporation 1994 for results).

The Phase 1 studies included the determination of the relationship between melt temperature and melt viscosity for a range of soil types with differing major oxide ratios (e.g. of (Ca + Mg)/(Si + Al)). The conclusion was drawn that the viscosity and operating temperature of a melt can be controlled by modifying the composition.

Based on their experience, Geosafe had concluded (Timmons 1995) that an ISV melt stabilised at a self-seeking melt viscosity of 100 poise. Figure 4.15 which is redrawn from Figure 1 of the Timmons 1995 paper depicts Geosafe's expectations of melt temperature as a function of major basic to acidic oxides for the soil being treated at Taranaki.

Figure 4.15 Relationship between melt temperature and the ratio (CaO+MgO)/(SiO_2+Al_2O_3).



The expectation by all parties (the Department, MARTAC, the ISV Contractor) that by varying the composition of the material being treated, the melt temperature and melt outcomes could be determined in a predictable way was fundamental to planning for the application of ISV to the Taranaki waste disposal pits (Geosafe Corporation 1996a). In practice, MARTAC held the view that these expectations were not met. MARTAC reached this conclusion because at Taranaki melt temperature versus the acidic oxide:basic oxide ratio did not follow the trend of Figure 4.15. The greatest outlier from the trend was for pit 17 (temperature 1619°C, ratio 0.22).

Melt temperatures

A feature of the Taranaki soils was their high calcium content which, unless modified, would lead to melt temperatures below that of the melting point of steel (Timmons 1995). This pointed to the need for the addition of silica-rich soil to raise the temperature of the melt. At a later date the ISV Contractor stated that:

> *... The resistance of a refractory sand melt containing only 2–3 wt% Na_2O (as starter) with the balance being predominantly SiO_2 will result in melt temperatures well in excess of 1800°C and melt electrical resistances well in excess of 1 ohm (10 or more times greater than a normal melt).*

The ISV Contractor's reply to MARTAC technical questions contained in facsimile from Project Manager to Geosafe Australia P/L 19 November 1998

A graph of 'T100P' (°C):

> *... against the oxide ratio can be used for preliminary field predictions (to estimate) the T100P of the subject composition. The graph appears to be accurate to ±100 °C …. If the temperature at which the viscosity of the melt is 100 poise (T100P) is greater than 1450 °C then the addition of cover soil for purposes of raising the melt temperature may not be required.*

Timmons 1996[18]

ISV equipment costs were estimated at this stage to be approximately US$6.2 million, with costs for treating 21 Taranaki pits less than US$9.8 million based on, among other factors, the British documentation of the pit sizes.

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[18] Timmons 1996 was not sighted by most MARTAC members until years after publication date. MARTAC became aware of it when it was obliquely referred to in a letter from the ISV Contractor to the Project Manager dated 4 December 1998. The letter states that the purpose of the geochemical design analyses was to maintain process melt temperatures at or above the melting point of steel for only some pits so that downward progression of electrodes is not inhibited.

Abbreviated summary of the conclusions drawn from the Phase 1 work (Geosafe Corporation 1994b)

- Within the ranges of soils and materials tested during Phase 1, the ISV process could be successfully applied to the Taranaki pits.
- The Taranaki range contains three primary soil types: silica sand, limestone and dolomite.
- It would be necessary to add sand (silica-bearing) soil as overburden to the Taranaki pits so that the melt can be established prior to encountering the calcareous concrete caps and to provide a source of silica for those locations where soil is predominantly limestone.
- Melt initiation at engineering-scale start-up in alkali-depleted silica sand proved difficult and indicated the need for start-up optimisation tests with fluxing agents (e.g. soda-ash or K_2CO_3) to improve start-up reliability.
- Samples of the vitrified soil product from Taranaki were 1.3 to 1.8 times stronger in compressive strength and four to five times stronger in tensile strength compared with unreinforced concrete.
- Product consistency tests showed that vitrified Taranaki soils were significantly more durable than simulated nuclear waste glasses.
- Based on the historical sizes of the Taranaki pits, approximately 33 individual melts would be required to treat the 21 pits, in a duration of approximately two years.

4.6.2.2 Phase 2: Engineering and intermediate-scale ISV tests

The laboratory trials of Phase 1 were followed by ten engineering-scale (kilogram) trials on samples of Taranaki soils, six additional engineering-scale trials (50–250 kg) and three intermediate scale (4 tonne) demonstrations, one at the Maralinga village and two at a trench adjacent to pit 1 at the Taranaki site.

Engineering-scale trials

The engineering-scale trials were designed to resolve the following issues:

- determination of the most reliable method of starting the melting process;
- the effect of a large proportion of barytes bricks on melt properties;
- the effects of up to 56 wt% debris (steel, lead and barytes bricks) in a scaled mock-up pit on the relationships between power consumption, melt temperature and melt chemistry;
- the effect of voids within a debris pit on off-gas generation rates and containment;
- measurement of pressures of gases and vapours generated under the melt; and
- the retention of plutonium and surrogates in a melt involving steel, barytes bricks and bitumen-stabilised soil.

Intermediate-scale demonstrations

The three intermediate-scale demonstrations were intended to confirm the behaviour of plutonium in melts of approximately 4 tonne (Geosafe Corporation 1996a). The first demonstration incorporated cerium oxide into the ceramic phase, which was 36% of the total ISV product mass, as a surrogate for plutonium together with soil and steel debris confined in a 1 m^2 x 0.75 m deep pit in an ISV melt. The second demonstration in a 1 m wide trench adjacent to pit 1 at Taranaki involved incorporation of 1 kg of uranium oxide as a plutonium surrogate into an ISV melt, together with bitumen-stabilised soil, steel debris, barytes bricks and electrical cable. The third demonstration was similar to the second but contained in addition a steel plate contaminated with 0.44 g of plutonium. While the results of the surrogate trials showed a cerium distribution different to that of uranium and plutonium in subsequent trials, analysis of samples from the ISV block produced in the third trial confirmed the homogeneity of plutonium in the ISV block and its retention by the ISV process.

At the conclusion of the Phase 2 studies, the ISV Contractor claimed that the electrical power data followed projections and provided confidence in the ISV Contractor's ability to estimate the power requirements for full-scale melts at Taranaki. In particular it was stated that for a substantial waste steel loading of 16%

Abbreviated summary of conclusions drawn from the engineering-scale trials (Geosafe Corporation 1996a)

- Reliable start-up could be achieved through the addition, as flux, of as little as 1 wt% Na_2O as Na_2CO_3.
- The addition of 3–8 wt% of BaO as barytes bricks increased the electrical resistance and lowered the melt temperature. However, following their complete incorporation and once the melt continued to incorporate the underlying sand, the resistance reduced again, indicating that, at the concentrations tested, BaO had no significant effect on melt resistance.
- When high percentages of metallic debris were present, increased power resulted in higher melt rates, but in two cases a ‘heat fin effect’ led to slower melt rates and a cooler melt. The ratio of sand to limestone was adequate (melt temperature of 1550°C) in one case but marginal (1475°C) in another.
- Voids had no significant effect, unless very large, when they could still be overcome.
- Gas pressures under the hood remained low.
- No significant CeO_2 was lost to the melt and it was fairly uniformly distributed throughout.
- Up to 9.2% of organic material in bitumen-stabilised soil was handled without difficulty.

Broad summary of conclusions reached by the ISV Contractor from the demonstrations (Geosafe Corporation 1996a)

- The full-scale ISV process could be expected to effectively treat the soil and debris combinations in the Taranaki pits.
- The vast majority (> 99.9999%) of the plutonium would be retained in the melts.
- The data suggested that health physics-related costs for ISV operations should be minimal and that a simplified off-gas treatment system could be used.
- The vitreous and crystalline product would be a uniform, dense and intrusion-resistant mass of high strength with exceptional leach resistance. It should provide effective immobilisation and intrusion resistance for many hundreds of thousands of years.
- The plutonium would be thoroughly mixed throughout the main vitreous and ceramic phase due to the convective flows that exist in ISV melts.
- Plutonium would not be distributed to any significant extent to other phases in the melt, such as the metal phase, the cold cap, or the unmelted berm material added to dampen excursions and provide additional thermal insulation.
- No factors were identified that would preclude efficient large-scale processing of the Taranaki pits.

by weight, the electrical resistance at the end of the melt provided critical data to support the design of the full-scale transformer.

4.6.3 ACCEPTANCE OF THE ISV PROCESS

The PWC reviewed the Project on 26 June 1995 and recommended that:

- an independent audit of the results of the ISV trials of material containing plutonium should be undertaken by independent experts not associated with the project;
- if the results of the review indicated that the ISV process provided encapsulation to prescribed standards, the process could be extended to full scale treatment of burial pits at Taranaki; and
- if the results of the trials were inconclusive, or did not provide results to prescribed standards, the further direction of the project should be reviewed.

In accordance with the PWC's requirement for an independent audit of ISV trials containing plutonium, ANSTO conducted an independent audit of leachability of plutonium from the ISV product from the Phase 2 ISV trials (*Attachment 2.2*). Samples from the plutonium melt were analysed in order to assess the degree of mixing of plutonium in an independent analysis of samples from the final (plutonium) trial. This report was sent to the PWC via the Regulator (ARL). The Regulator noted the sound technical approach adopted by ANSTO in the review, and agreed with the conclusion that the mixing of plutonium appeared adequate and that the durability of the ISV product was satisfactory (letter from GA Williams [ARL] to P Roberts [Secretary, PWC], 16 May 1996).

Treatment of the Taranaki pits by ISV was reviewed and approved at a meeting of the PWC on 20 June 1996.

Approval was given by the South Australian Government on 27 June 1996 for estimated levels of release of sulphur oxides at Maralinga, on the basis that they would not result in environmental harm or public health issues.

4.6.4 PHASE 3 PROPOSAL

A 'base proposal' for the preliminary design of ISV plant (Geosafe Corporation 1996b) visualised an ISV process with dry filtration of off-gases and provision for removal of SO_2 gas. The hood was to be moved between melts by a high capacity 250 tonne crane to be supplied from the United States Department of Energy. The design maximised containment of any radioactive particulate in the off-gas with a cyclonic separator, high temperature self cleaning HEPA filters with secondary standard HEPA filters providing backup. Off-gas extractor fans were duplicated together with a duplicate auxiliary power system. A modular system for removal of SO_2 with hydrated lime was included.

An 'alternative proposal' (Geosafe Corporation 1996c) incorporated simplified dry filtration of off-gases without an SO_2 removal facility. Off-gas treatment involved a cyclone separator and a fabric roll filter, with a single, variable speed, off-gas extractor fan for control of pressure in the hood. The hood was transported with a 250 tonne crane as in the base proposal.

A supplement to the alternative proposal (Geosafe Corporation 1996d) proposed off-gas treatment as in the first alternative proposal, but employed a modular hood design capable of being disassembled into sections, to permit hood movement with a 45 tonne crane.

An RDP for treatment of the Taranaki pits (Geosafe Corporation 1996e) was prepared on the basis of pit dimensions provided in British records, with the proviso that:

> *... if new information is obtained that indicates the pits are of a different size, the remedial design plan will be reviewed to determine if the changes are significant enough to warrant a revision to this RDP.*

Operational parameters for 26 melts were derived in a geochemical design analysis based on estimates of pit compositions (Timmons 1996).

The initial Phase 3 proposal for ISV plant design, construction, delivery and commissioning (Geosafe Australia 1996) contained ten design options, with variants from the base case including:

- melting with/without concrete cap;
- slow process rates;
- one or two hoods;
- additional depth of melt;
- standard or modular hood; and
- refractory sand trenches to constrain lateral melting.

Options lay in a cost range of $A23.94 million to $27.29 million. MARTAC's preferred option involved two modular hoods with removal of pit caps and construction of sand trenches ($A24.64 million). MARTAC's recommendation is covered in *Section 3.4.4*.

4.6.5 PHASE 3 CONSTRUCTION AND TESTING OF THE FULL-SCALE ISV PLANT

MARTAC recommended construction (in Australia as far as practicable) of full-scale ISV equipment for Phase 4 operation including:

- fuel storage tanks;
- three 1.5 MW three phase electrical generators;
- operations control equipment and cabin;
- an auxiliary generator;
- the two-phase Scott-tee transformer and power cables;
- the Teaser transformer associated with Scott-tee operation;
- two modular off-gas hoods;
- the off-gas pipe;
- the fan and damper for control of transient events;
- the off-gas filter, blower and 10 m stack; and
- off-gas instrumentation and calibration equipment.

The equipment was designed and constructed on a modular basis to facilitate transport of the ISV train between the widely dispersed pits in inner Taranaki. Modules for two fabricated steel hoods were designed and constructed by the ISV Operator in Adelaide, together with off-gas pipework.

Alternative treatment systems to remove droplets of melt containing plutonium and uranium entrained in off-gases ranged from construction of fixed bed granular filters located in pits adjacent to individual melting operations to a mobile filter located in a transport container. Coarse filtration of the off-gas stream was considered appropriate, with no treatment for acidic gases. The mobile design that was constructed involved a temperature resistant filter cloth on a framework with dislodgment of particulate from the off-gas filter by a vibrator on the outside of the filter housing. Trace concentrations of plutonium in stack discharges estimated by air dispersion modelling over a wide range of meteorological conditions used USEPA modelling technology (Geosafe Corporation 1997b) and incorporated comments by ANSTO. It was concluded, inter alia, that amounts and concentrations of plutonium in the downward plume would be extremely small, but that looping of the plume close to the stack, if it occurred, could create extremely localised contaminant concentrations. Alpha monitoring equipment was accordingly installed in the operational area.

No Australian company was available for construction of the 4 MW Scott-tee two-phase transformer and associated Teaser transformer, and these items were constructed in the USA.

A full-scale non-radioactive test of the ISV equipment was carried out in a purpose-constructed pit approximately 4 m x 3 m in lateral dimensions and 2 m in depth, built at the site of the Department of Defence: Defence, Science & Technology Organisation (DSTO) Salisbury, in South Australia. This test proved satisfactory in reaching a power input of 4.2 MW and a melt depth of approximately 1 m. A week later a fire developed in the uninterruptible power supply, resulting in examination, and cleaning or replacement of some integrated circuit control modules. The equipment was subsequently tested to be satisfactory through a further melt at DSTO Salisbury before transport and erection at Taranaki.

4.6.6 PHASE 4 ISV PLANT OPERATIONS AT TARANAKI

4.6.6.1 Incorrect historical recording of pit and pit cap locations

Early geophysical work conducted on the concrete caps over the Taranaki pits during Phase 1 had included high resolution gravity, high resolution magnetics, ground penetrating radar (GPR), transient electromagnetics (TEM), and frequency electromagnetic conductivity to locate metal objects in the pits to provide confirmation of the veracity of historical reports of pit contents (AR Dodds 1993 as reported in Morris & Walker 1993). GPR measurements on pit 11 indicated that the concrete cap was offset from pit boundaries by over a metre, but the method had encountered problems in data processing and interpretation. Strong magnetic anomalies detected near pits 10 and 11 indicated that there were metallic objects buried outside the caps of pits 10 and 11 but the method encountered perturbations in responses from the steel reinforcement in the concrete caps. The report concluded that an absolute resolution of the conflict between the geophysical measurements and reported pit contents could only be satisfactorily achieved by opening up at least one pit. Excavation outside some Taranaki pits to resolve the presence of steel objects was considered but did not proceed because of the lack of health physics support at that time, and because the Project Manager had advised that such objects could be removed with contaminated soil from Taranaki.

An independent review of the geophysical work reached contradictory conclusions (Davis 1995). Differences of interpretation of the data by geophysical specialists resulted in a decision to defer any further geophysical work until the soil had been removed from Taranaki (MARTAC meeting, August 1995) and in fact the proposed geophysics was never done.

It was a requirement of the soil removal contract that the Earthworks Contractor remove any of the contaminated soil from the top of the concrete caps over the burial pits in central Taranaki and remove the soil as close as practicable to the sides of the caps. During these operations, debris was discovered beyond the limits of the concrete caps for a number of the pits. It was decided that it was necessary to establish the limits of the pits beyond the concrete cap boundaries as far as practicable to assist with their later treatment by ISV (see below). This was done as a conventional radiation surface contamination survey using the gamma ray from Am^{241}. Figure 4.16 shows the degree that the buried radioactivity transgresses the footprints of the concrete slabs that were expected to cover pits 5, 8 and 11. The example is typical although it shows a worst case where the three pits had to be treated as a single conglomerate.

The locations of the pits, both formal and informal, in the Taranaki area as understood by the end of the Project are given in Figure 4.17.

Figure 4.16 Location of buried contaminated debris in relation to the concrete caps on pits 5, 8 and 11.

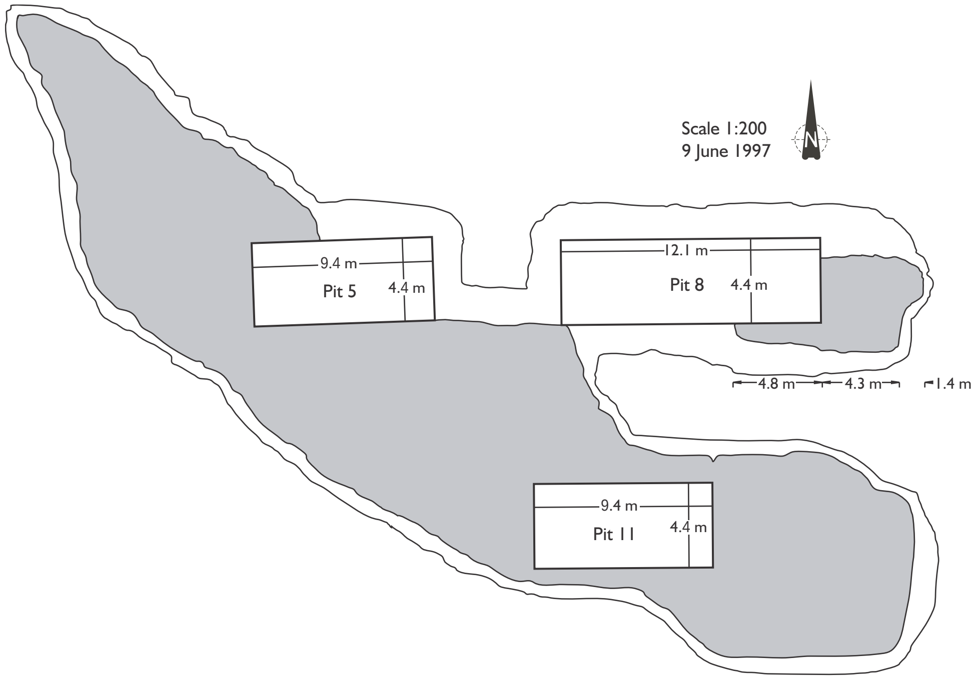
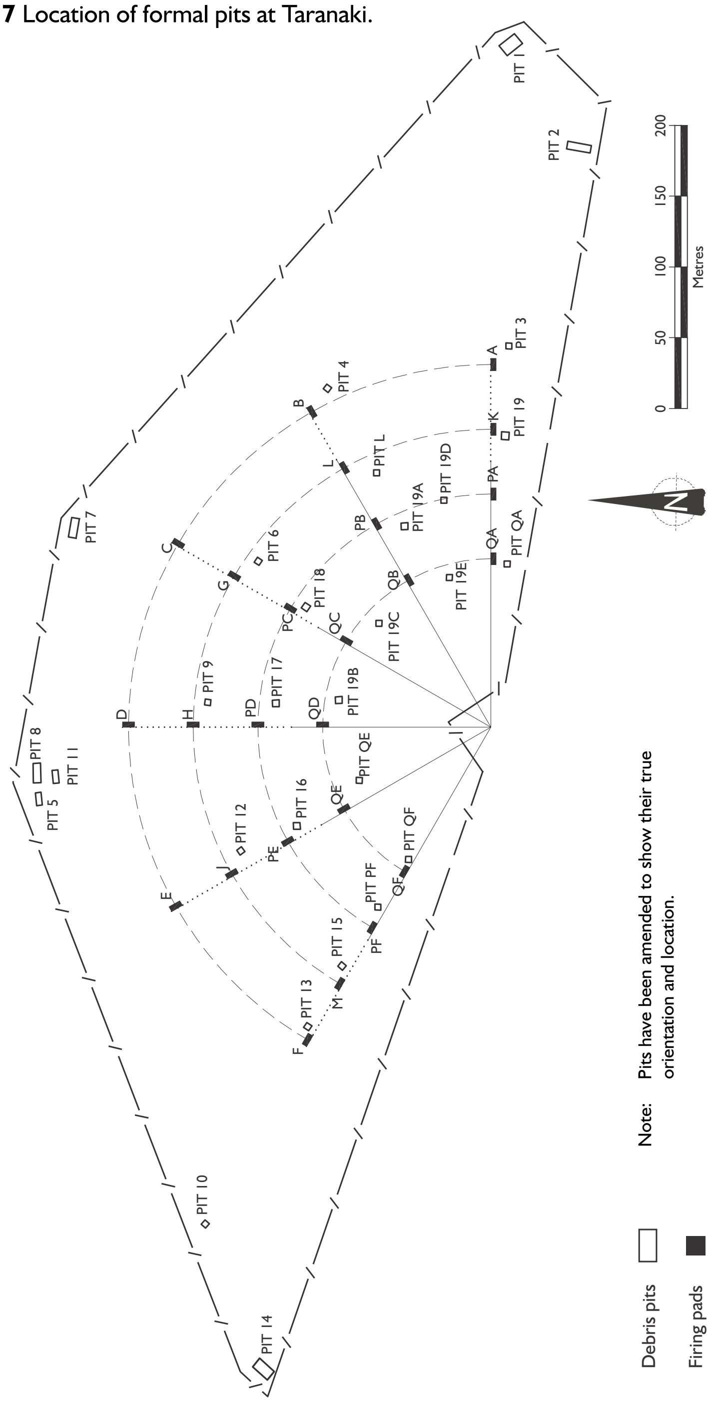


Figure 4.17 Location of formal pits at Taranaki.



Note: Pits have been amended to show their true orientation and location.

Removal of concrete pit caps

Removal of the concrete pit caps at Taranaki prior to ISV operations was expected to offer technical advantages although some were not realised in practice. These advantages included:

- energy savings through removal of low resistance material otherwise requiring a cover of silica soil to achieve a sufficient melting temperature;
- elimination of ramps to elevate the ISV hood over caps and mounded soil;
- reduction of melt volume further recessing the ISV block below ground level; and
- removal of voids beneath the pit cap.

Initial intention had been to remove the concrete caps, replacing them in the depression formed over the pit location after the ISV melt. This was not feasible for operational reasons and because they were smaller than the resultant ISV melt the caps were ultimately broken up and disposed of in the ISV burial trench.

Mislocation of pits and caps

Investigations around each pit before and after the removal of the concrete caps on pits 1 to 19A (20 pits) showed that the claim that the caps overlapped the pit boundaries by 3 ft (0.9 m) on all four sides (Cornish 1987) was incorrect (letter from RN Rawson [DPIE] to GT Stott [UKMOD], 4 June 1997). Following the soil removal from around the concrete caps, a radiation survey was carried out by the Health Physics Provider personnel using hand-held gamma detection equipment. An area of relatively higher contamination was outlined around or near to the concrete caps. In some areas these zones were also visually quite distinct where the soil removal had partially exposed the white 'limestone' cap rock layer which contrasted with the generally red sand backfill exposed at the pit locations.

Once the dimensions of the contaminated zones and their relationship to the concrete pit cap positions was established the exposed radioactivity was covered with a distinctive green-yellow sand or sandstone rubble, as an operational safety measure, pending the commencement of the ISV work.

Reality, as we now know it, is that the pits fall into four categories (see box, p. 237).

PIT CATEGORIES

- The caps covered only part of the pit and debris was visible alongside or protruding from under the cap (pits 1, 3 to 17, and 19). The cap on pit 1 had been laid at 90° across the long axis of the pit. Concrete caps on pits 5, 8 and 11 at the north of inner Taranaki had been carefully laid to be co-planar, but without reference to buried debris. Caps (4.4 m x 9.4 m) on nominal pits 5 and 11 had been laid over a trench about 5 m wide and over 50 m in length.

- The cap was nowhere near the pit (e.g. pit 2 where the pit was discovered 12 m distant from the cap, and pit 18, with a 4 m separation of cap and debris).

- Pits 19A, 19B (and the subsequently discovered pit 19E) were covered with an unreinforced or lightly reinforced concrete slurry cap that finished at or close to ground level. There was reference on a South Australian Department of Interior plan (drawing number CM 145) to an uncertainty about the locations of ... *pits 20, 21 & 22*. Two of these were subsequently to become known as 19A and 19B, making up the 21 pits advised through the British records. Pits 19A and 19B were reportedly used during *Operation Brumby* to dispose of contaminated materials, including featherbed plates, that were found on the surface at the Taranaki site. These pits were reportedly backfilled with slurried concrete as the debris was placed in them, a factor which contributed to the view held by some MARTAC members that in situ treatment would be more appropriate than exhumation. Perhaps because of the uncertainty expressed in notes on the plan the existence of the 22nd pit was not suspected. In practice the concrete slurry was limited to an amount that formed a slurry cap of thickness 150–300 mm.

- Pits QA, QE, QF, PF, 19C, and 19D had no caps at all and were covered with crushed rock. These pits were not reported in the same way as the 21 pits that were stated to contain radioactive debris. Nor were they accurately located in official maps of the Taranaki area and were found eventually through a detailed examination of the topography, reference to an old sketch plan that showed the test facility layout and by the use of a metal detector.

The pits in the fourth category above were not included in the tabulation of formal pits in UK documentation. Their contents were exhumed and buried in the debris trench and although some contamination was encountered they were much less hazardous than the 'formal' 21 pits.

As both pits 19B and 19E had concrete slurry caps then determining which was pit 19B of the Pearce Report could be based on the quantity of steel plate present in each pit. Pit 19B contained 0.7 t of steel plate and pit 19E contained 5.5 t (see *Attachment 4.4*, *Sections 11.6.1* and *11.7.1*). Perhaps for those pits at Taranaki that contained relatively small quantities of plutonium contamination, the distinction between a formal pit and an unrecorded pit was based on the quantity of waste steel contained in each.

Confirmation of pit dimensions and locations

It was clear from the investigations undertaken during the soil removal operations that the concrete pads frequently did not fully cover the pits and in some instances the pits appeared to be considerably larger, at least at the surface, than indicated in the British records.

In addition to the larger lateral extent it was considered that the historical records of pit depth could not be taken as correct. To this uncertainty was added the uncertainty of the height datum used, which was not recorded.

Based on the information obtained from the Health Physics Provider investigations following the soil-removal operations, the ISV Contractor re-estimated the pit dimensions as being considerably larger than listed in the British records.

To plan its melt approach the ISV Contractor needed to determine as closely as possible the location of the pit walls and the volume of pit material to be treated. The ISV Contractor investigated the limits of the pit at ground level by using a rock hammer mounted on a tracked excavator to probe the pit limits as determined by physical changes in the ground conditions. The probed pit outline was then compared with the results of the earlier gamma radiation monitoring undertaken by the Health Physics Provider.

After an initial period during which the British record of pit depth was used for planning and ISV operational purposes, the ISV Contractor used the long steel rock hammer chisel as a depth probe in an attempt to improve the picture of the pit limits. This was an extension of the use of the rock hammer that was used as a mechanism to compact the debris mass. In most locations the probe was stopped on steel debris items, but in some locations in some of the pits the probe passed between or around the debris items and an attempt was made to identify pit floor levels.

The probing method should have provided a reliable means of locating the pit margins where the pit excavation had been into the strong calcrete cap rock layer that was present over much of the site. However, where the pits had been excavated into soils the probing results were more difficult to interpret. Apart from the obstruction provided by the debris in the pits, the pit floors were generally excavated into soils and it was difficult to establish pit floor depths by this means.

Table 4.7 illustrates the disparity between the dimensions recorded by the British and those obtained by probing.

Table 4.7 Dimensions of Taranaki debris pits.

Pit no.	**Melt no.**	**Pit class (‘inner’ or ‘outer’)**	**Historical pit dimensions (m) (British records)**[1]				**ISV Contractor probed pit dimensions**			**Initial pit volume (m^3)**
			L (m)	W (m)	D (m)	Volume (m^3)	L (m)	W (m)	D (m)	
1		O	12.2	7.3	3.7	329.5	–	–	–	–
2		O	15.2	3.7	3.7	208.1	–	–	–	–
3	2	I	2.4	2.4	2.4	13.8	8.3	5.7	>2.2	(114)
4	3 & 5	I	2.4	2.4	1.8	10.4	9.8	8.6	1.8	152
5		O	7.6	2.4	2.4	43.8	–	–	–	–
6	11	I	2.4	2.4	1.8	10.4	5.7	4.5	2.2	56
7		O	12.2	3.7	2.1	94.8	–	–	–	–
8		O	12.2	3.7	3.7	167.0	–	–	–	–
9	10	I	2.4	2.4	1.8	10.4	7.5	5.2	2.4	94
10		O	2.4	2.4	1.8	10.4	–	–	–	–
11		O	7.6	2.4	2.4	43.8	–	–	–	–
12	9	I	2.4	2.4	2.4	13.8	10.1	6.2	2.5	157
13	7	I	2.4	2.4	2.4	13.8	7.5	5.2	(2.4)	(94)
14		O	12.2	6.1	3.7	275.4	–	–	–	–
15	8	I	2.4	2.4	1.8	10.4	8.5	5.1	1.8	78
16		O	3.1	3.1	2.4	23.1	–	–	–	–
17	13	I	3.1	3.1	2.4	23.1	7.6	7.3	2.6	144
18	12	I	3.1	3.1	2.4	23.1	7.6	4.9	3.0	112
19	1 & 6	I	3.7	3.7	3.1	42.4	7.4	4.3	(3.0)	(97)
19A	4	I	2.4	2.4	1.8	10.4	7.6	6.8	(1.8)	(93)
19B		I	2.4	2.4	1.8	10.4	–	–	–	–

	Historical	ISV Contractor
Comparison of 21 pit volumes: total volume (m^3)	1 388	5 589
Comparison of 11 ISV-treated pit volumes: ‘Inner’ pits volume (m^3)	182	1 191

[1] The British data reported here are drawn from Cornish (1987). The pit depths quoted differ significantly from those reported in *Appendix B* of Pearce (1968) for pits 1, 2, 8 and 14 (e.g. for pit 1, 7 feet from Pearce and 3.7 m from Cornish). The data provided here was as conveyed by the Department to Geosafe at the start of the project.

Reassessment of required ISV melts

Because of the substantial increase in volume of material now known to be contained within the Taranaki debris pits the initial number of 26 melts proposed in the RDP (February 1996) was increased by a further 15 to 41, with a corresponding increase in estimated costs. A later ISV Contractor draft paper listed ... *37 suspected melts* with ... *45 possible melts (but very unlikely)* (private communication L Thompson [Geosafe Australia] to G Chamberlain [Project Manager], July 1998).

4.6.6.2 General description of the full-scale operation of the ISV process

A range of operations was undertaken in order to prepare the pits for ISV treatment including:

- removal of the concrete pit caps (discussed above);
- determination of the pit surface area and depth (discussed above);
- installation of refractory sand trenches and associated instrumentation; and
- installation of the soil berm[19] to contain the starter material and to support the ISV hood

Installation of refractory sand trenches and instrumentation

In order to confine the extent of lateral melt growth into the clean geological materials surrounding the pit, the ISV Contractor excavated trenches around the perimeter of the pits, starting approximately 1.0 m from the position of the sides of the pit and extending down to a depth approaching the presumed pit depth. These trenches were also used to gain access near to the pit limits for the installation of thermocouples to measure the melt temperatures and to gauge the extent of melt development. Once the instruments were installed the trenches were backfilled with clean silica sand with a melting point significantly higher than the temperatures planned for the melts ('refractory sand'). From the time of the second melt the intact pit wall materials between the pit and the sand trench were fractured, using the rock hammer probe, to provide an escape route for the gases produced during the melting process.

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[19] A 'berm' is a containment structure. The soil cover was the fluxed high-silica sand cover that was contained by the berm. The berm top also acted as a stable and elevated foundation for the ISV hood.

Installation of the soil berm

Once the pit had been accurately located and the refractory trench sand installed, a relatively large soil mound was built over and around the pit. The berm contained the core zone (over the pit itself) of fluxed sand found necessary to achieve an appropriate composition of the melt material, taking account of the predicted composition of the pit contents. The berm height varied above ground level from approximately 1.05 to 2.5 m, generally being determined by the quantity of fluxed sand material required as an additive. A further layer of silica sand and limestone gravel that served to dampen the effects of possible transients caused by the energetic release of gas bubbles through the developing melts was added to the top of the berm. Although generally of 300 mm thickness, the 'transient suppression layer' varied from 1.7 m (melt 2) to nil (pits 18 and 17, the final two melts).

Set-up of the ISV equipment

While major components of the ISV equipment, such as the main diesel generators, could service several pits from the one location, other items such as the control cabin and off-gas equipment generally had to be relocated for each melt.

Once the berm was in place over the pit, the hood was installed, the electrodes positioned and calibrated for depth, electrical connections made and the complete system made ready for operation.

Figure 4.18 (see next page) shows the assembled hood behind its trailer-mounted support equipment. The three 1.5 MW diesel generators used to power the ISV process are outside the photograph, on the right hand side.

Objectives of ISV and indicators for melt termination

Objectives of the ISV process have been discussed in *Chapter 3*. In intent they were:

- that the contents of the pit were fully incorporated in the melt;
- that the melt temperature was sufficient to melt the steel; and
- that the plutonium was uniformly distributed within calc-silicate melt phase.

As these objectives could not be directly measured, the ISV Contractor developed a range of indicators that could be monitored to stablish, with a reasonable level of confidence, that they were in all probability being achieved.

Indicators to be used included (Geosafe Procedure GA-98-TP-004 ISV):

- changes in the level of several components in the off-gas;
- changes in the rate of electrode penetration;
- occurrence of burn out of low temperature thermocouples (Type K) surrounding the pit limits; and
- appropriate elevation of the temperatures as measured on high temperature thermocouples (Type C).

The thermocouples were used in two ways:

- they were inserted into the region between the pit and the refractory sand trench during pit preparation to provide a continuous reading during the development of the melt ('staged' thermocouples); and
- lowered down into the melt by an operator standing on the hood to provide an instantaneous reading of the melt temperature ('probed' thermocouples) and for determination of temperature gradient within the melt.

Figure 4.18 ISV equipment at Taranaki, March 1999.

Left foreground: pit 9 with melt face exposed for sampling of ISV block; centre foreground: off-gas discharge stack on filter trailer (out of picture); mid left (left to right): ISV control room trailer (with HP Clearance Hut on ground), ISV auxiliary power trailer, Teaser transformer trailer, transformer trailer; mid right: ISV hood on pit 17 with off-gas pipe.
Centre background: ISV hood on pit 18; behind ISV trailers: pit 6; background: pits 4, 3, 19a and 19.

Experience from the initial melts soon demonstrated that only the temperature data provided by thermocouples (both Type C and Type K) appeared to provide a reasonable indication of the extent of the melt growth as the other indicators did not appear to provide changes in the extensive array of monitored parameters that could be related to known features of the pit at the expected time. This led to concerns about the adequacy of the process quality control in relation to the melt development in particular. In addition it indicated that the selection of the point in time to shutdown a melt was subjective.

ISV melts of the contents of the Taranaki pits were carried out in the order shown in Table 4.8.

Because of its geometry and dimensions, pit 4 required two melts, and pit 19 required a remelt. All other inner pits that were treated by ISV required a single melt. The ISV Contractor's melt plan and its descriptions of the melts are provided at *Attachment 4.9*.

The first two melts were carried out on pits 19 and 3. These two pits were reported to contain debris from the plutonium-free calibration tests for the *Vixen* series *VB3* and *VB2* respectively. The first melt was suspended prematurely for safety reasons, following several transient events involving gas releases. It was later restaged and completed as the sixth melt.

Table 4.8 Order of in situ vitrification melts.

Melt	Pit no.	Date	
		From	To
1	19	21/5/98	25/5/98
2	3	15/6/98	25/6/98
3	4	2/7/98	11/7/98
4	19a	17/7/98	30/7/98
5	4 (second portion)	3/8/98	12/8/98
6	19 (remelt)	17/8/98	27/8/98
7	13	23/9/98	5/10/98
8	15	9/10/98	17/10/98
9	12	22/10/98	3/11/98
10	9	9/11/98	21/11/98
11	6	27/11/98	8/12/98
12	18	14/2/99	3/3/99
13	17	10/3/99	21/3/99

In the absence of any other indications, the melt at pit 3 was terminated on the basis of the slow rate of electrode penetration over the final 24 hours. This melt was subsequently disinterred and broken up as part of the assessment of the effectiveness of the ISV process. It was found that the melt had not reached pit bottom and had been terminated prematurely. It also demonstrated a lesser depth of melt in the central region within the square defined by the four electrodes ('hollow tooth', *Attachment 4.8*) and its steel content had not been melted. Because of an increase in the height of the berm to suppress the effect of transients, the pit 3 melt block finished proud of the ground surface by up to 0.4 m.

Changes in ISV procedures

Over time, as experience was gained, a number of changes were progressively introduced to reduce the likelihood of melt excursions, maintain the melt temperature and to provide an improved picture of melt development. These included:

- fracturing the surrounding limestone to provide escape paths for gases formed in the melt (all but melt 1);
- in line with an earlier MARTAC recommendation, the increased use of Type C thermocouples and their deeper placement in the sand trenches (for fourth and subsequent melts);
- increasing the extent of 'overmelting' beyond historical or probed depths (determined by the final electrode insertion depth) (to an increasing degree for third and subsequent melts)
- adding more fluxed silica at the pit surface in an attempt to raise melt temperatures (variable over program); and
- decreasing the height of the berm as far as possible, within the other constraints, so that the top surface of the completed melt block remained below grade level.

Ultimately it was established, as more of the ISV melts were disinterred and examined, that, in spite of these changes, the termination indicators had not provided reliable signals to ensure a satisfactory outcome. It was only in the final two melts that all or most of the steel contents were melted, an outcome that would ensure the incorporation of the pit contents within the melt mass.

4.6.6.3 The 'hybrid option'

Experience in the exhumation of the TM pits and the airfield cemetery had shown that contaminated pits could be exhumed efficiently and without any radiological hazard to the operators that was not controlled through the use of Class II vehicles. Thus, in parallel with ISV operations, a 'hybrid option' was developed to deal with the outer pits which were very much larger than had been reported at the time of *Operation Brumby*.

The concept of a hybrid option developed gradually from a MARTAC proposal in mid-1998, when MARTAC first considered the possibility of exhumation and reburial of the outer pits as a safe cost-effective alternative to ISV (see *Section 3.4.4.3*). At its next two meetings in August 1998 and mid-January 1999, the hybrid option was considered in greater detail and a proposal examined whereby the outer pits would be exhumed, their metallic contents separated from the soil backfill and sorted into small (< 10 cm) and larger (> 10 cm) items. The larger material was intended for vitrification in specific 'pods' at a high enough temperature to completely melt the steel. The remaining, smaller, debris would also be vitrified in 'general debris' pods, with the requirement that all plutonium be incorporated into the calc-silicate melt phase and all items either melted or fully encased. A feature of the hybrid 'pods' was that they would be designed to include unambiguous indicators of melt completion. The contaminated soil that was excavated from the outer pits along with the (< 10 cm) debris was to be buried in a new trench under the same conditions as those set down for the main soil burial trench. A more detailed discussion of MARTAC's deliberations on the hybrid option is contained in *Section 3.4.4.3*.

A second burial trench was therefore constructed to accommodate the soil from these pits. This was constructed by the Earthworks Contractor, who had been engaged earlier to exhume and rebury at depth the contents of the pits at the TMs and at the airfield cemetery (further detail is provided in *Section 4.7*).

4.6.6.4 ARPANSA consideration of ISV

Initially the Regulator was supportive of the ISV process for the treatment of the formal Taranaki pits and, later, for the hybrid option. It concluded that the separation and burial of contaminated soil in a purpose-built trench would achieve the same safety outcomes that had been applied for the soil removal phase of the clean-up, and that the hybrid approach was a safe and reasonable option, consistent with the principles enunciated by TAG in Option 6(c) (letter from J Cable, ARPANSA, to C Perkins, DISR, 27 October 1998).

In response to a formal request from the Department regarding the acceptability of the outcome of ISV, following excavations around pit 19A and pit 3, the Regulator (letter from J Loy, ARPANSA, to C Perkins, DISR, 23 November 1998) considered that:

- where the level of unencased contamination below an ISV block was consistent with that remaining on the surface, there would be no need for further action;
- where the level was significant but believed to be below the Category C limit for near surface disposal (10 kBq/g of Pu^{239}), there should be at least 3 m of monolithic melt above the unencapsulated debris—it might reasonably be inferred that this condition would be met when the activity concentration of the homogeneous melt material was less than 1 kBq/g of Pu^{239}; and

- where evidence suggested that the level of unencapsulated contamination might exceed Category C limits, the specific situation should be considered on its merits and referred to the Regulator.

The Regulator noted in the same exchange that the process of excavating around and below completed melt blocks was undesirable and should be limited to one further melt of the inner pits and to one of the engineered hybrid pods made up of the contents of the outer pits. It further stated that tops of melt blocks must be flush with or below the surrounding surface and proposed that the finished blocks be capped with concrete and that the whole of inner Taranaki be covered by a 1 m layer of clean soil. Subsequently, this proposal was relaxed to allow a good quality grout in lieu of a concrete cap and a minimum of 300 mm of clean fill to be placed over pit surfaces. The purpose of these measures was to disguise the presence of ISV blocks and to aid revegetation.

4.6.7 THE ISV BURIAL TRENCH

In anticipation of contaminated material likely to be accumulated during ISV processing, a trench known as the ISV burial trench was prepared to the south of the Taranaki soil removal area (see Figure 4.6) The initial excavation of this burial trench was undertaken by the Earthworks Contractor in late 1997.

4.6.7.1 Contents and closure of the ISV burial trench

The purpose of the ISV burial trench was to provide a location to bury waste materials, debris and unwanted equipment from the ISV work (i.e. spent electrodes, glass from sampling and melt investigation, soils containing glass fragments, personal protection equipment (PPE), spent filters, and other process-related rubbish). At times, general rubbish consisting of items such as cardboard boxes and timber was burnt in the trench with the approval of the Health Physics Provider. It was also to serve as a site to bury material exhumed from the airfield cemetery pits.

The trench was initially excavated to a depth of 7.5 m with overall dimensions at ground level of approximately 40 m x 40 m. Side slopes were approximately 1:1 and access was provided with external ramps from both the east and west ends.

As the project proceeded, further requirements arose for burial space to dispose of ISV-related materials and other contaminated materials.

The surface of the earth bunds used in the ISV process to support the hood and associated equipment became contaminated with glass fragments after the completion of the melt from either cleaning of the hood superstructure or during the process of removal of the frothy and glassy ‘cold cap’ using the excavator and hammer. It was a requirement of the Regulator that this glass material and any soil contaminated with it be finally removed from the central Taranaki area and buried in a trench. Thus prior to removal of the berm at a melt, the surface was scraped to remove as much of the shards and associated soil as practicable. While a fair proportion of the berm soil was then re-used for later melts it was all required to be buried eventually as it was not possible to avoid the glass mixing in with the soil. Due to the large volumes of soil involved and the need to dispose of ISV block core material that had remained proud it became necessary to increase the size of the ISV burial trench. Thus in February 1999, a 50 m long extension to the east was excavated to a depth of 11 m.

In April and May 1999 a further 70 m extension of the ISV burial trench was excavated to the east with a maximum depth of 16 m at the eastern end over a length of 30 m to accommodate burial of soils from lots 41 and 42 and to allow for a further significant increase in the amount of contaminated waste resulting from the ISV process. The explosion at pit 17, discussed below, also led to a requirement to dispose of damaged equipment including the ISV hood.

The exhumed material from the airfield cemetery pits was the first material placed in the trench. It was placed at 7.5 m below grade in the northern two-thirds of the trench width taking up an area of approximately 30 m x 20 m and approximately 1.2 m deep. On final placement of all exhumed material from those pits a 500 mm cover layer of clean soil was placed over the contaminated debris. In March 1999, the Environmental Monitor suggested through the Department that further soil be removed at Taranaki from what were nominated as lots 41 and 42. This material was placed in the ISV burial trench as the soil burial trench had been closed off by that time.

The trench became the burial site for waste ISV materials and equipment and materials from the forward area facilities as the site disestablishment was implemented.

The following list (*Attachment 4.4*, *Section 10.6.12.3*) is typical of the material placed in the ISV burial trench from the start of the ISV operations in late May 1998 up to 1 October 1999 when it can be considered that disestablishment operations were commenced.

- Soil arising from the removal of the containment berms and containing glass fragments and shards (by far the most significant component of the volume).
- Contaminated soils from lots 41 and 42.
- Uranium fragments from Kuli in nine 44 gallon drums.
- Core samples and ISV melt samples from the village.
- Three 44 gallon drums from the half way tank (waste from the old RO [reverse osmosis] plant).

- Debris from Kittens Lanes, special Kittens Site, Naya and One Tree.
- PPE including most red area boots and contact clothing.
- Lead contaminated soils from beneath ISV melts.
- ISV glass from the breaking up of melts for investigation of melt performance or for the taking of samples as well as glass from the cold caps.
- All ISV glass from the pit 17 melt.
- Spent electrodes.
- Cables and debris from various excavations in central Taranaki.
- The 300 mm thick concrete caps removed from the central Taranaki pits (33 pieces in all with an average size 8 m^2).

From October 1999 to the closure of the ISV trench in March 2000, the following plant, equipment and materials were buried in the eastern end of the ISV burial trench.

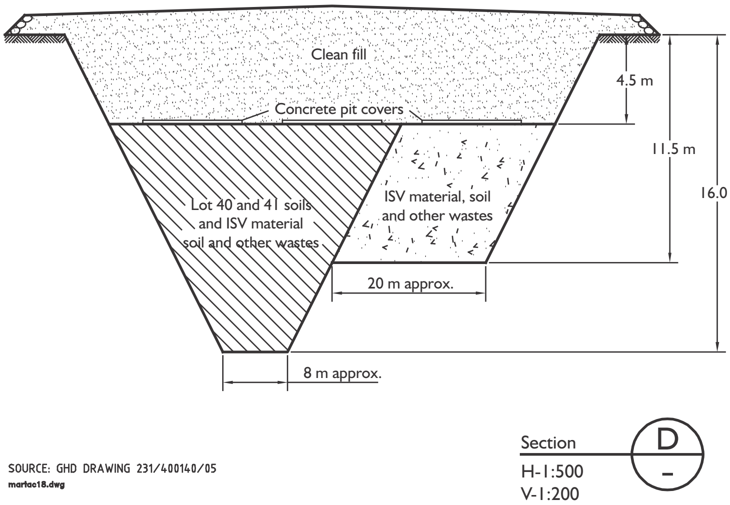
- Three 40 foot shipping containers which contained the filters from the ISV process. The roof of each container was removed and the all voids filled with soda ash which was surplus to requirements.
- Soda ash placed in the filter containers and also placed loose.
- The two vacuum trucks.
- The tray bodies from the two Volvo trucks.
- Stripped cable casing and other waste cables from the ISV operations.
- Star pickets and bunting.
- Two dismantled hoods and accessories from the ISV process.
- Five electrode feeders.
- Stack and off-gas duct from the ISV off-gas filtration system.
- Contaminated soil from the site of the British health physics facility (HP2).
- Analysed samples of glass and melt returned to site from ANSTO, Amdel and a USA laboratory.
- 44 gallon drums.
- Used PPE.
- Ducts, filters and motors from air conditioning plant on the personnel change room and the laundry.
- Three portable buildings. This included the ARPANSA portable change room, the mud room or OPC (outer protective clothing) room and the shower cell, and

the part of the ex-TMs change room used for pit exhumation operations. All were dismantled first and the change room was burnt prior to burial.

- All wall cladding from the vehicle decontamination building as well as the HEPA filter system including the fan.
- All wall cladding from the workshop building.
- The roof of the contaminated vehicle service facility plus the structural columns.
- All potentially contaminated equipment from the ISV process that it was not considered to be cost-effective to decontaminate. This is listed in the Departmental asset register.
- Structural steel ramps used by the Earthworks Contractor for plant decontamination and servicing.
- The Earthworks Contractor's excavator bucket and one set of excavator tracks.
- Contaminated high density polyethylene (HDPE) water tanks used for storing of the recycling water in the decontamination process together with pipework and pumps.
- General rubbish including fences, pallets, empty drums and the stand pipe.

A cross-section through the ISV burial trench is shown in Figure 4.19. This is a cross-section approximately one-third of the distance in from the eastern end, and is not typical, as the trench varies considerably along its length (see *Attachment 4.4*, *Section 10.6.12* for a more complete account).

Figure 4.19 Cross section through the ISV burial trench.



SOURCE: GHD DRAWING 231/400140/05
martac18.dwg

4.6.7.2 Provision for future burials

Provision was made at the eastern end of the ISV burial trench for deep burial of small contaminated items that could possibly be discovered at the site following the closure of the trench. This was achieved by the placement of three 200 mm diameter plastic pipes in a bundled group, vertically from approximately 14 m below grade up to the surface where the pipes are capped.

A hinged lid was placed over the top of the pipes.

Small contaminated fragments or particles will be able to be ‘posted’ in these pipes for burial in future at 11 m depth.

4.6.8 THE PIT 17 TRANSIENT EVENT

On 21 March 1999, at approximately 12:32 pm, a significant transient event occurred during the later stages of processing pit 17 by the ISV process. At that time the melt had been in progress for approximately 262.5 hours. This transient and the resultant fire caused severe physical damage to the hood including the frame structure and the shielding panels, electrode feeders, power cables and instrumentation and control systems mounted on the hood. There were no injuries to personnel. Power to the melt was immediately shut down. Other personnel near the site of the event were evacuated. Glass was displaced by the severe eruption that characterised the severe transient and was distributed up to a distance of 50 to 75 m. Larger globules of glass were distributed closer to the hood inside the exclusion zone. The event pushed the side panels of the hood outward and then they fell inward onto the melt surface. The event also caused the roof of the hood to fail and fall down onto the melt surface. Once the roof and side panels were pulled down, the support equipment on the hood was exposed and was subsequently sprayed with molten melt material and heat damaged. A complete report on the incident can be found in an ISV Contractor report (*Attachment 4.5*). This event had the potential to cause injury to personnel through burns or impact from molten glass had they been in the near vicinity of the hood or on the equipment at the time of the transient. ISV operators normally walked around on the hood, within the hood exclusion zone, on a regular basis to check equipment, and add electrode segments or replace broken electrodes. They also took dip samples and melt temperatures from a position on the top of the hood. It was understood that the ISV Contractor's instructions for personnel access onto the hood required the prior isolation of the power input to the melt.

The event raised several issues needing to be addressed in relation to the practical approach to the completion of ISV treatment of pit 17, and the ISV treatment of the remaining two inner pits and also the hybrid pods. The ISV Contractor was requested to address these matters in its report. The Project Manager (facsimile from the Project Manager to the Department, 22 March 1999) stated that it was clear that the incident would delay the ISV work and there would be a financial loss to the project associated with the damage to the hood and equipment. The incident, however, would not delay the Earthworks Contractor's operations on the preparation of the hybrid pods.

Over the next few days, as the assessment/investigation continued, the ISV Contractor continued to work on plans for the ISV of the general waste pods of the hybrid option.

Investigations into the cause of the explosion

Initial investigations examined:

- the damaged equipment—glass, steel and other ejecta from the melt pool;
- damage to the hood and other equipment;
- residues in the off-gas ducting and on the surfaces of the equipment;
- the electronic records maintained during the melt processing; and
- the personnel witness statements.

On site (see *Attachment 4.5*, *Appendix E-6*) and laboratory (see *Appendices E-1–5* & *E-7* in *Attachment 4.5*) forensic investigations indicated the presence of organic materials in trace quantities but were inconclusive with respect to the cause of the explosion. The ISV Contractor therefore undertook further investigations of the cause.

The ISV Contractor tasked VitChem of Issaquah, Washington, USA, to investigate the pit 17 transient event and its report was issued in July 1999. This investigation of the pit 17 solidified ISV block was of a physical nature and was charged with the task of finding any physical evidence (such as parts of a damaged drum or gas cylinder) at the base of or within the ISV block, and to collect samples of other materials that may have indicated the cause of the event. The investigation appears to have localised the seat of the explosion to a crater-shaped depression to the west of centre of the base of the melt, but it, too, was inconclusive as to the cause of the event. No metallic fragments were recovered that could be linked to a container.

The ISV Contractor also engaged SHE Pacific to further investigate the incident. SHE Pacific concluded that the most likely cause of the event was an explosion involving 2–3 kg of ANFO (amonium nitrate fuel oil). The ISV Contractor prepared a covering report on the pit 17 incident that included all of the physical and laboratory evidence as well as the opinions of the investigators (*Attachment 4.5*). It concluded:

> *... the most likely cause of the explosion is believed to have been the detonation of an explosive material such as ammonium nitrate fuel oil (ANFO).*

As a caution, MARTAC advised the Department that the ISV Contractor report and all the evidence that had been collected referenced above should be independently reviewed to ensure that all scenarios for this off-normal event had been addressed. The Department tasked the Project Manager with this responsibility. The audit of the ISV Contractor report on the incident at pit 17 was carried out by Entec UK Limited and RobSearch Australia Pty Limited in December 1999. Their audit concluded that the scenario of an explosion of ANFO, postulated by the ISV Contractor as most probable, was most unlikely to have been the cause of the pit 17 incident and concluded that the hydrocarbon scenario was the likely cause. They also stated that the ISV process is not well-suited to treatment of uncharacterised, heterogeneous materials in other than purpose-constructed pits, especially when there is no certainty of the absence of materials that are liable to present hazards to plant and personnel under the conditions generated by the process.

Attachment 3.1 contains all technical advice received by the Department on the stability/long-term hazard arising from explosive material and ordnance used at the Maralinga Range. On the basis of the reports referenced in this section, MARTAC concluded that the cause of the pit 17 explosion was probably something other than active explosive material being present in the pit.

4.6.9 REASSESSMENT OF THE ISV PROCESS

Safety considerations

Immediately after the pit 17 incident, the ISV Contractor initiated reviews of safety procedures that were normally associated with operations on the hood. The ISV Contractor considered that this was particularly important for the remaining two inner pit melts because of the uncharacterised nature of the pit contents (facsimile from L Thompson [Geosafe Australia] to G Chamberlain [GHD] 22 March 1999). They considered that this may not be the case for the hybrid pods since the pit contents would be screened prior to placement into the designated pods to remove any unsuitable material.

Numerous management meetings were held to address this issue. The ISV Contractor took the view that the transient event was not the result of an uncharacteristic response from the ISV process, but rather was due to some foreign material or object in the pit (view expressed by L Thompson at the special meeting following melt 13, pit 17 incident, 22 March 1999).

At this stage, the ISV Contractor was still considering two major issues relating to the continued application of ISV at Maralinga:

- whether it was preferable to proceed with the single undamaged hood for the remaining pits, be they original or hybrid; or whether to repair/reconstruct a second hood; or

- whether there was too much risk with proceeding to treat pits 16 and 19B without knowledge of their contents, considering the risks of worker safety, even when severely limiting personnel access in the vicinity of the hood.

The Project Manager's view was that the project would be in a difficult position if it were to proceed to treat the remaining two inner pits in situ and then suffer a similar occurrence, even if the outcome were only to result in further equipment damage. The Project Manager further stated that it could be the case that ISV was proving too unpredictable and inherently risky to continue to perform in this environment, possibly due to soil conditions or other unknown site factors, and that the Department should carefully consider whether the process should be stopped and the remaining materials exhumed and buried at depth (facsimiles from G Chamberlain, GHD, to C Perkins, DISR, 22 March 1999 and 23 March 1999).

Further considerations by MARTAC

During this time MARTAC was also engaged in internal discussions regarding the effectiveness of the vitrification process and whether or not it should be discontinued at Maralinga in favour of exhumation and reburial. Factors considered by MARTAC included:

- the limited understanding of the vitrification process, leading to uncertainties in properly identifying the point at which melting should be terminated, and the consequent shortcomings to date of the ISV melts;
- the difficulties that had emerged in verifying that the objectives of the ISV process had been achieved in previous melts;
- the lack of clear indications that future melts, even though carried out in engineered pods, could be guaranteed to meet the specified requirements;
- the continuing uncertainty surrounding the pit 17 explosion and the concern that it may have been intrinsic to the vitrification process itself and that similar events could not therefore be excluded from applying the ISV process to the engineered pods;
- the need for a complete redesign of the ISV hood and plant to manage risk to the operators and the consequent delay in project completion and the costs associated with the delays;
- the high cost of continuing with vitrification, given the much larger volume of material than had been anticipated and planned for within the pits, most of it being clean or only lightly contaminated soil backfill;
- the knowledge that exhumation and reburial under 5 m of clean fill (consistent with the National Health and Medical Research Council [NHMRC] code for near-surface disposal) offered a valid low cost alternative, acceptable to the Regulator from a radiological perspective; and

- the disproportion in residual risk between disposal to a burial trench and that associated with the untreated outer plumes that would remain, albeit with permanent land-use restrictions.

MARTAC had serious concerns regarding occupational risk to the operators during the staging of the hybrid pods as well as about subsequent operations. As the staging process was described by the ISV Contractor (Geosafe Australia 1999), it appeared likely that the requirements for the placement of the heavy steel items could lead to unacceptable occupational exposures.

Design of the hybrid pods continued through this period. MARTAC still had reservations about the verification methods which might be used by the ISV Contractor to determine the temperature of the melt and to determine when the melt had reached the bottom of the pod. An assessment by the ISV Contractor of the various options for determining temperature and melt end-points was inconclusive and even concluded that the end points may remain unpredictable (Geosafe Australia 1999). MARTAC remained concerned that the only secure method of verification might still be exhumation of the completed blocks.

Concurrently, the Department received from the Regulator a facility licence application pack for the licensing of Maralinga under the ARPANSA legislation (see *Attachment 5.2*). The licence application pack clearly stated that the information required for licensing any process, specifically in this case ISV, should be commensurate with the hazards of the process and the ISV Contractor's ability to establish the safety of the process at the operation's site. A similar assessment would be required of the Earthworks Contractor, but for it, it was an assessment of OHS considerations associated with the exhumation process. This was required for both hybrid and reburial options, and for the extra sorting and staging of the waste components required in the hybrid option. The ISV Contractor notified the Project Manager that it considered the ISV process to be safe and provided historical discussions on the matter (facsimile from L Thompson [Geosafe Australia] to G Chamberlain [GHD] 28 March 1999).

Suspension by the ISV Contractor of ISV for remaining inner pits

On 29 March 1999, the ISV Contractor notified the Department that:

> *... because we cannot be sure of the pit contents, we cannot guarantee a similar event will not occur during the treatment of the two remaining pits. Therefore, Geosafe recommends that the remaining two inner pits be included in the hybrid option. As such Geosafe will be unable to treat the two remaining pits.*
>
> Facsimile from L Thompson, Geosafe Australia P/L, to G Chamberlain, GHD, 29 March 1999

ANSTO risk assessment

Following the pit 17 explosion, ANSTO was engaged by the ISV Contractor to make an assessment of the risks associated with the ISV process at Maralinga (*Attachment 4.16*). To assist ANSTO in this task, the ISV Contractor provided information about the full-scale performance of the ISV process worldwide.

ANSTO REPORT FINDINGS

(based on information supplied by Geosafe [see *Attachment 4.16*])

- Triggers for melt displacement include perched water, a large sealed void, sealed container and a pressurised bottle.
- Defining a severe transient as one in which a melt displacement is of a severity that will damage equipment and components means that there has been a total of five severe transients during 75 large-scale melts worldwide. The figures for Maralinga (included in the totals) are one severe transient in 13 melts.
- Non-severe transients also occur. The Maralinga experience is an average of approximately two per melt.
- Analyses of the monitoring data for the off-gas discharges indicates a good correlation between the concentrations of total hydrocarbon and carbon monoxide but poor correlations between the concentrations of total hydrocarbons and carbon dioxide or sulphur dioxide.
- Analyses of the less severe transients suggest that eight were associated with the decomposition of hydrocarbons.
- The second of the five transients reported for melt 10 involved a drum floating to the top of the melt.

Although the risk assessment from ANSTO did provide some quantitative data, it was not considered to be comprehensive. Included in the conclusions were that *... any further use of the ISV process should occur only with well characterised pits ...* and that the operations should be such that *... at a minimum this should include keeping the operators away from the hood during melts*.

Reassessment of exhumation option

The ‘exhume and rebury’ option was now reconsidered, as it was recognised that it could be carried out within an acceptable risk to workers and that by itself it therefore offered a workable alternative to vitrification. There was sufficient experience on-site to establish that exhumation of untreated waste pits could be done safely and its costs could be reliably estimated to be lower than the ISV costs; and in particular, lower than the indicated costs of the hybrid option.

On 16 June 1999, the Department received the first draft of the AEA Technology (AEAT) risk assessment of intrusion into the burial trenches (AEAT 2001). The central question addressed in this paper was whether the burial of heavily contaminated material provided an acceptable level of public safety for the future. The Regulator reviewed the AEAT report which assessed the likelihood and consequences of inadvertent human intrusion and found the proposal acceptable in that health risk outcomes in the short- and medium-term were very low. The report noted that it did not attempt to address consequences of deliberate intrusion but did address the risk of intrusion should it occur.

The Department decided not to take the hybrid option any further. Factors that played a part in that decision included:

- MARTAC advice of May (see *Section 3.4.4.3*);
- AEAT intrusion risk assessment;
- the occupational risk associated with the staging of the hybrid pods as conveyed by MARTAC and the Project Manager;
- the Regulator’s formal licencing requirement that the ISV Contractor would need to establish the safety of the process at the operations site;
- the conclusion in the ANSTO risk assessment that ‘at a minimum this should include keeping the operators away from the hood during melts’; and
- the views expressed by the Environmental Monitor’s officers at the March meeting on the pit 17 explosion and subsequently, on the issues that would need to be addressed prior to the granting of a licence covering the hybrid option and some factors thought relevant to those issues. Some of these issues were formalised by the Regulator in a minute dated 30 July 1999 (see *Section 4.7.4*).

The Department decided to proceed with the exhumation of the formal pits and the burial of their entire contents in the pit debris burial trench, employing work procedures that had earlier been developed for the exhumation of pits at the TM sites and the airfield cemetery.

4.6.10 ESTIMATES OF THE PLUTONIUM CONTENT IN PITS TREATED BY ISV

4.6.10.1 Approaches to the estimation of melt masses and volumes

MARTAC had placed considerable importance on the estimation of melt masses in particular, as a way to estimating the plutonium content of each pit from a knowledge of the mass and the average plutonium activity concentration. Such estimates, however, are reliant on the ISV to take to completion the process of incorporating all of the plutonium, whether it was mixed with the soil contents or attached to the surface of steel components, and whether it is on exposed surfaces or sandwiched between the steel debris items.

Electrical energy consumed in melting

The approach by the ISV Contractor for the estimation of melt mass involved a relationship between the integrated power input in kilowatt hours and mass of soil melted, based on an efficiency range of 0.7 to 0.8 kWh/kg of soil melted. This relationship appeared to have been empirically determined by Geosafe Corporation on a range of soils in the USA. The energy per kilogram of soil melted was related to soil composition as well as to melt size, and values between 0.5 to approximately 1.2 had been determined by the ISV Contractor (see *Attachment 4.9*) for the melts at Taranaki. Geoprojects (2001) reported the energy consumption in practice as 0.85 to 1.3 kWh/kg of soil melted. MARTAC had never supported energy consumed per kilogram of melt as an adequate measure for determining melt volume and for this reason advocated the use of certain rare earth elements as ‘tracers’.

An additional approach for the estimation of melt size was made through visual observations, where measurements had been made of the melt dimensions. Although hampered by measurements of inconsistent reliability, the melt sizes by this means were similar to those obtained by the rare earth tracer method.

Rare earth tracers

The addition of known quantities of tracer elements into the material to be melted was considered by MARTAC as a way to determine the melt mass from the tracer concentration in the vitreous product. Details of this approach are covered in *Attachment 4.8*. A summary is presented below.

Following evaluation of a number of potential tracers, MARTAC proposed the addition of defined quantities of the (non-radioactive) rare earth lanthanum as an oxide, and in cases where two melts were required, the addition of cerium oxide to the second stage. In both case, the quantities added (usually 25 kg but up to 150 kg [pit 17]) were expected to produce concentrations in the final ISV product of approximately five times their average natural abundance.

Known quantities of lanthanum oxide tracer were added on top of soil melted in pits 4, 6, 9, 13, 15, 17 and 18, 19 and 19A with all but 19 expected to contain substantial quantities of plutonium. Cerium oxide tracer was similarly introduced into the second melt on pit 4 and it was also used as the tracer in pit 12. The tracers allowed a better estimation to be made of the plutonium inventory. In the absence of the physical examinations that were undertaken the tracer method could also have been capable of providing some confirmation of the depth of the melts.

Sampling of ISV product by the ISV Contractor

The ISV Contractor took dip samples directly from the molten masses during the processing of several of the pits. Each melt block was also sampled shortly after its completion with solid samples collected from the melt top, around the electrodes. A third suite of samples was taken by the ISV Contractor from the exposed core of several of the solid blocks after several weeks of cooling and after breaking away a portion of the sides with an excavator-mounted hydraulic hammer.

Dip sampling during the melt involved isolation of the power input and the taking of a sample from the melt itself via a vent port where there was access through the overburden and the solidified, glassy cold cap for insertion of a dummy electrode into the liquid melt. Melt that adhered to the electrode surface or that had entered pockets cut into the sides of the electrode was broken away and subsampled, once it solidified. However, uncertainties in relating the sample to its original location within the melt occurred in this mode of sampling and potential for cross-contamination of the sample with cold cap or overburden material occurring during withdrawal. The ISV melts were expected to be well-mixed. However, early sampling of the top surface of the blocks failed to consistently provide samples that represented the 80 to 90% of the product blocks that made up the central core zone. Other sampling was then undertaken as specified in the ISV Contractor's procedure (Geosafe Procedure GA-TP-98-005, see *Section 5.3.3*). Samples of the solid block that were taken from the dense mixed crystalline and glass phase from the core, well into the sides of the blocks, were found to be of very consistent geochemistry and radionuclide concentrations. It was those samples that were established to be 'representative' of the core of the ISV blocks that were used to determine the block masses and hence the plutonium contents. Where the ISV Contractor's samples proved inconsistent or where samples were not available, the samples obtained by MARTAC were used for the mass and plutonium estimates (see *Attachment 4.11*).

Sampling of ISV product by MARTAC

MARTAC obtained independent samples after an initial period of solidification and cooling of the melts, following the exposure of the melt block outer zones and of cross sections through several of the ISV blocks. This meant that samples could be taken from any selected location including the cold cap, block edge zones, top and base of the block, from the core zone that was representative of 80 to 90% of each of the melt blocks, and from regions adjacent to electrodes at specified depths. These were used to characterise the ISV blocks with respect to their central homogeneity and their peripheral zoning, and to examine the block surroundings. Samples taken from the partially melted and unmelted geological materials around the sides and below the sectioned blocks enabled an examination of the behaviour of radioactive materials at the melt block boundaries.

Estimated plutonium content of the treated pits

Nine of the pits treated by ISV contained appreciable quantities of plutonium. Table 4.9 sets out for each the mass of the calc-silicate phase of the ISV product, the average concentration of plutonium in the block and the corresponding mass of plutonium. These values were derived from the net tracer concentrations in a subset of the samples from the melt block. The samples in the subset were determined by the method set out in *Attachment 4.8* to be 'representative' of the core zone of the block.

The plutonium contents in the table are derived from the Pu:Am ratio data from British sources, using the more abundant Am^{241} gamma emission at 59.3 keV.

Table 4.9 Estimates of block masses from tracer concentrations and plutonium content (Pu estimated from British VB Series Pu:Am Ratios, adjusted to November 1998).

Pit no.	VB series & firing	Mass of melt (t)	VB Pu concentration (Bq/g)	VB Pu mass (g)
4 (melt 5)	VB 2/3	678	206	62
6	VB 2/2	281	251	30
9	VB 2/1	508	341	73
12	VB 2/4	324	323	45
13	VB 2/5	367	283	45
15	VB 3/4	269	504	58
17	VB 3/1	603	269	71
18	VB 3/3	609	233	61
19A	VB3(?)	427	164	30
Total		**4066**		**475**

4.6.11 MARTAC'S QUALITY ASSURANCE (QA) PROGRAM

MARTAC's QA program had two main components:

- verification that all the waste components were incorporated or encased into the ISV ceramic phase; and
- verification that the plutonium was uniformly mixed within the ceramic phase of the ISV melt.

Initially it had been intended to diamond drill some ISV blocks to obtain data for the QA verification but when the block from pit 3 was so proud of the top limestone surface to the extent of needing approximately one third of the block removed it was decided to completely dismantle that block as part of the QA program.

A full description of the inspection of this block and others that followed is provided in *Attachment 4.8*.

Pit 3 did not contain any plutonium so it was recommended that a further block be excavated. Pit 19A was chosen, mainly because during its melting no unambiguous signs of when to terminate the melt occurred. A consequence of there being uncertainty about the completion was that the pit 19A melt was continued for a further 24 hours prior to its eventual termination.

Since neither of these blocks lived up to MARTAC's expectations, it was decided to excavate a third block from about the middle of the intended ISV program by which time the ISV Contractor had introduced changes to its staging procedures. The block chosen was from pit 15. It was relatively small and with indications that the temperature attained was above the melting point of steel. Beneath the unmelted steel plates in pit 15, there was a quantity of untreated plutonium and a zone of unincorporated pit fill (see *Section 4.7.4*).

After an inspection of the excavated pit 15 block, the Department, the Regulator and MARTAC all recommended the excavation and reburial at much greater depth of all the steel aggregates associated with the ISV blocks.

The demolition of blocks provided opportunities to obtain representative samples from various parts of the melt. Extensive data were obtained for the blocks from pits 3, 4, 15 and 17. These data are reproduced in *Attachment 4.11*. An even more extensive data base covering all analyses performed on any sample from the ISV program are at *Attachment 4.12*. In all cases the core zone of the ceramic phase of the ISV melt showed uniformity of all components.

4.6.12 MARTAC'S CONCLUSIONS ON THE ISV PROCESS AT MARALINGA

MARTAC's conclusions on the ISV process are based on its observations of four ISV blocks during their demolition and excavation, the photographic record provided in *Attachment 4.8* and extensive discussion of the process during MARTAC's eight years' existence. Following a recommendation from MARTAC, one of its members was engaged to carry out a detailed investigation of the ISV outcomes and his report is reproduced as *Attachment 4.8*. In all cases the conclusions reached by MARTAC relate only to the Maralinga host geology, the initial nature and composition of the wastes in the debris pits being treated, the initial orientation and distribution of these wastes relative to the ISV electrode array and the non-availability of an electrical grid and stand-by plant. The importance of these bounding attributes cannot be over-stressed. The following observations perhaps indicate their importance.

- The melting point of the steel component of the waste is above that of the host rock such that unmelted steel can sink in the melt to the position of the advancing melt front.
- Some of the waste components (e.g. lead) had melting points below that of the soil.
- The UK reported that the lead was one of the first of the wastes thrown into the pit and that the steel plates of the featherbed were thrown in sequentially.
- The steel plates were of dimension of approximately 2.4 m by 1.2 m (a notional total volume 2 m^3 per pit) and the electrodes connected to the diesel power generator had separations of 3.5 m (pit 3) or 4.5 m (remainder).

The need for extensive site and pit investigations

Despite the extensive sample collection and analyses that were carried out at Taranaki as a precursor to the ISV Contractor program and the scope of the ISV Contractor investigations during Phases 1 and 4, in retrospect, insufficient site investigations were directed at characterising the pits with respect to their depth and host geology prior to undertaking ISV at the Taranaki site. This meant that no clear and unambiguous endpoint indicators, if any existed, had been identified before treatment of the Taranaki pits. This was a consequence of the variability of the host geology at Maralinga and the desire, if not insistence, of all parties to have the ISV process and its preliminary investigations non-intrusive at that time.

The disruptive nature of the ISV process

Substantial earth works were required prior to the ISV process for:

- building the berms and pads;
- adding the fluxed sand;
- probing the pit dimensions with a rock hammer;
- constructing a trench for melt confinement; and
- placing thermocouples, to fracture the pit edges.

Following the ISV treatment, works required included:

- removal of the off-gas containment hood;
- scraping off the cold cap material and removing the protruding section of the electrodes; and
- chiselling away the component of some of the melt blocks that remained standing above grade after termination of the melt.

Collectively these activities resulted in major disturbances to the soil and rock in and surrounding each pit and where prograde portions of melt blocks were to be removed. This proved to be destructive of the intrusion resistance of the remainder of the ISV blocks.

Safety of process

The process required operators to be present on the hood platform above molten rock in order to manually add electrode sections, undertake maintenance and to sample the melt. It is MARTAC's opinion that the severe eruption of melt from pit 17 showed these manual procedures to be too dangerous to contemplate a continuation of the current ISV procedures. A high probability of serious injuries or fatalities was judged likely in the event of a recurrence of the pit 17 incident. Further in MARTAC's view the process design needed to be modified to preclude workers from the vicinity of the hood both during melting operations and during melt solidification. These views imply that mechanical systems would need to be developed and applied for the addition of electrodes lengths during the development of the melt, for the replacement of broken electrodes during the melt, for sampling of the melt and for determining the temperature of the melt and the temperature gradient within the melt.

Physical structure of the ISV block

The Taranaki blocks were not monolithic as they had fractured during cooling[20].

Apart from pit 18 and (effectively) pit 17, all melts had unmelted steel at the base of the melt and unincorporated pit contents remained at the bottom of a number of melts (see *Attachment 4.8* and Figure 4.20).

Lead metal in the pit debris was not generally processed by the ISV treatment and a substantial proportion of the total lead inventory escaped from the pits during the processing.

The ISV process

It was the ISV Contractor's belief that a characteristic of the ISV process was that the melt would 'self-seek' a viscosity of 100 poise and that at a specified viscosity there was a known relationship between the ratio of the basic oxide to acidic oxide components of the melt and the melt temperature. Consequently it was believed that the melt temperature could be predicted from the composition of the material to be melted. This was the basis for the geo-chemical modeling. In practice, there was inadequate predictability in the melt temperature that followed from the design of the pit staging.

Outcome melt temperatures measured by thermocouples placed around and dipped into the melt body, however, deviated from those predicted from the actual melt block core geochemistry to an extent that suggests that the melt was not always at 100 poise viscosity, the viscosity being the only unverified variable in the relationship.

The ISV electrical plant was sized to allow in excess of 4 MW of power to be input to the melt. The transformer had a maximum current rating of 5300 A at the maximum ambient design conditions of 50°C (and 6000 A at a transformer temperature of 20°C). These design parameters are consistent with the measured resistivity of the plutonium trial of the Phase 2 ISV studies. In practice, the published (*Attachment 4.9*) and unpublished melt reports give values that are not consistent with plant specification (0.05, 0.1, < 0.05, 0.1 and < 0.05 ohms for melts 2, 3, 4, 5 and 9 respectively). Consequently the ability to maximise melt turbulence during that period when the melt was attacking the steel, by increasing power input, was denied to the project[21].

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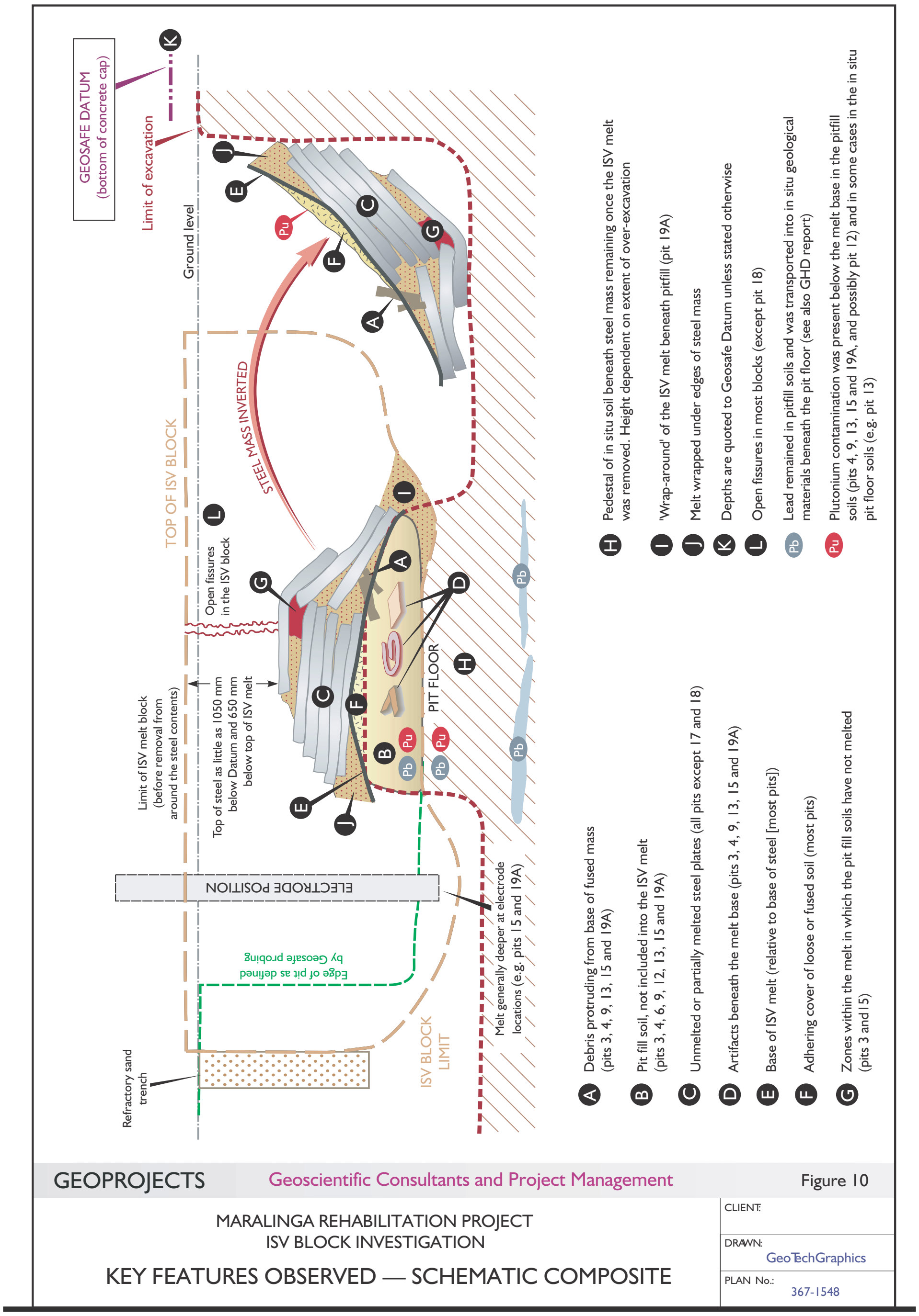
[20] Monoliths could have been advantageous at Taranaki, had they been produced, as they would have contained no open pathways to the atmosphere through which air and water could have penetrated to attack the steel masses. This matter would not have been of significance, however, if the ISV treatment had incorporated all of the pit contents and if it had melted all of the steel contents, thus ensuring the transfer of all plutonium to the well-mixed oxide phase of the melts.

[21] For melt 17, SHE Pacific Pty Ltd reports (*Attachment 4.5*, Appendix B4) that: *Power was reduced to 3.3 MW due to temperature constraints on generators. Current levels less than 4500 amps.*

Figure 4.20 Investigation of ISV blocks.



Quality assurance

Ultimate QA on the ISV process could not be established without intrusive physical investigations.

The application of the ISV process in a Maralinga situation was not sufficiently predictable to provide any indicator useful for product quality assurance and few for process control.

Product acceptability

It became apparent as ISV blocks were disinterred and examined that the presence of large quantities of unmelted steel shadowed the material below it, such that the steel remained suspended upon a pedestal of unmelted soil and/or backfill when the melt was terminated. The presence of the pedestal meant that unincorporated and transferable plutonium contamination lay at a distance below the ground surface which was not acceptable to the Regulator.

4.7 EXHUMATION AND REBURIAL OF THE REMAINING TARANAKI PITS

4.7.1 EXTENSION OF THE DEBRIS BURIAL TRENCH

The burial trench intended to take the contaminated soil and small debris from the eight large outer pits (see *Section 4.6.6.3*) was extended to take into account the changes in the works program as they developed.

Initially the requirement for its size was that the trench have the capacity to bury 5000 m^3 of contaminated material, 5 m below grade. The footprint of the trench was 60 m x 40 m with access within the trench being obtained via a ramp in the north-east corner. The overall depth of the trench was originally designed to be 9.5 m deep.

Following the explosion during the ISV treatment at pit 17, it was evident that as long as the ISV Contractor held the view that the explosion was the result of some undesirable item being present as a waste component, then the two remaining inner pits that had not been treated by ISV, namely pits 16 and 19B, would not be treated by ISV and the capacity of the burial trench was therefore increased to cater for possible burial of their contents.

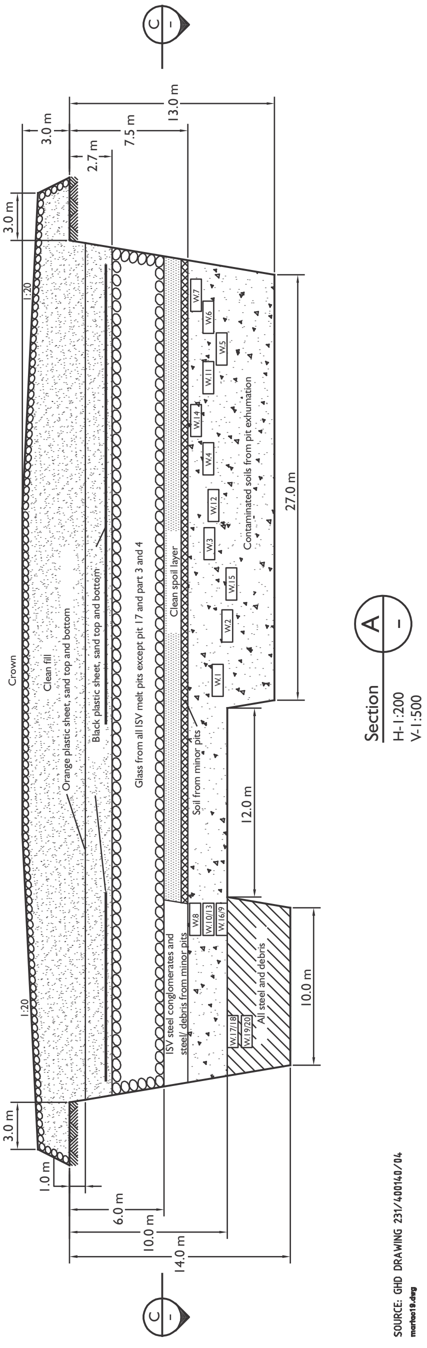
As the reason for the explosion at pit 17 was not known and was still being investigated at this stage, it became likely that no further vitrification would be undertaken and that the hybrid option might be discarded.

To maintain progress on-site, it was agreed to proceed with the exhumation of the outer pits but to sort and store the exhumed material in the debris burial trench in case the pods would be later constructed and treated by vitrification.

The burial trench was therefore modified again to suit the sorting and storage of the three categories of material (i.e. steel debris, concrete and soils/material less than 100 mm in size) pending a decision on the hybrid option. As is noted in *Section 4.6.9* the hybrid option was not pursued, and eventually all material excavated from the formal Taranaki debris pits remained where it had been placed or stockpiled and was buried in this trench, which became known as the debris burial trench. The exception was the barytes (blast) walls that were specifically located within the trench after discussion with the Regulator, and they were buried with their contaminated sides face down.

The final configuration of the burial trench is shown in Figure 4.21.

Figure 4.21 Long section of debris burial trench.



SOURCE: GHD DRAWING 231/400140/04
martac19.dwg

4.7.2 PIT EXHUMATION—UNTREATED PITS

In early April 1999 exhumation started at pit 2. The sequence of exhumation was: pits 2, 1, 10, 14, 16, 19B, 5, 8, 11 and 7. Pits 16 and 19B remained untreated by ISV and were added to the outer pits for excavation. Exhumation of all pit contents was completed in mid-June 1999.

Prior to the commencement of exhumation of each pit, the following pre-work was undertaken.

- 'Red' haul roads were formed from the pit to the debris burial trench by the introduction of fill material. All red haul roads were delineated with star pickets and bunting.
- Each pit was bunded and pre-soaked for a minimum of two days.
- A comprehensive pre-start training session was held.

The exhumation process was supervised from the Class II 4WD troop carrier located at the pit. The vehicle was used by the Earthworks Contractor's supervisor and a representative of the Health Physics Provider. All construction plant was in contact with the supervisor's vehicle and all instructions were issued via two-way radio.

Once the cover material had been removed from each pit and transported to the burial trench, the Class II standard excavator was used to sort the pit debris within the pit into four categories.

- *Steel plates*. These were the featherbed plates which had formed the platform on the test structures.
- *Steel wall sections*. These were the large steel plated wall sections containing the barytes bricks.
- *Other large debris*. This included general steel sections and other debris over 100 mm in size including concrete, barytes bricks, lead bricks, cable and general rubbish such as PPE.
- *Contaminated soils*. All soil and minor debris smaller than 100 mm in size.

The excavator at the pit was able to remove the material selectively to allow each truck load to contain effectively only one category of material that was then deposited in separate areas within the burial trench. The excavator located in the burial trench spread the material and maintained the burial trench base in an orderly fashion. Operations in the debris burial trench are discussed in *Attachment 4.4*, *Section 11.9*.

The blast walls were handled separately and generally at the earliest opportunity, in part because of their weight and size and also the plutonium contamination on them was at the highest concentration and in total represented a high percentage of the contamination on debris items.

4.7.3 CONTENTS OF EXHUMED PITS AT TARANAKI

The contents exhumed from each pit are shown in Table 4.10 (*Attachment 4.4*, *Section 11.6.1*).

Overall the debris exhumed consisted mainly of:

- steel plates from featherbeds generally of dimensions 2 m x 2 m x 50 mm thick;
- steel structural sections;
- steel boxes containing barytes bricks (blast walls);
- cables and wire;
- tubing;
- concrete fragments;
- loose barytes and lead bricks;
- scaffolding tubing;
- plastic bags and rags; and
- soil.

Table 4.10 Contents of exhumed Taranaki pits.

Pit no.	Steel plate (t)	Structural steel (t)	Large debris (m^3)	Soil small debris (m^3)
1	30.0	4.7	0.30	325
2	0.5	0.2	0.10	323
5, 8, 11	25.0	5.6	53.0	1645
7	2.0	–	10.0	280
10	2.0	0.2	10.0	360
14	38.7	3.8	0.3	430
16	7.8	0.4	0.1	55
19B	0.7	2.2	1.4	115
Totals	**106.7**	**17.1**	**75.2**	**3535**

Twenty blast wall units were exhumed in total. They were of varying dimensions, but typically approximately 1.5 m x 1.5 m x 0.5 m. These were removed from the following pits:

- pit 7 – 4 wall sections;
- pits 5, 8 and 11 – 18 wall sections; and
- pit 10 – 4 wall sections.

In Table 4.10, the steel plate forming up the blast walls is included in the steel plate column and the barytes brick from within the walls is in the large debris column.

To the extent that pits 1, 2, 10 and 14 contained wastes from, and only from, the *Vixen B1* trials, these estimates of masses for the various waste components can be compared with the estimates provided at Table 3.8 which were developed by the UK from schematic drawings of the featherbed structure.

Table 4.11 ISV material removed from Taranaki pits.

Pit no.	Melt volume[1] (m^3)	Cold cap volume to ISV trench (m^3)	Sample volume to ISV trench (m^3)	Volume placed in debris trench (m^3)	Volume placed in ISV trench (m^3)
3	132	18	–	86	46
4	195	23	–	142	53
6	104	12	2	102	–
9	105	17	2	103	–
12	123	23	2	121	–
13	112	21	2	110	–
15	80	17	2	78	–
17	292	24	–	–	292
18	161	21	–	161	–
19	107	13	2	105	–
19A	243	23	4	239	–
Total	**1654**	**202**	**16**	**1247**	**391**

[1] Melt volume is tracer-derived melt mass divided by 2.7 t/m^3. Other volumes are estimates based on truck volumes.

Within these uncertainties the agreement for individual blast walls, the total steel plate and total steel are remarkably close. As suggested by Cornish, all blast walls were not necessarily encased in steel plate. In any case, that possibility, together with the failure to locate most of the lead bricks suggest that a rake that had been expected to retrieve brick-sized debris from the dumped soil component of the pit did not succeed in doing so.

4.7.4 REMOVAL OF THE ISV BLOCKS

The investigation into the outcomes from the completed ISV melts that had begun on pit 3 in October 1998 was reactivated in July 1999 with the supervised break-up of the eighth ISV melt (pit 15) following the ISV Contractor-led investigation of pit 17. The confirmation that the steel in pit 15 had not been melted, followed by the discovery of relatively large quantities of plutonium contamination on the base of the steel, contributed to the Regulator raising concerns as to whether the remaining completed melts could be left in their present state within 2 to 3 m of the surface. The Regulator noted that a very satisfactory outcome would be achieved if all the ISV blocks were exhumed and placed in the debris burial trench where they would make up a distinctive marker layer on top of the more highly contaminated debris from the outer pits (letter from J Loy [CEO ARPANSA] to C Perkins [DISR] 30 July 1999).

The Regulator (Loy 1999) pointed out at this stage (30 July 1999) that the inability of ISV to incorporate all debris brought into question the ISV process, particularly when large quantities of contaminated steel were involved. It stated that it would require a clear demonstration that ISV satisfactorily encapsulated the contaminated material in the melt matrix before it could approve the use of ISV in the hybrid option.

Investigations of the outcomes of applying the ISV process to pits 3, 19A, and 4 had demonstrated the nature, texture and hardness of the in situ melts. The pit 17 melt investigation, involving the first complete removal of a melt block, was also indicative of the plant requirements and time required to remove an ISV melt block.

Melt blocks were broken up for removal using one or more tracked excavators with rock breakers. Broken block material was loaded into the 25 tonne Volvo dump trucks that transported the material to the debris burial trench. Class II plant was not required during the removal of the glass/crystalline portion of the ISV product as any contamination was locked within the ISV material.

Table 4.12 ISV staging, melt and steel debris physical details (depth data). Staging depths and probing depth by Geosafe Australia are both assumed to be related to the ISV Contractor's datum at the base of the concrete caps. Data sources are Geosafe including AMEC drawings and PAD surveys where available (see *Attachment 4.8*). Positive values are below datum. All depths in metres. Probed depths are considered indicative only.

Pit no.	Melt no.	Limestone grade(1)	Pit depth			Staging details		ISV melts		
			Historical (Ref. 2)	Probed(1)	Actual	Berm height	Transient suppress	Electrode depth layer(12)	Actual melt	Melt top(9) base
3	2	0.3	2.4	>2.2	2.0–2.1	-1.5	-1.7	2.1	1.6	-0.1
4	3 & 5	0.3	1.8	1.8	2.15	-1.5(3)	-0.55	2.3(2)	1.8	-0.5
6	11	0.15	1.8	2.2	3.1	-1.5	-0.3	2.8(5)	3.1	(1.15)
9	10	0.15	1.8	2.4	3.2	-1.5	-0.3	3.1	3.2	(1.15+)
12	9	0.3	2.4	2.5	1.6–1.8	-1.5	-0.3	3.0	1.6	0.3
13	7	0.3	2.4	–	2.1	-1.05	-0.3	2.8(5)	2.1	0.75
15	8	0.3	1.8	1.8	2.0–2.2	-1.05	-0.3	2.5(5)	1.6–1.8	0.4
17(6)	13	0.15	2.4	2.6	<3.2	-2.5	0.0	2.6(13)	3.2–4.0	0.4
18	12	0.15	2.4	3.0	<3.2	-2.5(8)	0.0	3.8	<3.2	(1.15+)
19	1 & 6	0.3	3.0	–	<3.2	-1.5	-0.53	3.5	3.2	0.75
19A	4	0.0	1.8	–	3.5	-2.16(4)	-0.9	2.8	<2.7(10)	0.5

1 Geosafe Australia P/L 1999 *Assessment of the MARTAC criteria for the treatment by ISV of radioactive pits at Maralinga*, report presented to DPIE August 1999; & AMEC drawings where available, or Geosafe tabulation in Appendix F3. Probed depths are indicative only.

2 Melt 5 electrode depths used.

3 Pit 4, Melts 3 & 5 both used 1.5 m fluxed sand, and pit 19 was restaged with 1.5 m.

4 2.16 m berm height in final melt report of 10 September 1998. Datum is the *top* of the concrete plug for Pit 19A (only).

5 Refer Appendix F, Table F1–6 for source data.

6 Pit 17 melt was terminated by the explosion of 21 March 1999.

7 PAD surveys for steel in pits 3, 4 & 15 are in Appendix F2. GHD survey of top of steel in other pits in Appendix F4. Pits 12 & 17 measured by Geoprojects. Pit 18 GHD string line survey.

8 Pit 18 ISV operation used an electrode depth relative to 2.0 m of berm height, but the fluxed sand was subsequently increased to 2.5 m thick.

9 Spreadsheet in Ref. 41 provided by GHD has suspect values for *top of melt*. Field data values have been used. The values in brackets are considered overestimates, resulting in underestimates of melt thickness & melt cover over the steel for pits 6, 9 & 18.

10 The base of the melt was not exposed.

11 The thickness of melts is an average value, in the vicinity of the steel mass. Some data are from surveys & others are estimated from field measurements.

12 Transient suppression layer was added as additional soil above the berm.

13 The electrodes were suspended well above the melt base.

Table 4.12 ISV staging, melt and steel debris physical details (depth data) continued.

Steel debris mass(7)

High point (approx.)	Base of steel on steel		Melt(11) thickness	Melt above at steel	Comments Referring to steel steel
	High	Low			
1.25	1.6	2.1	1.95	1.35	Surveyed during demolition
1.16	1.8	2.1	2.45	1.7	Surveyed during demolition
2.6	3.1 av.		(2.0)	(1.5)	Melt Top from Spreadsheet(9)
2.6	3.2 av.		(2.0)	(1.4)	Melt Top from Spreadsheet(9)
1.35	1.6 av.		1.3	1.05	Measured during demolition
1.3	2.1 av.		1.35	0.55	Spreadsheet, Ref. 41
1.05	1.6	1.8	1.3	0.65	Surveyed during demolition
3.05*	3.2 av.		3.1	2.65	*Top of unmelted parts of 2 plates reported
3.1	3.2 av.		(2.05)	(1.9)	Melt Top from Spreadsheet(9)
2.3	2.9 av.		2.45	1.55	Spreadsheet, Ref. 41
1.6	3.2 av.		<2.2	<1.1	Surveyed base during demolition

Table 4.13 Key features of the steel agglomerates.

Pit no.	**Extent of melting of the featherbed plates**				**Disposition of steel plates within the agglomerate**		
	Complete (ingot)	Reduced thickness	Protruding edges	Partially melted	Sandwiched	Separated	Dislodged plates
3	No	No	Yes	Yes	Most	Some	Some
4	No	Some	Yes	Yes	Most	Some	None
6	No	Probably	Yes	Yes	All	–	–
9	No	No	Yes	Yes	Some	Some	Some
12	No	Yes – a considerably reduced mass (top surface and sides)			All that remained	Not likely to have survived	–
13	No	No	Yes	Yes	Some	Most	Some
15	No	No	Yes	Yes	All	–	–
17	Near complete	Little on 2 part-plates	All edges were melted	Extensive	2 part-plates remained	–	–
18	Yes	n/a	n/a	n/a	n/a	n/a	n/a
19	No	No	Yes	Yes	Most	Some	None
19A	No	Some structural	Not observed	Not observed	None seen	Most ?	Most

'Some'	1 to less than half.
'Most'	more than half of the featherbed plates exhibit the characteristic described.
1	The calc-silicate block was not observed during its demolition.
n/a	Not applicable

Outcomes from the ISV treatment of the Taranaki pits continued

Table 4.13 Key features of the steel agglomerates continued.

Condition of steel surfaces and edges		**Extent of steel mass encasement in melt**		**Photos in** *Attachment 4.8*
Pitting	Welding	Above steel	Base of steel	
Some	Probably	Fissured block	No (vesicular melt)	3–15 3–20
Some (upper)	Yes	Fissured block	Probably (50–100 mm melt)	4–5 4–7
Probably (upper)	Probably	Probably fissured or jointed(1)	No (discontinuous)	6–1
None	Little	Probably fissured or jointed	No	9–1 9–2
Melting in progress	Yes	Probably fissured or jointed	No (vesicular melt)	12–1
Little	Little	Fissured block	50–150 mm	13–3
Deep, extensive (upper)	Yes	Fissured block	No	15–5 15–15
Melting in progress (advanced)	Melting in progress	Jointed block	Thin (0–20 mm)	17–4 17–5 17–6
n/a	n/a	n/a	n/a	18–1
?	Probably some	Fissured block	Probably	19–1
None seen	None seen	Fissured block	No	19A–5 19A–7

'Some'	1 to less than half.
'Most'	more than half of the featherbed plates exhibit the characteristic described.
1	The calc-silicate block was not observed during its demolition.
n/a	Not applicable

In most cases a large conglomeration of partially melted steel, mainly the heavy steel plates from the featherbed structures, was found at the base of each of the melt blocks. The exceptions were pits 18, in which all the steel was melted and pit 17 in which only a small quantity of recognisable steel plate remained intact (Table 4.13). Once the conglomerates were fully exposed, they were turned over to enable the Health Physics Provider to scan their bases and any pit contents that may have been left in the 'hollow tooth' zone beneath the steel for plutonium. Since it was not known whether untreated plutonium could be exposed, Class II equipment was used for this work. Tables 4.13 and 4.14 indicate the state in which the steel was left at the completion of the ISV processing and the qualitative extent of plutonium contamination that had not been incorporated into the calc-silicate phase of the melts.

The conglomerates were generally too large to handle with the 20 to 25 tonne excavators and most were broken apart prior to loading and disposal in the debris burial trench.

Table 4.11 lists the net quantity of material removed from each pit and the volumes disposed of in both the ISV burial trench and debris burial trench.

The following comments on a pit-by-pit basis refer to statements made by the Project Manager during the melt block removal (*Attachment 4.4*, *Section 11.8.2*).

Pit 3. Pit 3 was an uncontaminated pit and the melt was progressively broken out over a two-year period involving several surveys and investigations. Unmelted and partially melted steel was found at the base of the melt.

Pit 4. Pit 4 was progressively investigated over a two-year period. The base of the melt contained a large partially melted conglomerate. When the conglomerate was turned over, reasonably high contamination levels were found on its underside.

Pit 6. A small conglomerate of melted steel was evident on completion of breaking out and removal of glass. No contamination was found at the base or beneath the steel.

Pit 9. A large steel conglomerate was found at the base of the melt with the steel having undergone melting to various degrees. The estimated mass of steel within the conglomerate was 25 tonnes and it had to be broken up prior to removal. Readings in two places were recorded above that of the melt material and the contamination was found to be transferable.

Pit 12. A small mass of partially melted steel was found in the base of the melt which exhibited no contamination above background.

Pit 13. A conglomerate of steel having experienced various stages of the melt process was found at the base of the melt. Elevated readings were recorded on the material beneath the melt and the turned conglomerate.

The excavator was unable to lift this conglomerate into a truck and as it could not be broken, it was wrapped in plastic, placed on a sled and dragged to the trench behind the excavator.

Pit 15. A conglomerate of generally unmelted steel plate was exposed at the base of the melt. High gamma levels were found on the steel and on the material at the base of the melt. On turning the steel over, what is believed to be a collimator tube was found embedded in the conglomerate, again with high gamma levels. The pit base and conglomerate were the subject of intense investigation prior to removal under red area work restrictions.

Pit 18. The melt glass appeared to be much harder than had been experienced with all other melts and it proved difficult to remove. It was also still very hot towards the centre. A large melted steel conglomerate or ingot was found at the base of the melt. No contaminated material was detected underneath this steel apart from the glass itself.

Pit 19. A neat pile of steel plates partially melted and 1.4 m high was found at the base of the melt. No elevated contamination readings were detected on the steel.

Pit 19A. The distribution of steel within this melt was not typical. A considerable amount of unmelted steel section and plate was found throughout the entire melt including plate in a vertical orientation. A partially melted steel mass was exposed at the base of the melt. It was found to be slightly contaminated.

MARTAC made its own observation on some melts and one of its members assessed in detail some of the melts and made observations on the remainder (*Attachment 4.8*). The following three tables provide a summary of those observations that in places refines and expands the information from the Project Manager reproduced above.

Table 4.14 Radioactivity external to the melts.

Pit no.	**Radioactivity observed at or below the melt base**[1]	
	Base of steel & contacting materials	
	Exposed base of steel	**Melt layer, edge wrap & semi-melt**[2]
4	Not exposed.	Melt layer on base of steel generally 300–1000 cps gamma, 15 000 cps gamma in localised edge wrap (western side). No transferable alpha. *Photo 4.7*
6	Low levels of gamma & transferable alpha on steel & vesicular glass interface	Vesicular melt & partially melted limestone. No edge wrap noted. *Photo 6.2*
9	Generally not visible. Corner of exposed steel with transferable with transferable alpha.	Covered with a thick layer of soil. Melt cover not universal.
12	Not exposed, but gamma low.	–
13	Not exposed.	–
15	5000–15 000 cps gamma on exposed steel. Transferable alpha. *Photo 15.16*	Melt wrap and semi-melt. 5000 cps gamma (SW corner). Semi-melt in contact with steel 15 000 cps gamma (SE corner). No transferable alpha.
19A	Main mass of steel not exposed; probably a few featherbed plates within the melt body.	A small zone of melt between two artefact featherbed plates contained 25 000 Bq/g Pu^{239} (below melt base).

1 Primary source for gamma and alpha values is Reference 35, *Attachment 4.8*.

2 See Table 2.29, *Attachment 4.8* for outcomes indicating the removal and dispersion of Pu contamination.

Outcomes from the ISV treatment of the Taranaki pits continued

Table 4.14 Radioactivity external to the melts continued.

Radioactivity observed at or below the melt base[1]		
Artefacts	**Pitfill soils**	**Pit floor in situ soils**
Black 'bricks' and associated fine-grained powder 17 000 cps gamma. Transferable alpha. *Photo 4.9*	Calcareous soil with up to 32 000 cps gamma. 2500 alpha, transferable. *Photo 4.8*	–
–	–	–
Black powder with 900–15 000 cps gamma (discrete artefact and locally distributed black powder was also adhering to the steel plates). Transferable alpha. *Photo 9.2*		–
–	Gamma emitting particles in soil.	–
2–5000 cps gamma associated with black powder on pedestal soil. Transferable alpha.	Dispersed radioactivity to 10 000 cps gamma, adhering to base of melt. Transferable alpha. *Photo 13.4*	Gamma emitting particles of *high activity* individually 300 – 2000 cps.
8–40 000 cps gamma on 'collimator' tube. Alpha reported on first exposure where gamma was approx. 15 000 cps. *Photo 15.18*	Dispersed gamma and transferable alpha in sand and fused sand in contact and below steel base. Point sources of gamma-emitting particles. *Photo 15.7*	–
Low gamma on exposed steel plates (artefacts). No transferable alpha.	Localised zones of contamination throughout sand mass but not point sources. Appears to be unrelated to diffusion. No transferable alpha noted.	–

1 Primary source for gamma and alpha values is Reference 35, *Attachment 4.8*.

2 See Table 2.29, *Attachment 4.8* for outcomes indicating the removal and dispersion of Pu contamination.

4.7.5 DISCOVERY OF LEAD BENEATH MELTS

High concentrations of lead (and copper) had been noted in the pit floor soils but were insufficient to account for the anticipated 3 tonnes of lead inventory used in each *VB* series firing. In September 1999, following the removal of the ISV block material and the steel masses, the pit floors were searched with a metal detector for the presence of any remnant metallic debris, as part of the pit clearance QA program. Much larger quantities of lead were discovered in the in situ soils and rocks beneath the floor level of each of the pits that had been treated by ISV. It appears that the lead from within the pit debris had become molten during the ISV process and had settled to the base of the melt and then flowed into fissures and cracks in the underlying heat-affected soil and rock.

This raised immediate questions as to whether the lead was contaminated and if so, whether this contamination was of such a level that the lead had to be removed.

Samples of the lead were taken from each pit and sent to the Thermo NUtech Laboratory in Oak Ridge, USA, for testing for radioactive contamination. In order to have a definite basis to proceed with work on these pits once the test results were received, the Regulator provided categories of actions to be taken based on the range into which the test results fell (Table 4.15).

While waiting the results of the tests, various investigations were undertaken to establish the extent of lead migration beneath each melt and horizontally into fissures in the excavated pit walls. At pit 19 it was evident through excavation, visual inspection and metal detection that lead had migrated to 1.5 m below the base of the melt and 2 to 3 m outside the melt base area. The lead had therefore migrated from the pits into in situ geological materials below the pit floors.

The test results of the analysis of 12 samples of the lead gave only one statistically significant result for Am^{241} in the lead from pit 18 of 2.7 Bq/g Am^{241} which was well below the action level defined by the Regulator. No significant plutonium content was identified. A copy of the test results is to be found at *Attachment 4.4*, *Appendix D3.*

Table 4.15 The Regulator's recommendations regarding contamination in lead.

Current pit depth	**Plutonium in lead levels (determined by USA analyses)**		
	$> 10^7$ Bq/kg	10^5 Bq/kg – 10^7 Bq/kg	$< 10^5$ Bq/kg
5 m or more (pits 6, 9, 17, 18, 19, 19A)	Excavate to remove all lead	No action	No action
Less than 5 m (pits 4, 12, 13, 15)	Excavate to 5 m depth and also to remove all lead	Excavate to 5 m depth	No action

On the basis of this result it was acceptable to leave the lead in place and just to have the pits monitored by the Environmental Monitor and then, if this resulted in a clearance for radioactivity being given, to complete the backfilling.

While waiting for the test results, work had continued at the site on the removal of lead from the bases of the pits. All pits, except for pits 4, 12, 13 and 15, were taken down to a depth of at least 5 m below grade with most of the significant pockets of lead removed. Table 4.16 lists the estimated masses of lead associated with each pit (ranging from several hundred kilogram to tonne quantities [*Attachment 4.4*, *Section 11.8.3*]) together with the mass of lead retained in each ISV block (*Attachment 4.8*).

The approximately 9 tonnes of lead beneath the melts and the 11 tonnes retained in the ISV melt blocks accounts for approximately 70% of the anticipated lead inventory. No other significant quantities of lead have been found, although an unknown quantity was discharged through the off-gas system during the ISV processing and dispersed as particulate at the moment of detonation of the *Vixen B* devices.

The lead removed from the 11 pits was buried in the ISV burial trench.

Table 4.16 Estimated masses of lead.

Pit no.	**Lead contaminated soil removed** (m^3)	**Estimated mass of lead beneath the melts** (kg)	**Mass of lead retained in the ISV melt block** (kg)
3	82	450	77
4	60	500*	322
6	254	700	447
9	242	665	2 016
12	112	615*	525
13	40	220*	949
15	52	285*	598
17	140	1 155	1 386
18	384	2 105	2 814
19	212	615	670
19A	440	1 650	806
Total	2 018	8 690	10 610

* Lead remained in the pit floors in pits 4, 12, 13 and 15.

4.7.6 OPERATIONS IN THE DEBRIS BURIAL TRENCH

The contents of the exhumed outer pits and inner pits 16 and 19B were sorted into four categories and transported to the burial trench in separate loads. This was to facilitate the final placement of some of the contaminated material in engineered 'hybrid pods' in the event that the ISV process continued.

The four categories were:

- steel plates—the featherbed plates which had formed the platform on the test structures;
- steel wall sections—the large steel plated wall sections containing the barytes bricks;
- other large debris—including general steel sections and other debris over 100 mm in size including concrete, barytes bricks, lead bricks, cable and general rubbish (e.g. PPE); and
- contaminated soils—all soil and minor debris smaller than 100 mm in size.

Steel plates and walls were stored in a slot at the base of the burial trench in the south-west corner. Debris was stored in a slot in the south-east corner and soil was placed in the northern part of the trench.

The area between the steel/debris slot and the soil storage area was used for truck turning and as a hardstand area for the excavator to handle the material in the slot. This area was approximately 10 m below grade with the base of the slot and soil storage area some 3 m below this 'island'.

As material was deposited in the trench, the excavator would level the steel/debris piles to minimise voids and spread the soil in 200 mm layers and track roll it.

The Health Physics Provider monitored each area on a regular basis to establish data to assess the plutonium content in the trench. In the case of the steel and other debris in the south-west slot, the Health Physics Provider made regular measurements (Am^{241}) as material was added and turned over to obtain an average value for the plutonium concentration (*Attachment 4.10*).

During the exhumation of pit 10, the first of the 20 wall sections, each of 8 tonnes in weight, were exhumed. These sections were all intact and consisted of barytes bricks fully encased in 12 mm plate steel. They measured approximately 2.4 m x 2.0 m and were generally highly active.

The original plan was to open each wall section at the pit and remove all of the barytes bricks. However, it was found that the 36 tonne excavator could safely lift each wall section and consequently they were transported to the burial trench fully intact.

In order to assess the much higher plutonium activity on the blast walls, each section was placed along the west wall of the trench and separately scanned on each face by the Health Physics Provider using a collimated scintillation detector. At the request of MARTAC, a second independent series of measurements was carried out by the Environmental Monitor using the OKA system. Each section was then transported to the eastern edge against the access ramp for storage. Estimates of the quantity of plutonium on the blast walls, on contaminated steel and in the soil and '< 100 mm' debris in the debris burial trench are given in Table 4.17.

Once the soil level in the northern portion of the trench had reached the 10 m level below grade, subsequent layers were placed sloping from the north wall down to the 12 m wide turning area.

The steel and debris areas were covered with fill on an as-required basis to fill voids.

4.7.7 CLEARANCE AND CLOSURE OF EXHUMED PITS

Once the pits were exhumed, they left potentially contaminated empty holes in the ground. Clearance of these areas by the Environmental Monitor required different criteria than those for the rest of the soil-removal area. Because the pits were to be re-filled with clean material, it was not necessary for them to be cleared to criteria as stringent as surrounding surface areas so the same approach was adopted as was used to set the clearance criteria at the TM site (see *Section 3.3.5*). It was considered that a suitable criterion was that the inside surfaces of the pits should not be more contaminated than those areas remaining outside the soil-removal area. This corresponded to dispersed contamination of approximately 20 kBq/m^2 of Am^{241}.

The surface areas surrounding the pit were cleared using the Nissan measurement system. The Nissan was driven as close to the pit as could be achieved safely. This was typically 0.5 to 1.0 m from the edge. The normal particle criteria were used for this scanning. The surface area between the edge of the pit and the limit of the Nissan's scan was monitored with hand-held Rascal/PG-2 equipment. Where possible, the sloping lip down into the pit was also checked to whatever depth could be safely reached. This was, however, frequently not possible.

Table 4.17 Plutonium in the debris trench from pit exhumation program[1].

	Plutonium (g)
Blast walls	53
Steel plates	20
Structural steel	18
'< 100 mm' material	82

[1] Excluding the content within the ISV blocks (see *Section 4.6.10*)

OKA measurements were conducted over each pit with the detector at the height of the surrounding ground. In most cases this was done with the OKA parked near the edge of the pit but for some of the larger pits the OKA was driven into the pit. The aim was to notionally divide the pit volume into approximately cubic spaces with the detector at the top centre of each cube. Hence, in the case of a long narrow pit, the OKA detector would be placed on the centre-line of the pit and spaced along the pit at distances roughly equal to the width or depth of the pit. The highest values observed were at Taranaki pit 2 and corresponded to a uniformly distributed activity of 5.6 kBq/m^2.

The Regulator issued a pit clearance certificate for each pit.

Finally, all exhumed pits at Taranaki, following the removal of the lead, were surveyed with a metal detector, to confirm that the pits had been fully exhumed. Upon receipt of the Environmental Monitor's approval, each pit was backfilled with material stockpiled from the ISV burial trench excavation.

4.7.8 CLOSURE OF THE DEBRIS BURIAL TRENCH

On completion of the exhumation of the outer pits and pits 16 and 19B, the Earthworks Contractor was given approval to commence closure of the burial trench in late July 1999. The approval was given following the Department's decision not to consider the ISV hybrid option further.

The contaminated soil was then levelled over the debris and steel slot. Wall sections were moved as they were exposed during the levelling process. Care was taken to record the final location of each wall section.

A 1 m clean fill layer was placed over the trench contents after the contaminated material had been levelled. Following the decision to break out all ISV melts, the glass from the ISV melts was placed over the clean fill. The steel conglomerates taken from the base of each melt were placed in the southern section of the trench to the eastern side. The clean fill layer was removed to accommodate the steel conglomerates.

The ISV glass was placed in layers approximately 800 mm thick and clean fill introduced between each layer to fill voids and to form a trafficable access surface over the glass for placement of the next layer.

On completion of the final layer of glass and clean fill, a black plastic (HDPE) sheet was placed on 100 mm of sand over the area in plan where wall sections and steel debris had been placed below. This HDPE was covered with sand prior to the introduction of further clean fill to 1 m below grade.

At the 1.0 m below grade level an orange plastic layer was introduced over the entire trench area. Laps were 100 mm and taped. A 100 mm sand layer was placed over the orange plastic prior to completing the clean fill backfill to ground level.

A further 2 m of fill was then placed over the trench with rock introduced on the side slopes to limit erosion. The trench was finally crowned and finished to falls to allow for drainage.

Topsoil was added to the completed trench and the top of the trench ripped in an effort to promote growth of plants. The top of the trench was seeded in early March 2000.

Two settlement plates were placed on top of the trench in January 2000 with reference plates at grade. An initial survey which established that there had been negligible vertical movement was undertaken in late February 2000.

4.7.9 GROUNDWATER MONITORING

Generic codes and guides for the operation of shallow ground radioactive waste disposal sites recommend the monitoring of groundwater. These generic guides are for a mixture of radioactive wastes covering a large number of isotopes and compounds with a corresponding wide range of solubility. No code covers the Maralinga situation of a single contaminant in an insoluble form—plutonium oxide formed at high temperature which is extremely insoluble (ICRP 1985).

Nevertheless, as Maralinga's plutonium was buried in a number of engineered trenches, the issue has arisen for the need or otherwise for measurements to monitor for possible migration of contamination from the trenches to the groundwater below.

The Department is complying with the Regulator's Special Licence Condition 4.6, which states that:

> *... the licensee must establish a program designed to demonstrate that radioactive contamination from the disposal structures has not significantly affected the water table.*

(see *Attachment 5.2*)

MARTAC however advised during its June 2001 meeting that groundwater monitoring is very difficult (and costly) if cross-contamination is to be prevented[22] and not necessary in Maralinga's arid environment for insoluble plutonium oxide and credible groundwater scenarios. Studies at the Nevada Test Site in the USA, which is also located in an arid region, have demonstrated that movement downwards of surface precipitation (rainfall) is extremely slow in the face of a very high evaporation rate which opposes it[23].

At its final meeting in June 2001, MARTAC considered and accepted a discussion paper prepared by one member on this issue, the content of which is summarised in the preceeding paragraph. The discussion paper is reproduced as *Attachment 4.15*.

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[22] An important consideration, since the reporting of a 'false positive' arising from cross-contamination leads to great confusion.

[23] This result is supported by equivalent studies commissioned by the Department for the Woomera region (Kellett et al. 1999) where downward penetration of the wetting front to the watertable is estimated to take hundreds to thousands of years.

4.8 SURVEYS WITH A METAL DETECTOR AND MAGNETOMETER

4.8.1 USE OF A METAL DETECTOR

In June 1999 a Minelab SD 2200D metal detector was purchased for the Project to be used in undertaking surveys to assist in confirming that pits had been fully exhumed and to check for the presence of remaining buried debris or pits including buried cable runs that remained on the Taranaki site.

Following their use in the exhumed pits, the detectors were then used to locate and record on the ground the locations of radially disposed buried cable trenches. Some cable trenches had been found previously during soil stripping operations and were contaminated at some locations. They were removed under red area work controls at the time of exposure. Some identified uncontaminated cable runs were left in place.

4.8.1.1 Discovery of further pits

The metal detector was also used to locate further burial pits, that were not documented but had been noted on an informal contemporary British diagram (see *Chapter 3*). Two large targets (6 m x 6 m) with consistently strong readings over the total surface area indicated the presence of further pits. The two areas were carefully excavated under health physics supervision proving the existence of two pits, both with low level contamination. These pits were adjacent to unused firing pads QA and QE and hence were given the same designation (i.e. pits QA and QE).

A further metal detector survey over other probable pit locations at unused firing pads confirmed the existence of a further five pits. Exploratory excavations revealed that all contained lightly contaminated debris and soil. Pit 19E had a grouted concrete cap. These additional seven pits were numbered 19C, 19D, 19E, PF, QA, QF and QE.

They were all exhumed and their contents taken to the debris burial trenchfor disposal (*Attachment 4.4*, *Section 11.7.1*). These pits were cleared by the Environmental Monitor before being backfilled with clean soil.

Cable trenches were excavated in 22 locations and their cables were later removed and disposed of in the ISV burial trench. Other targets found by the metal detector revealed sand-filled 44 gallon drums on the south-east side of pit 19, 2.5 m deep and similar drums to the south of pit 12. These sand-filled drums were not contaminated but were also removed.

4.8.2 MAGNETOMETER SURVEY

4.8.2.1 Purpose of survey

A magnetic survey was conducted at Taranaki, Wewak and TMs to identify any debris pits or large metal objects remaining buried in defined areas. Removal of any identified items would then provide a high level of confidence that no unlocated debris of significant size would remain at relatively shallow depth at the three main test sites of Taranaki, Wewak and TMs on completion of rehabilitation works.

An advantage of the survey was its link to GPS and its consequent ability to provide an assured 100% ground surface coverage at Taranaki, Wewak and TM sites, as well as its sensitivity in locating ferromagnetic objects.

4.8.2.2 Scope of the survey

The required survey areas covered approximately 160 ha in the three areas. The extent of these surveyed areas is shown in *Appendix 1* of *Attachment 4.6*, the report prepared by the contractor, Geophysical Technology Limited (GTL). It was accepted that while small items buried at depth may not have been detected in this survey, such items stood only a very small chance of being located and retrieved in future and could safely remain in place.

Figure 4.22 Magnetometer survey equipment in use at the TM site.

Specifically the survey was calibrated to detect items of the following typical sizes:

- sheet metal 0.1 m x 0.1 m x 0.0016 m to depth of 0.1 m;
- heavy plate 2.4 m x 1.2 m x 0.05 m to depth of several metres;
- RSJ (sections) 0.3 m long to depth of 2 m; and
- cables 0.5 m long to depth of 2 m.

The magnetometer surveys were carried out over a period of eighteen days, using a quad bike and trailer. The trailer was custom-built, made of aluminium and carried eight magnetic sensors together with GPS equipment.

4.8.2.3 Procedure for target investigation

Once on-site experience had accumulated, it became evident that the magnetic survey equipment was identifying a significant number of locations where subsequent excavations showed there was no metallic object. These were stated by the GTL to be anomalies resulting from the nature of the geological materials at the site. Thus, to some extent, the above procedures were implemented as a matter of expediency. If targets could not be confirmed by the metal detector, they were most likely to be geological anomalies or were too deep for the detector to find, in which case it would be extremely unlikely that they could be readily found in future. Metal detector surveys that were conducted on completion of all magnetometer target investigations confirmed that all metal objects at each location had been removed.

Apart from two small pieces of metal found at a magnetometer target at Taranaki, no contamination was found on any objects identified by the magnetometer survey. This would lead to the conclusion that very few contaminated metal objects remain in the surveyed areas.

The Environmental Monitor issued clearances of the target excavations at Taranaki before they were backfilled.

4.8.2.4 Conclusions

The GPS-located magnetometer survey covered the entire operational areas of the Taranaki, Wewak and TM test site areas. Confirmation of targets was by using the metal detector and confirmatory metal detector surveys following excavation of the targets and of the removal of any metallic objects that were found. This combination proved to be a sensitive and practical way to establish that the sites are free of buried metallic objects of a significant size.

The magnetometer surveys at Taranaki, Wewak and TMs confirmed with a high level of confidence that no debris pits or large metal objects were buried at a relatively shallow depth within the surveyed areas.

Criteria for target investigation

Large targets, greater than 10 m^2

- Confirm target with metal detector.
- If target not confirmed, cease investigation.
- If target confirmed, excavate with loader or excavator under the health physics regime.
- Site clearance, following excavation and removal, by metal detector scan.

Small targets

- Confirm target with metal detector.
- If target not confirmed, cease investigation.
- If target confirmed, excavate by hand in the presence of the Health Physics Manager technician.
- Site clearance, following excavation and removal, by metal detector scan.

4.9 TREATMENT OF INFORMAL PITS

4.9.1 OVERVIEW OF THE INFORMAL DISPOSAL PITS

Prior to commencement of the rehabilitation project, considerable effort had been devoted to locate burial pits that were not officially recorded, but were present in large numbers and in various states of disarray. These were numbered in sequence, with a suffix 'U' and were initially known as the 'un-numbered pits'. In this report they are identified as 'informal pits', but the original numbering convention is retained.

4.9.1.1 Categories of informal pits

Categorisation of informal disposal pits

Category 1 (13 pits) had surfaces in good condition with secure vegetation and the pit was not obvious to the casual observer; these pits presented no hazard and received no treatment.

Category 2 (60 pits) presented no radiological or toxic hazard, and received cost-effective minimum treatment (e.g. removal of debris protruding above ground, crushing, compaction, recontouring, and revegetation). Debris painted yellow, that might have come from destruction of glove boxes, was checked for contamination before burial. Debris containing traces of plutonium was removed from four of these pits for separate burial.

Category 3 (one pit) where radioactive or hazardous material discovered required exhumation and the contents buried elsewhere, followed by back-filling, recontouring and revegetation of the pit.

Pits in these three categories are listed in Tables 4.18 to 4.20.

The informal pits listed in Table 4.20 together with the related MARTAC recommendation were in the main incorporated into the scope of works for the Program Manager. Fourteen informal pits were not incorporated. These are separately considered in *Attachment 4.13* .

Table 4.18 Informal debris pits where plutonium was detected.

Category	Pit no.	Description	Radioactive content	Treatment recommended by MARTAC
3	2U	Contaminated bitumen wrapped in plastic	60 micrograms of Pu^{239}	Exhumation and reburial at TM trench
2	23U	Some contaminated debris was placed in a separate area marked with a star picket for recovery	90 micrograms of Pu^{239}, traces of Co^{60}, Cs^{137}	Contamination removed and reburied in the ISV burial trench
Treated as Category 2	28U	Twisted steel plate contaminated with Pu^{239}, together with contaminated soil underneath the plate.	50 micrograms of Pu^{239} (on plate)	Contaminated steel and soil subsequently removed to TM trench
Treated as Category 2	32U	Pu contamination in an industrial vacuum cleaner	7 micrograms of Pu^{239}	Contamination not significant intrusion Not re-found after initial reburial
Treated as Category 2	45U	Contamination of underneath of a trailer with Pu^{239}	Approximately one mg of Pu^{239}	Contaminated trailer removed and buried at Wewak

Table 4.19 Informal debris pits where traces of activity other than plutonium were detected.

Category	Pit no.	Description	Radioactive content	Treatment recommended by MARTAC
Treated as Category 2	33U	Radium dial gauge buried separately for retrieval	1200 cps (Eberline detector)	Dial gauge not located
Treated as Category 2	37U	One piece of corroded uranium metal	Not measured	Re-contoured, revegetated?
Treated as Category 1	38U	Sand with uranium oxide scattered on surface	Not measured	No action
Treated as Category 1	40U	Area lightly contaminated, probably with uranium	200 cps gamma	No action

Table 4.20 Summary of informal pits by category.

Category	Pit no.	Assessment by MARTAC	Treatment recommended by MARTAC
1	3U, 38U, 39U, 40U, 57U, 58U, 74U, 75U, 76U, 77U, 78U, 81U, 82U	Surfaces of these pits were in good condition, vegetation was secure, and the pits were not obvious to the casual observer. The pits present no hazard	No treatment required
2	1U, 7U, 8U, 9U, 10U, 11U, 12U, 13U, 15U, 16U, 17U, 18U, 20U, 21U, 22U, 23U, 24U, 25U, 26U, 28U, 29U 32U, 33U, 34U, 35U, 37U, 41U, 42U, 43U, 44U, 45U, 47U, 48U, 49U, 51U, 52U, 54U, 55U, 56U, 59U, 60U 61U, 62U, 63U, 64U, 65U, 66U, 67U, 68U, 69U, 70U, 71U, 72U, 73U, 80U, 83U, 84U, 85U, 86U, 88U	Pits in this wide-ranging category do not present either a radiological or a toxic hazard. However, particular attention was given to pits in which such items as yellow painted ducting or glove boxes were apparent	The most cost-effective of the following treatments were implemented as appropriate to each pit: · checking any yellow painted surfaces to confirm there was no significant radioactivity · minor importation of soil followed by recontouring and revegetating · removal of surface rubbish for burial elsewhere, crushing of other surface debris · compacting of the pit contents to below grade · covering, recontouring and revegetating
3	2U	Plutonium contamination on bitumen	Exhumation and reburial, pit back-filled, recontoured and revegetated.

1 Pit 79U is recorded to be at Emu, but was not located.

2 Pit 87U was excavated as part of the Taranaki trench works. Contained electrical fittings.

3 Pits 4U, 5U, 6U, 14U, 19U, 27U, 30U, 31U, 36U, 46U, 50U, 53U were mounds but not disposal pits.

4.9.2 INFORMAL PITS WHERE PLUTONIUM WAS DETECTED

4.9.2.1 Pit 2U (Category 3)

This pit was uncapped, and was found to be four times greater in area than formerly believed. Investigations by the TAG had discovered 60 micrograms of Pu^{239} on bitumen wrapped in plastic sheeting in shallow burial. Water was sprayed onto the pit and allowed to soak in before pit contents were removed to the TM trench. The pit was totally exhumed over a nine-day period.

4.9.2.2 Pit 23U

Debris backhoed from pit 23U contained a whole range of contaminated articles including:

- a flywheel;
- one con-rod;
- a steel section (possibly a chassis member); and
- other twisted pieces of metal.

A light alloy piece was contaminated with an estimated 215 kBq of Pu^{239}, together with Co^{60} and Cs^{137}. Prior to the commencement of the rehabilitation works, these materials were placed in separate shallow burial nearby, and marked with a star picket for subsequent removal and burial. The flywheel from pit 23U was subsequently removed and placed in the ISV burial trench (*Attachment 4.4*, *Section 9.6.3.3*). A following survey with a metal detector revealed a con-rod, an aluminium cone and assorted pieces of metal, one of which was approximately 3 m long. This debris was lightly contaminated, and the debris was bagged and deposited in the ISV burial trench. A final exhaustive survey by metal detector did not reveal any further metallic debris between the pit 23U marker sign and pit 23U (*Attachment 4.4*, *Section 9.6.3.3*).

4.9.2.3 Pit 28U

This pit, located at Foremans Folly, was not found to contain radioactivity. However, a steel plate contaminated with 0.2 mg of Pu^{239} had been adventitiously discovered approximately 5 cm below the surface approximately 4 m distant from pit 28U. Soil beneath the plate contained corrosion products containing 0.05 mg of Pu^{239}. This contamination was removed under health physics supervision and placed in the TM soil burial trench (*Attachment 4.4*, *Section 9.6.3.4*).

4.9.2.4 Pit 32U

Debris backhoed from pit 32 on the XA Road contained an industrial vacuum cleaner contaminated with 7 mg of Pu^{239}, subsequently reburied by the TAG-commissioned back-hoe group for eventual intended retrieval and final disposal.

Despite a search, the reburial site was not located. This quantity of plutonium was approximately one-thousandth of the 10 mg necessary to breach the one-exposure acceptable risk limit implicit in the TAG report. Accordingly, no further action was taken to locate the vacuum cleaner.

4.9.2.5 Pit 45U

A trailer contaminated with approximately 1 mg of Pu^{239} on its underside was removed from pit 45U to burial in the trench at Wewak.

4.9.3 ACTINIUM BURIAL SITES

Seven point four kilograms of natural or depleted uranium and 5.6 MBq of Ac^{227} were used in five trials at Wewak. Ac^{227} was discovered during the determination of the soil removal boundary in seven shallow unrecorded burial sites at Wewak. The actinium was exhumed and buried in the Wewak disposal trench.

4.9.4 CONTAMINATED STEEL AT TARANAKI

A contaminated steel girder was discovered buried in soil on the northern side of the former Taranaki fence after contaminated soil had been cleared from the area. It was removed to the soil burial trench.

4.10 THE HEALTH PHYSICS FACILITY SITE

4.10.1 DETECTION AND REMOVAL OF CONTAMINATION

During the scanning of the 'yellow' roads running from Taranaki to the village, some contamination was located near the site of the old British health physics site, HP2 (*Attachment 4.3*). The area nearby had several large mounds of dirt in which debris was evident. Further investigation revealed gigabecquerel (gram) quantities of plutonium associated with a pile of bitumen on the site, together with other particles in a gravelled area. Two small pits were located nearby and British information (letter with attached drawing [PFE/RF/294/2] from G Stott to J Harries, 17 August 1999) indicated that they had originally been drainage pits used for decontamination of vehicles.

Following the removal of the contaminated bitumen and other materials, the pits were excavated and the area thoroughly scanned with the Nissan measurement system. Some 28 measurements, covering the soil-removal area, were also made with the HPGe detector.

The Nissan measurement system was also used to scan the area opposite HP2 across the bitumen road. This scan showed that no contamination was present in this area.

All detected particles above 50 kBq Am^{241} (corresponding to approximately 0.02 mg of plutonium) were removed; but a large number of low-activity particles remained. Because this area is outside of the restricted-access area surrounding Taranaki, the whole area was covered with at least 10 cm of clean fill, on MARTAC's recommendation.

4.10.2 INVESTIGATION OF OTHER POSSIBLE CONTAMINATED LOCATIONS

Following the discovery of contamination at HP2, the EG&G aerial survey data were re-examined to see whether any contamination was apparent in other areas. While the final contour plots provided by EG&G did not show any indication of the HP2 contamination, the raw data and early contour plots produced at the time of the survey showed an anomaly at the precise location of HP2 which corresponded to approximately the amount of plutonium found.

The aerial survey results were then examined for other anomalies and many were found. It was apparent that the equipment used during the aerial survey frequently produced single isolated data points very much higher than those in the surrounding area and this mimicked exactly that observed at HP2. Several of these sites were investigated by visual examination, measurements with the OKA measurement system and a partial (30–50% coverage) scan with the Nissan measurement system over areas within 100 m of the nominal position indicated on the aerial survey. No contamination was found at any of these other sites. The sites investigated were essentially to the south of the Taranaki restricted land-use zone.

4.11 CONFIRMATION OF THE OUTER PERIMETER FENCE LINE

4.11.1 LOCATION OF THE OUTER BOUNDARY

For unrestricted occupation, a boundary 'fence line' was established, where full-time occupancy would not lead to annual dose commitments to the critical group above 5 mSv. At Taranaki this corresponds to a surface activity of approximately 3 kBq/m^2 and, because campsites are moved frequently, averaging over 3 km^2 was considered appropriate.

4.11.2 TAG AERIAL SURVEY

On the basis of the TAG aerial survey, a boundary was placed along West Street, Tenth Avenue, Right Street and a new diagonal track to the south-east. The enclosed area is approximately 412 km^2. The whole enclosed area was covered in the EG&G aerial survey. Most of the area within the boundary shows less than 1.4 kBq/m^2 of Am^{241}. The location of the fence line is shown in Figure 3.6.

4.11.3 CONFIRMATORY MEASUREMENTS

Given the plume structure of the contamination and generally monotonically decreasing trend shown by the EG&G survey, it was considered sufficient, with one exception, to measure the 3 km^2 average levels of Am^{241} along the boundary. However, the aerial survey did not cover the extreme westerly edge of the north-west plume beyond West Street, so this was given additional attention.

Ground-based measurements with the OKA (*Attachment 4.3*) were used to make confirmatory measurements at an average spacing of approximately 250 m around the northern half of the boundary. The southern portion, where the EG&G survey shows essentially no plumes, was measured at larger spacings. Measurements were made at spacings of 100 m where they, or the aerial survey, show the proximity of a plume. At other places, spacings of 500 m were used.

The grading of the boundary road to allow the placement of the markers was expected to decrease the local levels of Am^{241} on the road. Such a decrease is apparent if the measurements made along West Street in previous years are compared with those made during 1998. This change may be due to other factors such as long-term drifts in detector response functions, changes in vegetation and its effect on gamma-ray fluxes at the detector, or to atypical weathering and movement of the Am^{241} deposit due to recent very heavy rainfall. To ascertain the importance of such changes, measurements were made 100 m either side of West Street. These results show a general 25 to 45% increase in level of Am^{241} compared with the values found on the road.

To derive a better estimate of the average over 3 km^2, additional off-road measurements were made wherever a plume crosses any part of the boundary.

The minimum detectable level for these measurements was approximately 0.6 kBq/m^2 of Am^{241} and depended on the local background and acquisition duration. A circular area of 3 km^2 has a diameter of approximately 2 km, so an average along 2 km of road was used to approximate the area average.

4.11.4 MEASUREMENTS WEST OF WEST STREET

On the EG&G survey east of West Street, the north-west plume is shown to have split into two portions. The southern extent of this meets West Street very close to its intersection with Fifth Avenue. The aerial survey was extended beyond West Street but its diagonal southern boundary coincided very closely with the edge of the plume. It was therefore uncertain whether any activity was present further south. As is evident on the north-east plume, it is possible for a late wind change to have split the plume into two parts at a considerable distance from ground zero. If this had happened after the activity had passed West Street, the aerial survey would not necessarily have observed this.

To explore this possibility, several north–south lines of measurements were made at distances of 0.5 km, 1.0 km, 2.2 km, 3.0 km, 3.2 km and 4.2 km west of West Street. These measurements covered the region up to 2 km south of the edge of the aerial survey.

The measurements confirmed the general plume structure as shown by the aerial survey and found no activity south of the area covered by the aerial survey.

4.11.5 SUMMARY

The ground-based measurements made during 1998, taken with the EG&G aerial survey, show with a high degree of confidence that no area outside the region defined by the boundary markers at Taranaki exceeds the MARTAC criterion of 3 kBq/m^2 of Am^{241} averaged over 3 km^2. The highest local value encountered was 3.9 kBq/m^2 and the highest average over 3 km^2 was 2.5 kBq/m^2.

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APPENDICES

4.1 Earthworks

ATTACHMENTS

4.1 Reports on nuclear engineering design

4.2 Sample lot clearance certificate

4.3.1 Maralinga Rehabilitation Project radiological field monitoring at Taranaki

4.3.2 Maralinga Rehabilitation Project radiological field monitoring at TMs and Wewak

4.4 Project Manager's report

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4.10 Pu inventory in debris burial trench

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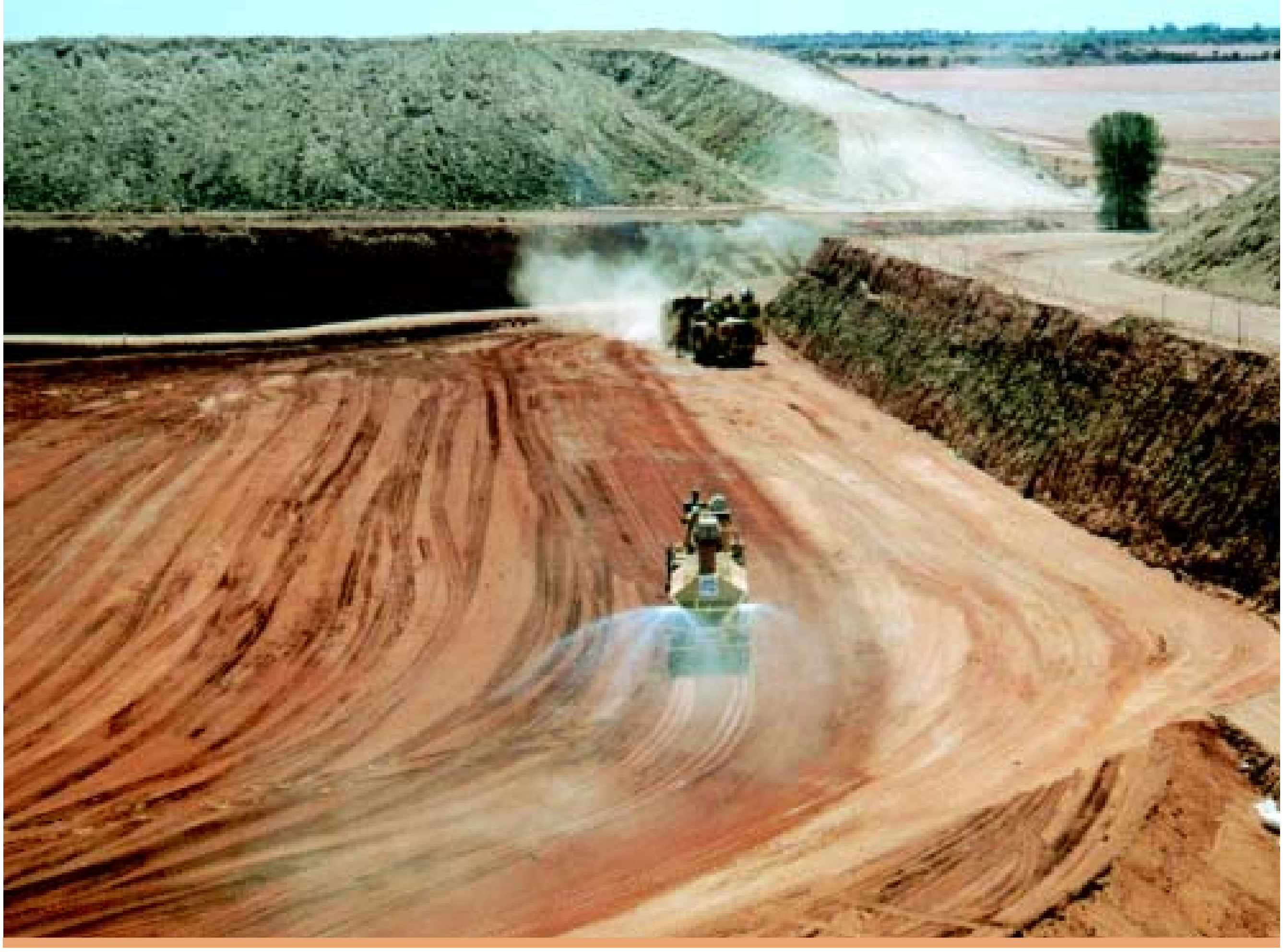
4.14 Minutes of Lessons Learnt Meeting of 13 June 1997

4.15 Factors for consideration re groundwater monitoring for plutonium at Maralinga

4.16 An assessment of the risks associated with the Maralinga in situ vitrification process



CHAPTER 5

HEALTH AND SAFETY

5.1 OCCUPATIONAL HEALTH AND SAFETY

5.1.1 INTRODUCTION

The TAG report (see *Attachment 1.3*) stressed that any on-site remedial works would present risks to workers employed. They noted, for example, that during the radiological clean-up of Enewetak by the US, six workers had been killed and 63 had suffered injuries significant enough to be recordable, arising from occupational or recreational causes that were unrelated to the radiological hazards at the site. When carrying out site rehabilitation to address effectively the theoretical risks to a local population, real risks are potentially faced by the workers who carry out the work.

In recognition of this potential, the Project was designed with not only the desired end-state outcomes in mind but also, and of equal importance, overall OHS at the site.

As the hazards associated with working in a radioactively contaminated environment were considered to be potentially of great significance, the OHS program had to be responsive to radiation issues as well.

Accordingly, a considerable portion of the overall project budget was allocated to the development and provision of both radiological and general health and safety systems.

This chapter gives an overview and critique of the systems that were implemented at the site during the Project.

5.1.2 REGULATORY ENVIRONMENT

The PWC report (1995) relating to the then proposed Project, stated (p. 37)
… Occupational health and safety (OH&S) is the responsibility of every employer and employee.

This responsibility is further enforced by State and Commonwealth legislation. At the Commonwealth level, the *Occupational Health and Safety (Commonwealth Employment) Act 1991* (Cwlth) imposes a range of duties on Commonwealth Departments to protect the health and safety of their employees, contractors and third parties. At the State level, the South Australian *Occupational Health, Safety and Welfare Act 1986* (SA) imposes similar duties on private sector employers working in South Australia.

Given both this complex legal environment and an objective of ensuring worker safety during the Project, an integrated site-wide safety system was developed and implemented.

5.1.3 OHS SAFETY SYSTEM

An OH&S Strategic Plan was prepared (*Attachment 4.4*, *Section 17.7*). It set out the general safety framework implemented at the site and provided guidance to each contractor for their establishment of their own OHS plan tailored to the rehabilitation works. It included measures to guard against radiation hazards in addition to conventional hazards.

The site-wide safety system implemented at the site contained a number of components including:

- OHS Strategic Plan and contractors' OHS plans;
- contract requirements and policy;
- hazard identification, risk assessment and control;
- permits, procedures and other documentation;
- induction and training;
- monitoring and assessment of doses to workers;
- planning to deal with emergencies, accidents and incidents;
- record keeping; and
- system audits.

A site safety committee with management and employee representatives operated at Maralinga. All primary contractors at the site participated on the Site Safety Committee, including the Environmental Monitor when its visits to site coincided with the timing of the meetings. These meetings were used to monitor the level of overall site safety, to coordinate actions to improve site safety and to investigate any safety incidents.

The primary responsibility for investigation of non-radiological incidents at the site rested with the appropriate contractor/subcontractor with oversight from the Project Manager and the Department.

Of key importance, from both radiological and general health and safety perspectives, was the approach taken at the site to implement what is generally known in OHS as the 'control hierarchy'. Most notably, precedence was given to the use of engineering controls over the use of lower level controls (e.g. training and procedural controls) to manage risks at the site.

5.1.4 SITE SECURITY

The Department maintained tight control of access to Section 400. The security of the site was ensured through the implementation of a contract for services between the Department and the APS. Access to the site was strictly controlled and monitored by APS. A minimum of two APS staff were maintained at the site at all times.

Entry was only permitted to visitors and Project workers who had authorisation by the Department and only persons with a valid reason for access connected with their employment were allowed entry. Occasional visitors (e.g. local police, Parliamentarians, members of the MCG and members of the Maralinga Tjarutja community) could be authorised to visit the site, but while at the site, their movements were supervised by Project management staff and red area access (see below) was undertaken only with appropriately qualified escorts.

The *Maralinga Rehabilitation Project Site Arrival and Departure Procedure* outlines the basis for ensuring that only approved persons entered the site, that they attended appropriate induction training, and that records were made of their arrivals and departures.

Entry to the forward area was limited to personnel undertaking authorised work duties and to approved visitors. Controlled (red) and supervised (blue) areas were defined in accordance with the ARL policy document (ARL 1994, see *Section 5.2.1* and *Attachment 5.1*) and working rules regarding access, and the level of required health physics support were established. Areas not requiring any radiological control were categorised as ‘white’. Employees were classified as ‘designated’ if they were to work under conditions where their annual effective dose might exceed 1 mSv or ‘non-designated’ otherwise. In practice, their designation generally coincided with the areas where they regularly worked (the former in red areas) and a rigorous system of access control through colour-coded passes was implemented. Designated employees were subject to a dosimetry regime, through regular lung monitoring supported by urine sampling, particularly in the case of fitters, who serviced the vehicles and who were therefore subject to a higher risk of an intake of plutonium. Permanent records of assessed doses were required to be maintained.

Approval as a ‘designated employee’ was subject to ‘acceptable’ medical examination results and to lung monitor measurements, and culminated in the issue of a personalised pass. Depending upon their need to access different areas, workers were issued with either red or blue colour-coded passes. Each pass was bar-coded and electronically scanned as they moved in and out of red and blue areas. This served both to check training and authorisation status and to provide a record of all entries and exits.

Project experience gained over time with the security arrangements demonstrated that they were compatible with, and did not diminish, the safety of site and other personnel, and that they did not interfere with the emergency arrangements for the site.

5.1.5 EMERGENCY PLANNING

Emergency response, evacuation and first aid were controlled in accordance with the *Site Management Plan* and the *OH&S Strategic Plan* (*Attachment 4.4*, *Chapter 17*).

Emergency planning was based on an initial review of hazards, some subsequent work-specific analyses, and site experience gained over the course of the Project. This led to flexible and extendable emergency arrangements that addressed foreseeable emergencies at the site and ensured that appropriately trained personnel and equipment were available at all times to deal with emergencies, accidents and incidents.

All contractors and subcontractors were provided with copies of the emergency response procedures that applied at the site, and adequate emergency response facilities and equipment were maintained in a state of readiness for use in foreseeable emergencies, accidents or incidents with the potential for causing injury and/or damage.

Figure 5.1 Fitters decontaminating caterpillar tracks.

5.1.6 RECORD KEEPING

Generally, all Project records, except those relating to the Environmental Monitor, were coordinated by the Project Manager for eventual transfer to the Department for archiving. Records related to health physics for all individuals visiting or working at the site included:

- attendance at induction course;
- site arrival/departure records;
- site movement records;
- site visit authorisation; and
- training received.

For designated workers, the following additional records were to be kept:

- radiological incidents;
- medical fitness test;
- lung monitor attendance and results;
- urine samples collected and analysed; and
- personal air sampling.

Personnel files were generated for all designated workers, gathering together the information and paperwork relating to their work on site.

Operational health physics records, including personal air sampling results, bioassay status and analyses, radiological training and environmental monitoring results were also kept by the Health Physics Provider. These records were transferred to the Department at the end of the Project.

5.2 RADIOLOGICAL SAFETY

5.2.1 REGULATORY ENVIRONMENT

The rehabilitation of a contaminated nuclear test site is an example of an intervention to address an unacceptable potential chronic exposure situation. The intervention process itself is also a practice and is therefore subject to the normal regulatory requirements for occupational and public radiation protection.

Accordingly, following a recommendation to the Minister from MARTAC and by agreement between the then Minister of Primary Industries and Energy and then Minister of Health and Community Services, the Australian Radiation Laboratory (ARL) was appointed from 1 July 1994 as the Health Physics Auditor to ensure that occupational and public radiation exposures would meet Australian and international radiation protection standards. A guidance document (ARL 1994, see *Attachment 5.1*) was developed by the laboratory (*Policy on Radiation Protection Practices in the Rehabilitation of Former Nuclear Weapons Test Sites at Maralinga*) and made available to the Project Manager in draft form prior to its formal publication in February 1995. This policy drew heavily on a large body of doctrine and experience developed in Australia for the regulatory oversight of the uranium mining and mineral sands industries. It was updated to include the most recent national and international recommended standards (ICRP 1990, IAEA 1996). Subsequently, the document was revised and reissued in July 1997, largely to update its terminology, to bring it into conformity with that employed in the field.

The nature of the rehabilitation project shares many features with the mining of radioactive ores and the principal exposure pathway for both is the inhalation of alpha emitters attached to fine aerosol particles. Thus, the policy document is quite similar in its structure and requirements to the Australian *Code of Practice for the Radiation Protection of Workers in the Mining and Milling of Radioactive Ores (1987).*

The policy sets out the respective responsibilities of the Project Manager, supervisors and employees and defines the relationship between the auditor/regulator and the Project Manager, particularly during the development of health physics procedures. It identifies two categories of employee ('designated' and 'non-designated'), who are distinguished on the basis of whether they are likely or unlikely to receive effective doses in excess of the dose limit for members of the public. It draws attention to other national codes and standards covering radioactive waste, transport and the basic radiation protection standards promulgated by the National Health and Medical Research Council and the National Occupational Health and Safety Commission.
It also specifies the methodologies for dose assessment, which in this case were expected to be dominated by the inhalation of respirable plutonium, americium and uranium isotopes.

It was expected that a well-conceived radiation protection approach would ensure that occupational exposures would be extremely low, and far below the occupational dose limit of 20 mSv/yr. The auditor, after consultation and agreement with the Project Manager, therefore specified an occupational dose constraint of 2 mSv/yr.

In addition to its audit role, the contract between ARL and the Department covered other activities including the determination of soil removal boundaries, the final certification that soil clearance criteria had been achieved and the provision of sensitive lung monitoring services for all designated employees.

Prior to 1999, the Commonwealth Government lacked legislation that would enable it to license the Project as a radiation practice and to provide regulatory oversight in the normal way. The role of the Health Physics Auditor was therefore very important, since it served the function of de facto regulator with a responsibility to ensure that radiological protection was maintained to a high standard. This was achieved by auditing operations in the field against the requirements of the ARL policy document, as expressed in the health physics procedures. The Health Physics Auditor in fact formally approved all health physics procedures and had the opportunity to review all RWPs and MOWSs that subsequently followed.

In practice, dialogue continued between the Health Physics Manager and the Health Physics Auditor as these documents were being developed and there was never any need for the Auditor to disallow or seek amendment to any final procedure, RWP or MOWS.

From time to time, auditors from ARL made visits to the site to conduct impromptu inspections of field operations, particularly in the months following the completion of the soil removal program when plant was being decontaminated and cleared for removal from the site. Formal audit reports were prepared and filed at the laboratory and copies were provided to the Health Physics Manager and to the Department.

In February 1999, the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cwlth) was proclaimed, and a new Commonwealth regulatory body was formed to regulate the Commonwealth's own radiation practices. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), which absorbed the ARL, came into being, and since 5 August 1999, the work at Maralinga was carried out under the regulatory authority of ARPANSA. ARPANSA continued ARL's involvement at Maralinga with the Regulatory Branch of ARPANSA (the Regulator) providing regulatory services and the Environmental and Radiation Health Branch of ARPANSA (the Environmental Monitor) providing radiation monitoring services. ARPANSA formally issued a facility licence on 30 October 2000, which essentially adopted the concepts and requirements previously developed by ARL in its audit role, in a seamless way. A copy of the licence, together with its licence conditions, is provided as *Attachment 5.2*[24]. In practice, the transition to formal regulation by ARPANSA was straightforward, and similar audit and approval processes to those formerly exercised by ARL were continued.

5.2.2 HEALTH PHYSICS SYSTEM

The control and management of radiation protection at Maralinga was the responsibility of the Project Manager who in turn appointed AEA Technology as its specialist subconsultant to fulfil the role of Health Physics Manager, as defined in the ARL policy document, to provide specialist health physics advice and to oversee and monitor the provision of health physics services. These services were provided by the Health Physics Provider, CH2M Hill, who was appointed by the Project Manager as the contractor for this purpose.

In the period 1994 to 1996 much preliminary field work was undertaken, to construct the village infrastructure and to define the characteristics of the test site (e.g. detailed determination of soil removal boundaries, geophysical location of Taranaki burial pits, investigation of general disposal [non-radioactive] burial pits, ISV trials, geochemical characteristics of soils at Taranaki and the consequent selection of burial trench sites). For this phase of the Project, health physics services were provided by ANSTO, in accordance with the general requirements of the ARL radiation protection policy document.

5.2.3 THE HEALTH PHYSICS PROGRAM

The objectives of the health physics regime, operating in compliance with the ARL policy document, were to:

- provide a conservative envelope of operations;
- conform to international standard practice; and
- complete the rehabilitation of Maralinga within the end-state criteria, as required by the Regulator.

However, it was recognised that health physics controls should not be unduly restrictive on operations and that an effective and efficient health physics service was required to support rather than hinder operations (*Attachment 4.4*, *Chapter 13*).

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[24] The Facility Licence , issued 30 October 2000, contained special conditions, including a requirement to implement a watertable monitoring program. All conditions have subsequently been met. The first watertable monitoring results (December 2001) confirmed nil contamination.

The radiation protection regime developed by the Project Manager adopted a philosophy that best reasonably practicable engineered measures would be adopted in preference to the use of personal protective equipment. Thus, for example, the plant used within red areas (Class II vehicles, see Figure 5.2) was modified so that the cabin ventilation and positive pressure achieved absolute particle filtration (*Attachment 4.4*, *Section 8.3*).

Control of all work involving a radiological hazard was exercised through the development of written health physics procedures and unambiguous workplace instructions. Further detail is provided in *Section 5.2.4* below.

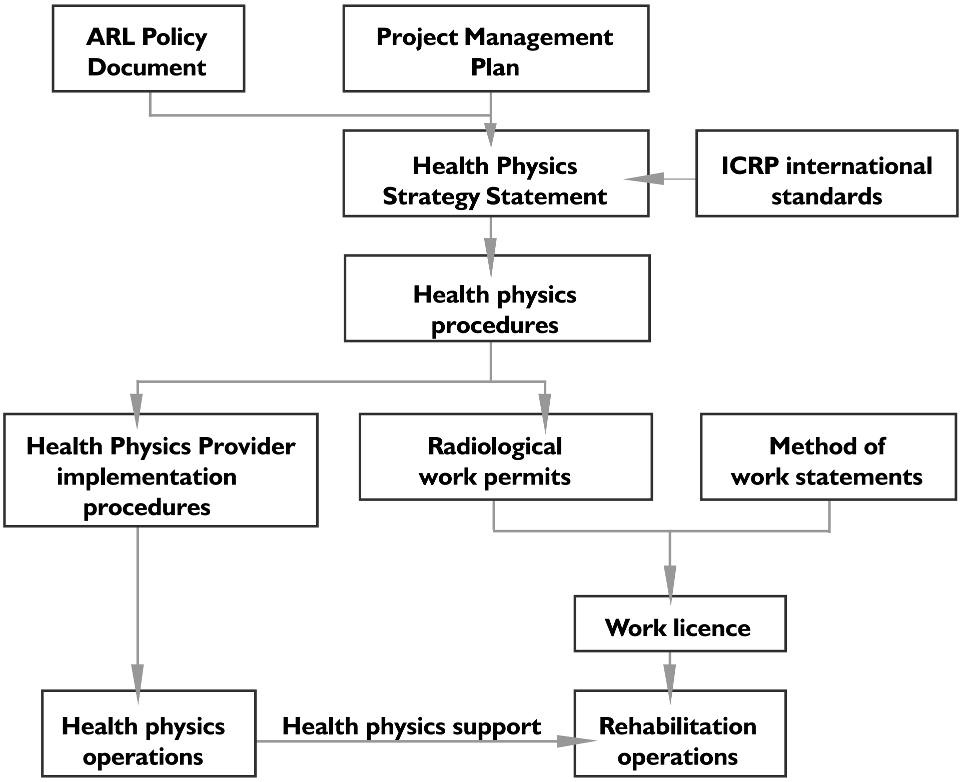
5.2.4 PROCEDURES AND PRACTICES

The strategy developed by the Project Manager, embodied in its *Health Physics Strategy Statement*, consists of a hierarchy of procedures and lower level derived documents, designed to implement the requirements of the ARL policy document in a disciplined manner appropriate to formal audit.

The hierarchy of documentation, taken from the Health Physics Provider's report (*Attachment 4.7*, *Chapter 14*) is illustrated in Figure 5.3.

Figure 5.2 Landcruisers modified for Class II work.

Figure 5.3 Hierarchy of documentation.



Health physics procedures, developed by the Health Physics Manager on behalf of the Project Manager, state the general health physics requirements to be implemented for all work. A listing of health physics procedures, all of which were approved by the Regulator is presented in *Attachment 5.3*.

The Health Physics Provider in turn developed implementation procedures that satisfied the requirements of the health physics procedures and described health physics operations. Contractors, such as the Earthworks Contractor, developed MOWSs that had to be acceptable to the Project Manager for all operations involving a radiological hazard and these provided the basis whereby the Project Manager issued a RWP. These were also sighted by the Health Physics Auditor before they came into use. Radiological considerations were then integrated into overall planning requirements as part of general program management. Listings of implementation procedures and RWPs may be found in the report of the Health Physics Provider (*Attachment 4.7*, *Chapter 14*).

5.2.5 BIOASSAY PROGRAM

5.2.5.1 Lung monitoring

As part of its contract with the Department, the Environmental Monitor provided two lung monitoring facilities, one at Maralinga (see Figure 5.4, Maralinga lung monitors) and a second more sensitive system in the laboratory in Melbourne (*Attachment 4.4*, *Appendix F9*).

The Melbourne-based system had a lower limit of detection of 7 Bq of Am^{241}, which translates to 30 to 60 Bq of Pu^{239}, depending on the location at Maralinga where the intake occurred, and corresponds to a (worst case) effective dose of 10 to 20 mSv. This makes use of the fact that approximately 5% of an intake of respirable plutonium remains in the lung 12 months after inhalation (Paulka 1996). The lung monitoring program was to provide an annual assessment of effective dose for designated employees, and an assessment at termination of employment, with sufficient sensitivity to demonstrate compliance with the dose limit.

The Maralinga-based system had a lesser sensitivity with a lower limit of detection of 27 Bq, and designated workers were monitored before leaving site at the end of their twenty-day work cycle. The lesser sensitivity was thus offset by the fact that a higher proportion of plutonium would still be present at the time of measurement and it is estimated that the lower limit of detection again corresponds to an effective dose of 10 to 20 mSv. Its purpose was to catch any occurrence of an inhalation incident promptly, so that corrective action could be taken immediately. Should an intake be detected in the field, the subject would be sent to Melbourne for a more sensitive measurement that would be supported by parallel urine analysis.

During the life of the Project there were no cases of plutonium intake detected either in the field or at the laboratory-based facility (*Attachment 4.4*, *Appendix F9*).

5.2.5.2 Urine analyses

As an independent alternative to the lung monitoring program, a regime was instituted at the beginning of the cleanup to collect urine from all designated workers at the end of each work cycle. This was desired because of anticipated differences in plutonium solubility at the different sites. The sample that was collected typically included voiding for a 24-hour period, approximately 2 L of urine (see *Attachment 4.4*, *Appendix F7*).

Although the primary radionuclide of concern for the cleanup was Pu^{239}, an alpha emitter, there was one site (Kuli) where Uranium (U^{238}), a beta plus weak gamma emitter, was the only radionuclide present. Because of different radiological, physical and chemical characteristics of uranium and plutonium, separate and distinct processes are required to analyse for each in the laboratory.

Over time, several samples from each worker were forwarded to a laboratory in the US (Thermo NUtech) to be analysed for plutonium using alpha spectrometry. This program targeted, in particular, vehicle maintenance workers (fitters), who as a group had the greatest potential for the inhalation of particulate contamination.

Later in the program, because of inadequate sensitivity available for some samples (see *Attachment 4.4*, *Appendix F5*), samples were sent to Harwell Scientifics laboratory in the UK. This analysis was also by alpha spectrometry.

Figure 5.4 Maralinga lung monitor.

To further investigate the sensitivity aspect of urine sample analysis, selected urine samples were sent to the University of Utah, Salt Lake City, Utah USA, for analysis using fission track analysis, which is considerably more sensitive for measuring plutonium alpha particles than the alpha spectrometry method.

The dose investigation of the minor uranium exposure incident discussed below also required urine samples to be sent overseas for analysis. This dose investigation was assigned to AEAT in the UK, later acquired by RWE NUKEM Limited, of the UK. AEAT contracted the services of Benchmark Environmental Laboratories, USA to analyse the samples for total uranium content necessary to allow the dose determination to the two exposed workers (see *Attachment 4.4*, *Appendix F10*).

The policy on radiation protection promulgated by the Regulator, specified an annual dose limit for the designated employee of 20 mSv effective dose in Schedule 1. Schedule 3 of the policy specified a dose conversion factor of 15 µSv/Bq for Pu^{239} and the inhalation pathway (see *Attachment 5.1*). Using this dose conversion factor an annual limit of intake (ALI) can be calculated. The ALI can then be applied to a urinary elimination rate (approximately 6.1 E-5 Bq/d) to determine the anticipated plutonium level that could be seen in a worker who has inhaled the equivalent of an ALI. This anticipated daily elimination is approximately 200 µBq/day after 100 days from the time of exposure. It is then required to have a MDA or sensitivity by the laboratory doing the analysis at least as low as 200 µBq per sample. The MDA is necessary to ensure that exposures do not exceed one ALI and the corresponding annual dose limitation of 20 mSv.

Initially, the contractor had not delivered the specified sensitivity, but this was mostly corrected following the second visit of the Audit Review Team (see *Section 5.6.3.1* and *Attachment 5.8*), when the earlier collections were reassessed at the required sensitivity. All samples were below the limit of detection applied by the analytical laboratory[25] and while the method did not lend itself to a precise estimate of effective dose, it did confirm that no worker was likely to have exceeded the annual dose limit of 20 mSv. A review of the non-conforming bioassays is provided at *Attachment 5.7*[26].

In November 1999 a teleconference took place between the Health Physics Provider, at Maralinga and Thermo NUtech in Albuquerque, New Mexico, USA, regarding the status of the urine samples in attempting to achieve the MDA of 200 µBq/sample. The minutes of the conference call, recorded by Mr Church, are at *Appendix 5.3*, together with his comments and observations. Details of further urine analyses undertaken by AEAT are provided in *Attachment 4.4, 13.11.5.3* to *13.11.5.8.*

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[25] Due to some samples (49 in all) being of insufficient volume and sometimes for other reasons, the laboratory could not quite achieve the desired sensitivity in every case.

[26] This review appears originally as *Appendix F5* of *Attachment 4.4*.

5.2.6 RADIOLOGICAL INCIDENTS

Significant ‘radiological incidents’[27] were required to be reported by the Project Manager to the Regulator, together with subsequent investigation reports, where the incident was serious enough to warrant further consideration. During the course of the Project, there were no occurrences of Level 2 or Level 3 radiological incidents and, apart from the Kuli incident (discussed below), no other incidents led to significant radiation exposure of workers. In practice, however, all incidents tended to be reported, regardless of their significance (e.g. occurrences of non-designated employees working in red areas that were breaches of procedure were reported as radiological incidents, even though they did not give rise to any radiation exposure).

One incident, which did not lead to any significant exposure, occurred in the final stages of the soil removal program (February 1998). An employee was discovered to have light contamination (0.7 Bq/cm^2) on his shirt when he arrived at ARPANSA for his termination lung count. It is not known how this occurred, but the individual concerned had breached procedures by making occasional forays into the red area to retrieve tools. The root cause of the incident was that the individual concerned disregarded procedure because of the very low level of contamination remaining (*Attachment 4.4*, *Appendix F1*).

Towards the end of clean-up activities at Taranaki, there were several further minor occurrences of low level skin contamination, none of which were of radiological significance. They were of management concern though, as the frequency of these events was considered to be unacceptable. Corrective action was taken, in the form of additional training, clearer demarcation of pit areas and the wearing of gloves for all central Taranaki areas (*Attachment 4.4*, *Appendix F1*).

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[27] To facilitate appropriate reporting and investigation, incidents were categorised as follows:

A Level 1 event required reporting internally only. As a minimum this included recording on the log of health physics events maintained by the Health Physics Manager.

A Level 2 incident required reporting internally, with the Department and the Regulator being informed of the incident and receiving a copy of the investigation report. The report would normally be issued within seven working days of completion of the investigation.

A Level 3 incident required immediate notification to the Department and the Regulator, and they additionally receive copies of the investigation report. Notification would normally be within 24 hours of identification of the incident.

More rigorous investigation would be initiated should low level incidents of a similar type occur at frequencies greater than would normally be expected, or if the incident/event was a ‘near miss’.

5.2.7 INTAKE DURING URANIUM REMOVAL AT KULI

Kuli was the site where uranium had been explosively dispersed and it was commonplace to observe fragments of weathered uranium on the surface. As part of the rehabilitation at Kuli, three trained health physics technicians undertook a survey with hand held instruments of the area near to the original firing pads and retrieved all of the uranium fragments which they detected (see Figure 5.5). This work was not considered to be radiologically hazardous and, apart from employing properly qualified technicians, no additional precautions were taken in carrying out this task.

Two of the workers returned positive urine samples, indicating intakes corresponding to worst case committed effective doses of 4.0 and 2.8 mSv respectively. These dose assessments were based on an assumed continuous inhalation of Class S (insoluble) uranium. Measurements of the solubility of Kuli uranium, reported subsequently (*Attachment 4.4*, *Appendix F8*), established that the Kuli uranium fragments were more soluble than had been assumed, leading to a downward revision of the doses to 0.006 and 0.005 mSv respectively. An AEAT report, that made use of analyses of total uranium in urine, carried out by Benchmark Environmental Laboratories (USA) was revised and reissued to take this into account (AEAT 2001). A more detailed account of these bioassay results and resultant assessed doses is provided in the Project Manager's report (*Attachment 4.4*, *Section 13.11.5.6*).

A source of uranium that could have resulted in radiation dose at the levels suggested by the bioassay results is not obvious from knowledge of the hazard and work. The air sample data also lend no support to the bioassay results. However, the pattern of the bioassay results appears to suggest a genuine dose rather than alternatives such as cross-contamination or prior work with uranium, and hence this is the conclusion agreed with the Environmental Monitor.

ARPANSA (*Attachment 4.4*, *Appendix F9*) has re-examined its lung monitoring measurements for the two individuals concerned, looking for the presence of uranium. None was found, giving confidence that no intake was significantly greater than that indicated by the urine results.

ARPANSA carried out an audit and then a revised audit of the exposure received by the two workers in question (see *Attachment 5.10*). ARPANSA concluded that for each worker, the worst-case estimate of the committed effective doses was less than one-tenth of the annual limit for uranium workers.

5.3 NON-RADIOLOGICAL OCCUPATIONAL HEALTH AND SAFETY AT THE SITE

5.3.1 SAFETY TRAINING AT THE SITE

Each contractor was responsible for developing and implementing appropriate safety training programs in the specific areas of their responsibility. The Project Manager provided the overall safety management at the site.

Training of workers began with their induction at the site and included basic radiation safety for all workers and more advanced specialised training for those who would be working in contaminated areas. Further detail may be found in the Project Manager's report, (*Attachment 4.4*, *Section 17.7*) and in the Health Physics Provider's report (*Attachment 4.7*, *Section 2.6*). General OHS training remained with the individual contractors.

Figure 5.5 Collection of near-surface uranium fragments at Kuli.

5.3.2 SITE SAFETY COMMITTEE

A site safety committee, containing representatives of all organisations with a regular site role, met on a monthly basis under the chairmanship of the Project Manager. Minutes were taken of each meeting. Significant safety incidents were addressed by the committee and action taken when there was an identified need to modify work practices to avoid any repetition of the incident.

The site safety committee maintained an overall watch on site safety issues; however, this did not remove or lessen the responsibility for worker safety of the respective employers. This policy was in harmony with relevant legislation.

5.3.3 HEALTH AND SAFETY FOR THE ISV PHASE

As a separate contractor, the ISV Contractor had developed its own OHS regime. They had prepared a general health and safety orientation manual and a health and safety plan, which was specific to their Maralinga operations. Associated with these, they had developed a set of general operating procedures, most of which included health and safety considerations (Table 5.1).

Table 5.1 ISV operating procedures.

Procedure no.	Title
GA-97-TP-001	Taranaki Cap Removal Procedure
GA-97-TP-002	Taranaki Pit Investigations and trenching
GA-98-TP-003	Melt Excavation Procedure (for DSTO Operations)
GA-98-TP-004	ISV Operations Shutdown Determinations
GA-98-TP-005	Sampling and Tracer Addition
GA-98-TP-010	Melt Start-up Procedure
GA-98-TP-011	ISV Operations
GA-98-TP-012	Off-Normal Conditions Response
GA-98-TP-013	Visitor Management
GA-98-TP-014	Hood Placement
GA-98-TP-015	Vitrified Product Excavation Procedure
GA-98-TP-016	Off Gas Filter Cleaning
GA-99-TP-001	Pit 17 Block Investigation

The purpose of these procedures was to explain, both to the ISV Contractor’s staff and to the Project Manager supervising staff, the nature and sequence of the various operations to be undertaken by the ISV Contractor at the site. Some of these procedures covered operations that related specifically to the ISV Contractor's actions, such as the ‘hood placement procedure’, while other procedures also impacted on other groups on-site such as the ‘off-normal conditions response procedure’ and the ‘visitor management procedure’.

5.3.4 ACCIDENT AND INCIDENT EXPERIENCE

5.3.4.1 Injury or incident statistics

A total of 38 reportable incidents or injuries occurred (*Attachment 4.4*, *Appendix K1*). Many of these were of very limited significance, reported over the four years of the Project, in a total workforce of approximately 230. This translates to an annual rate of reported incidents/injuries of approximately 4%. Of these, ten (26%) led to lost time, mostly for the remainder of the working day, or one or two days of light duties or rest. No injury or incident resulting from working or living at the site is known to have had any lasting effect on the workers involved.

The one serious accident that could have caused major injuries or fatalities was the explosion of the ISV melt at pit 17 (see *Chapter 4* for a detailed description), but at the time nobody was in the near vicinity, and no consequential injury occurred.

5.3.4.2 Comparison of site with national and international experience

Tables 5.2 and 5.3 provide a comparison between Maralinga and national (NOHSC 1995, 1998) and international experience. Given the very limited scale of the operation, it indicates that the Maralinga Project suffered an OHS injury rate generally comparable with other Australian and international rates for construction industries. Further detail on the OHS performance of the major contractor is provided in *Attachment 5.9*.

Table 5.2 Maralinga occupational worker safety comparison chart.

	Comparative element (country and division)						
	Australia (all industry)	**Australia** (construction)	**USA** (all industry)	**USA** (construction)	**Maralinga**	**UMTRA**	**Enewetak**
Comparison year	1994/95	1994/95	1997	1997	1996–1999	1980–1999	1977–1980
No. of workers	6.8 E+6	2.88 E+5	1.31 E+8	7.84 E+6	230 FTE	13 880 FTE	8 033 FTE
No. of inj. & illness	148 563	12 752	3.8 E+6	3.9 E+5	56	378	63
Non-fatal inj. & illness freq. rate	10.9	22.1	14.5	24.8	TRC 23.9 LWC 15.2	TRC 13.6 LWC 5.2	LWC 3.9
Non-fatal inj. & illness incident rate	21.8	44.3	29	49.7	TRC 47.8 LWC 30.4	TRC 27.2 LWC 10.4	LWC 7.8
No of fatalities	408	43	5 100	1 105	0	2	6
Fatal freq. rate	0.03	0.07	0.02	0.07	0	0.07	0.37
Fatal incident rate	0.06	0.15	0.039	0.135	0	0.14	0.75

UMTRA	Uranium Mill Tailings Remedial Action project
Enewetak	Remedial Action at the Enewetak Atoll, Marshall Islands
FTE	Number of full-time equivalent workers (total Project hours reported divided by 2000 hr/yr)

$$\text{incidence rate} = \frac{\text{number of occupational injuries and diseases x 1000}}{\text{number of wage and salary earners}}$$

$$\text{frequency rate} = \frac{\text{number of occupational injuries and diseases x 1000000}}{\text{number of hours worked}}$$

Table 5.3 Maralinga register of illnesses and injuries categorisation using USA system.

Year	Total	First aid cases	TRC	LWC	Other
1995	5	3	2	2	
1996	6	4	1	1	1?
1997	10	6	2		1?+veh w/pd
1998	22	16	4	2	2?
1999	12	9	1	2	1 Dngrs Occur
2000	1				Veh w/pd
Totals	56	38	11	7	7

?	Unable to categorise.
veh w/pd	Vehicle accident with property damage only.
TRC	Total recordable case using USA definition.
LWC	Lost workday case using USA definition.

Maralinga input data

Worker hours:

GHD Phase 1 = 41 680

GHD Phase 2 = 64 778

Department direct reported hours = 59 210

Thiess = 231 600

Miscellaneous short term = 60 000

Grand total hours = 460 000

Full-time equivalent = 460000/2000 = 230 person years

5.4 EXPOSURE OF WORKERS TO RADIATION AND RADIATION DOSES

5.4.1 ENVIRONMENTAL MONITORING

The Project Manager established a health physics monitoring program, designed to ensure a safe working environment and to ensure that there was no serious spread of contamination. Regular routine monitoring of the working environment was required to be maintained by the Health Physics Provider, including change room and decontamination areas, workshops, and areas where employees were working without respiratory protection (using air sampling). The Health Physics Provider was also responsible for:

- providing, maintaining and regularly calibrating appropriate instrumentation for monitoring surfaces;
- assessment of residual activity following soil removal; and
- sampling of airborne alpha activity.

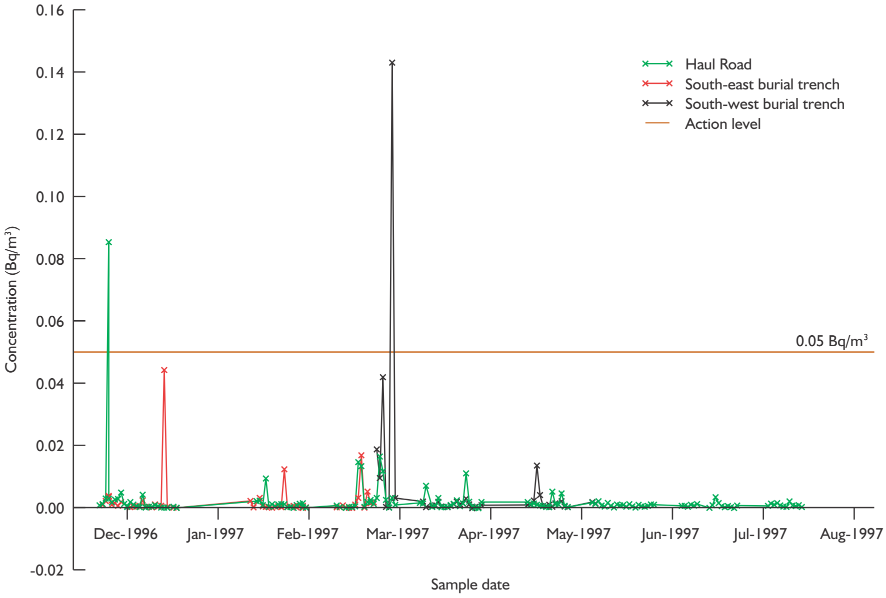
Maintenance and calibration records were required to be kept. Procedures covering the environmental monitoring program, written to conform to the requirements of the health physics policy document, were reviewed by the Health Physics Auditor, whose responsibility was to approve them.

On a few occasions detectable levels of airborne radioactivity were observed on air filters and as occasional contamination on surfaces of some forward area facilities, but in most cases results were below the limits of detection. Those few samples that were positive were well below levels of concern and implied potential exposures far below the occupational dose limit of 20 mSv/yr and the site dose constraint for designated employees of 2 mSv/yr.

Figure 5.6 shows an air sampling unit that was used as part of the air monitoring program. Figure 5.7 (see *Attachment 4.7*) illustrates the observed airborne concentration of long-lived alpha emitters around the perimeter of the soil burial trench during soil removal at Taranaki. Airborne contamination from this source was a potential exposure route for employees working in the occupied forward area facilities. A continuing level of 0.5 Bq/m^3 throughout the entire working year would lead to a committed effective dose of 20 mSv. Considerable effort was therefore devoted to the control of dust during soil removal, mainly through its suppression during soil removal and pit exhumation (see Figure 5.8), and through separation of work areas from unprotected personnel.

Figure 5.6 Air sampling unit (lower right) positioned near haul road.

Figure 5.7 Perimeter air sampling—Taranaki site.



5.4.2 OCCUPATIONAL EXPOSURE MONITORING RESULTS

The Health Physics Provider maintained a comprehensive program of occupational exposure assessment in the workplace, including regular monitoring of worker clothing and skin, workplaces (e.g. vehicle cabins, lunchrooms, toilets and office areas) and dust levels within working environments.

Summary data for surface contamination within the cabins of Class II plant during pit exhumations at Taranaki are presented at Figure 5.9. There was a single measurement of 0.051 Bq/cm^2, where soil had been tracked into the cabin of a Class II vehicle.

In general, although new work procedures involving intensive dust suppression measures, Class II plant and full protective clothing were required for pit exhumations, no other cases of contamination occurred. Figure 5.10 presents results of air sampling at a point between the pit exhumation work and the ISV area and illustrates that there was no significant transport of airborne contamination between these work areas. The six higher results from 6 and 7 May 1999 occurred while heavily contaminated blast walls from featherbeds were being exhumed from pit 14.

It is considered that the only significant pathway for exposure of workers at Maralinga derives from the inhalation of the plutonium isotopes Pu^{239}, Pu^{240} and the daughter radionuclide, Am^{241}. The report of the Health Physics Provider (*Attachment 4.7*) provides summary data of mean and maximum exposure from potential inhalation for all worksites and these are reproduced at *Attachment 5.4*.

Table 5.4 is derived from a summary table of mean and maximum annual exposures presented in *Attachment 5.4*. The final column transforms the reported numbers from intakes in Bqhr/m^3 to committed dose, assuming a breathing rate for workers of 1.2 m^3/hr and the dose conversion coefficient of 14 μSv/Bq. The estimated mean annual dose of 3.4 μSv with a maximum of 35 μSv is extremely small compared with a worldwide average annual background dose from all sources of the order of 2 mSv and an occupational dose limit of 20 mSv.

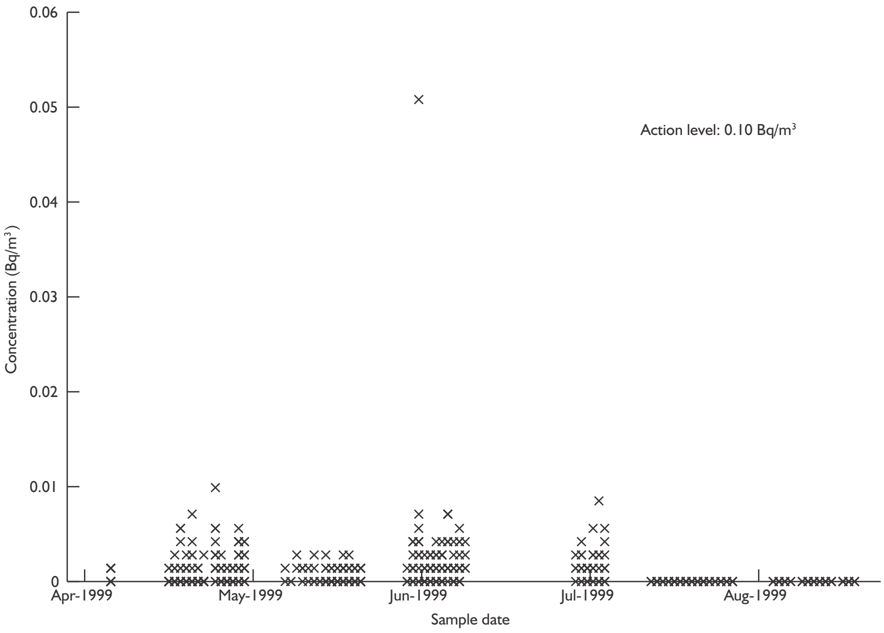
Monitoring of designated workers was performed routinely and it was only on a few occasions that any contamination was detected. In the case of skin contamination, none exceeded the 'Level 1 event' criterion of 0.4 Bq/cm^2 of alpha activity (see footnote to *Section 5.2.6*). Levels ranged from 0.01 to 0.25 Bq/cm^2

Table 5.4 Annual exposure and committed doses for designated workers at Maralinga.

	Exposure (Bqhr/m^3)	Committed dose (μSv)
Highest cumulative month for an individual	1.09	18
Highest cumulative year for an individual	2.07	35
Average monthly	0.05	0.8
Average annual	0.20	3.5

Figure 5.8 Dust suppression during pit exhumation.

Figure 5.9 Cabin sampling for surface contamination during pit exhumations at Taranaki.



(*Attachment 4.7*, *Section 17*). For these cases, which only involved contamination of the hands and was easily removable, the dose consequences to the individual were nil and of no concern.

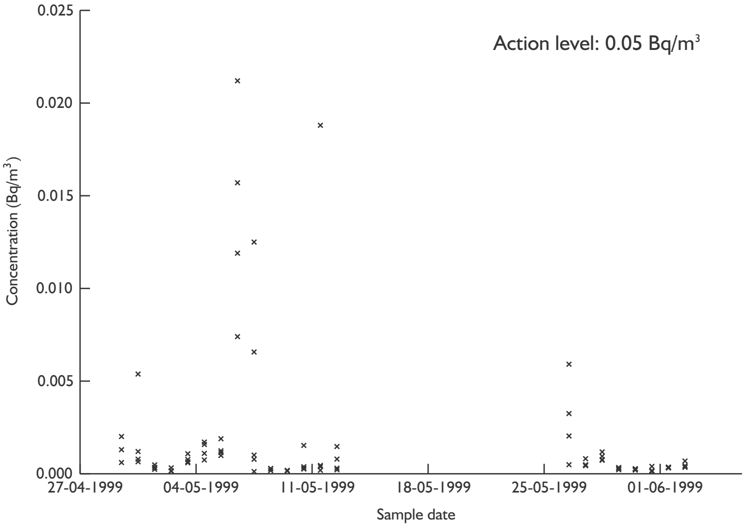
Late in the program the ARPANSA field team located an area of contamination 2 km south of Taranaki, that was subsequently recognised as an old health physics decontamination site named HP2. Contaminated fragments and soil were removed and two small pits exhumed without incident in accordance with work procedures written specially for this exercise (*Attachment 4.7*, *Chapter VIII*).

5.4.3 PERSONAL MONITORING DEVICES THAT WERE NOT REQUIRED

5.4.3.1 Thermoluminescent dosimeters (TLD)

Discussions at early MARTAC meetings influenced policy setting and provided guidance in the development of the Health Physics Program. MARTAC was specific in addressing monitoring programs (see *Subsection 5.4.2*) that, for technical reasons, the committee believed would not well serve the Commonwealth, the Maralinga Tjarutja or the individual worker (e.g. discussion at the fifth MARTAC meeting covered the purpose of TLD gamma monitors, given the nature of the rehabilitation program and the radiological condition of the Maralinga Range). It was the committee's understanding that no gamma source of sufficient magnitude would require the warning of personnel from trespass or exceed any international standard requiring

Figure 5.10 Air sampling, ISV operations and pit exhumations.



warning indications. Therefore MARTAC could not see benefit commensurate with the resources necessary to provide a TLD service and to maintain the records. In addition, their continued use would send the incorrect message that a gamma ray source of concern existed and that this could unnecessarily raise questions among workers and/or the returning Maralinga Tjarutja people.

However, there was a known significant hazard to workers from sources (i.e. transuranics) that by their nature are a hazard that is internal to the body and emit radiation (e.g. alpha) not measured by TLDs in their normal application. MARTAC therefore concluded that it was better to focus the radiation protection philosophy on monitoring for internal emitters and the nature of substances, which emit alpha particles as they decay (namely the plutonium isotopes and associated Am^{241}).

It was considered that the health physics program being developed (including training, monitoring, documentation of worker employment category and location, sampling and record keeping) would serve to drive a high level of interest and concern for personnel to follow procedures and practices required by the program.

It was requested at the fifth MARTAC meeting that the Regulator consider whether the use of TLD gamma monitors should be continued. If the use of TLD gamma monitors was to be discontinued a careful and thorough explanation of this decision should be incorporated in the induction training.

At the sixth MARTAC meeting, a paper by Mr Peter Burns of ARL that had been requested at the fifth meeting was reviewed. It concluded that use of TLDs could be discontinued except where site personnel (e.g. APS personnel) were expected to spend a lengthy period near the major trial sites. Further discussions concluded that prolonged visits to major trial sites for the Project would not be a problem since, with the exception of Taranaki, none of the major trial sites were within the scope of work. MARTAC subsequently recommended to the Department that use of TLDs be discontinued and that the reasons for doing so be made clear to the APS officers. A further discussion of this issue is provided in *Attachment 4.4*, *Appendix F8*.

5.4.3.2 Personal air samplers

During reviews of the early version of the Project Manager's proposed health physics procedures, MARTAC noted that plans were being made to use lapel or personal air sampling (PAS) devices during proposed work in plutonium-contaminated areas. Over the course of these discussions, experience and technical papers were reviewed by various MARTAC members. One conclusion is that:

> *... no basis of confidence has been found for interpreting the results realistically in terms of committed dose to internal organs or even quantitative intakes and no useful correlation has been observed between PAS and installed sampler results.*

Jones et al. 1983

These data were based on several hundred thousand samples collected in an indoor operating environment. Because the work being considered for Maralinga was outdoors and thus would be subject to confounding by additional environmental factors, MARTAC believed that it would be even more difficult to obtain meaningful and correlated data. It therefore recommended that PAS devices not be used. It was also noted that:

- PAS results could be misleading (e.g. they do not serve as an indicator of the environment in which a suited worker operates, as that environment is within the suit); and
- particles can fall off as the PAS is subject to the movement of the individual wearer.

The committee further stated that the use of static air samplers is more appropriate under most circumstances.

PAS devices were nevertheless used on lapels during some operations (see below). The decision to use these units was taken by the Project Manager and Health Physics Provider on the basis of their experience with their use. While accepting a low accuracy produced by low flow rate of the units, the tight focus of the data on an individual's activities enables good day-to-day dose control. This supplements the area and trend analysis of larger volume environmental air sample units and *in vivo* and in vitro dose assessment and were judged useful in the planning for the protection of workers.

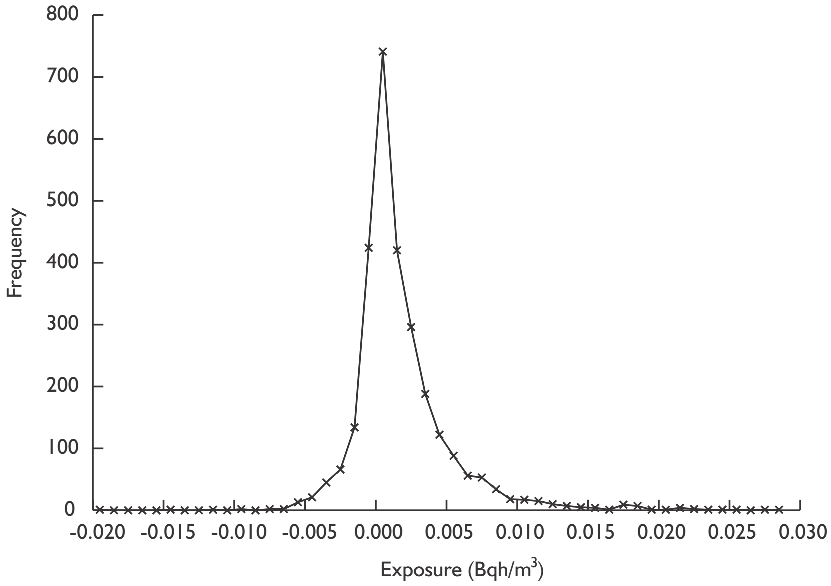
At Maralinga the radiological environment at the work face could not be forecast with any confidence so the general approach was to use engineered controls that were totally able to handle the range of situations that might arise. This approach meant that cabins of vehicles used in the red area during the course of the earth works being outfitted to seal the occupant from the dust raised and use of dust suppression methods. Even though airtight seals were employed, vehicle cabs were maintained under positive pressure, using filtered air. Each cabin's ambient air was sampled over the course of the workday. The results of this monitoring are reported in detail elsewhere (*Attachment 4.7*, *Section X*) and are summarised in Figure 5.11.

5.4.4 SUMMARY AND CONCLUSIONS

The radiation monitoring program carried out by the Health Physics Provider under the management of the Project Manager, and subject to continuous audit by the Environmental Monitor was adequate. It met fully the requirements of the ARL health physics policy document and has ensured a robust and thorough record of the radiation exposure histories of all workers on-site. Environmental and workplace monitoring results, and adherence to health physics procedures and method of work statements by themselves demonstrated that potential exposure to radiation was well controlled throughout all phases of the Project. Most commonly, exposures were below the limits of detection and even when positive results were recorded, they indicated annual effective doses well below the annual dose limit of 20 mSv and the site dose constraint of 2 mSv.

Regular lung monitoring and urine sampling found no evidence of any intakes of plutonium and confirmed that no worker would have received an annual effective dose above the occupational dose limit.

Figure 5.11 Distribution of personal exposures for Class II operators.



5.5 OTHER HAZARDOUS SUBSTANCES

5.5.1 POSSIBLE EXPOSURE TO LEAD OXIDE DURING ISV OPERATIONS

It was known that many tonnes of lead had been used for shielding during the *Vixen B* trials and this was understood to be buried in the Taranaki pits destined for treatment by ISV. The possibility existed therefore that workers associated with ISV could be exposed to lead, especially those who were involved in cleaning the off-gas filters in the ISV plant. The ISV Contractor had not addressed this as a significant hazard and no particular hazard assessment, worker training or operational procedures had been developed to deal with the issue.

Early in 1999, the Project Manager raised concerns about this matter with the ISV Contractor and advised that no further work should be undertaken until a hazard assessment had been carried out. While the lead oxide inhalation route was adequately protected during the actual cleaning of filters through employment of respiratory protection (used in case of radioactive contamination), no procedures had been developed for handling equipment and clothing once respirators were removed. The Project Manager noted that blood monitoring is the appropriate health surveillance and indicated employer responsibility to conduct appropriate monitoring for its workers (letter [*Lead Oxide Issue*] from the Project Manager to Geosafe Australia P/L, 11 May 1999).

Following these concerns, all persons involved were tested. The five Health Physics staff returned lead in blood concentrations within normal limits and the ISV Contractor advised that all 19 results for its workers were below the levels recommended by the NHMRC (letter from the Project Manager to K Lokan, 2001).

5.5.2 ASBESTOS

Considerable asbestos had been used in the construction of the original Maralinga village and support facilities. This was subsequently removed and buried at the time of *Operation Brumby* in 1967.

Asbestos encountered during the Project was removed by a licensed contractor and buried in accordance with the requirements of the South Australian EPA (*Attachment 3.2*; *Attachment 4.4*, *Section 12.9*).

5.6 HEALTH PHYSICS AUDITS AND REVIEWS

The necessity of auditing was discussed at the first MARTAC meeting and was a continuing topic at subsequent meetings. An early decision was that ARL (later ARPANSA) would have key roles in this area. The Department decided that ARL would define the boundary of the contaminated areas and check residual contamination levels on completion of the earth works (verification), perform lung monitoring of workers and serve as the Health Physics Auditor. As the Health Physics Auditor would only visit the site periodically, the Department made the decision in late 1996 to augment this role with a Health Physics Review Team (HPRT). The Health Physics Auditor was a member of the team, making the health physics reviews an extension of its audits.

5.6.1 HEALTH PHYSICS REVIEW TEAM (HPRT)

In November 1996, MARTAC reported parts of the health physics regime as being excessive in some respects (e.g. in change room operations). Members were advised that, as a matter of course, all health physics procedures were passed to the Health Physics Auditor for review. The auditor had indicated that some of the procedures appeared unnecessarily strict but would not recommend relaxing them. The task of the Health Physics Auditor was to ensure that health physics procedures satisfied the health physics policy. As the radiation risks were owned by the principal, the auditor had no obligation to question standards that were set at a more stringent than necessary level.

Concerns for efficiency influenced the terms of reference given to the HPRT and were included in its scope (see *Attachments 5.5* and *5.6*). Thus, the audits went beyond just determining whether the procedures and methods of execution merely satisfied radiological safety, but also assessed whether they were being accomplished in a cost-efficient manner.

The first HPRT audit and review commenced in February 1997 and a second audit, embracing the later ISV phase, took place in June 1998. Both audits were organised at the direction of the Department, which had no influence on the writing of the HRPT reports, but had considerable influence on the implementation of their recommendations.

In preparation for the successive audits the review team was furnished with policy documents and procedures from the various organisations that formed the Health Physics program for the Project. The members of the review team shared the responsibility of reviewing/reading and interviewing the personnel responsible for the various phases of the program. The team examined how the delegation of responsibility operated in the various organisations, how they assured themselves that the work was being done and how they met their quality assurance obligations.

The reports were organised both to discuss the results by subject and then to index each procedure by number and title to allow easy reconciliation of the recommendations to subject and procedure. The reports concluded with a discussion of general conclusions parallel to the terms of reference and highlighted high priority recommendations. The results and recommendation sections served as the executive summary. A more detailed summary of the two audit reports is provided as *Appendices 5.1* and *5.2* and the full reports as *Attachments 5.5* and *5.6*.

Because many of the recommendations of the first audit were still outstanding at the time of the second audit, the team recommended a further review to take place six months later. This recommendation was not adopted by the Department.

5.6.2 FIRST AUDIT OF THE HPRT

Timing of the first audit was set to take place after a period that allowed field experience of actual operations to be incorporated in revised and updated procedures. The audit team considered that it would not have been possible to identify all possible departures from initial preplanned procedures in the light of operating experience and encouraged managers and staff of all organisations to conduct their own internal audits—as they should have done as part of their quality assurance programs. The audit team expected that, rather than simply responding to HPRT findings and recommendations, all organisations would complete the job on their own, in response to their own internal reviews. This observation was repeated at the second audit.

5.6.2.1 Findings

The general finding for the health physics regime at Maralinga for ensuring radiological protection, documentation of dose to workers and for keeping participants within regulatory limits was more than adequate.

The suitability and effectiveness of processes implemented by the health physics regime were found to be effective as had been shown by all monitoring data up to that time. The team had concerns, however, with the suitability of many of the written procedures, which often did not reflect actual occurrences. Thus, all organisations were advised to examine their procedures and update them so that when the written record was tested in the future, its credibility would not be compromised.

Record keeping was considered adequate, despite the HPRT finding that the records being generated were very extensive. They examined the personnel monitoring and bioassay programs and considered that they were probably more extensive than necessary, due to the inappropriate classification of many employees as designated workers. More people were listed as designated workers than conditions and experience required. This had an impact, because designated employees were required to be participants in the annual and the monthly screening programs. Workers engaged in contaminated soil/particle handling would necessarily be designated workers but others, even management personnel, who did not deal with contaminated soil/particles and who should never have exceeded 1 mSv/yr, yet required access to red areas, should not have needed to be participants in the screening program. This would have led to a significantly smaller volume of records and a lesser impact overall on workers' time.

The HPRT noted that it would be necessary at some stage for the Department to develop an overall record management protocol, against the day when all records were forwarded to them at the conclusion of the Project.

The HPRT considered the bioassay program would be enhanced by including at least one fitter per month in the urine analysis program and by specifying data quality objectives (DQO), requiring Level 3 reporting and providing blind unknowns from the health physics auditor to the urine analysis contractor.

The health physics staff were well-qualified and possessed adequate experience, but the HPRT found their approach to the application of the health physics regime very conservative. The downside to this approach was the potential for unnecessary concerns that this may have caused in individuals and the culture of the Project. Overall, however, the HPRT believed that the health physics staff contributed to a

Figure 5.12 Scene at Taranaki, September 1996. Work suspended during dust storm arising from south-westerly winds in excess of 40 km/hr.

satisfactory safety culture, although it hoped to see in the future more definitive written guidelines that clarified why actions were taken. It was considered important, therefore, that a consistent guideline be developed to define whether a significant radiological incident had actually taken place. By writing it down and then applying it consistently, inadvertent alarm in workers would be minimised. MARTAC notes that opposite points of view can be developed and both positions can list examples favouring their conclusion.

The HPRT had some concerns about the environmental monitoring for contaminated dust in the forward area at Taranaki and recommended that further samplers be arrayed between the forward area facilities and where work was being performed (i.e. very near to actual dirt moving/dust raising). The team believed that accumulation of this 'worst case' type of data which would be integrated over all weather conditions (e.g. including willy-willies and dust storms) and time would provide the essential data against which decisions (e.g. the temporary suspension of work in adverse conditions) could be made.

The team was positively impressed by the Earthworks Contractor's system of documenting what it called 'radiological incident reports' in a register and the way in which it used these reports to improve the quality assurance aspects of its programs as well as demonstrating a proper concern for the radiological safety of the worker.

Figure 5.13 Walkway to provide access to vehicles without walking on ground.

5.6.2.2 Summary of recommendations

The recommendations listed below were considered significant enough to highlight as primary recommendations. There were considerably more recommendations, many of which were specific to individual procedures or implementing procedures of the Health Physics Provider. The HPRT report was approximately 100 pages in length and covered the Health Physics regime of the Project in some detail. In total 119 findings and 62 recommendations were made. The magnitude of these totals however, should *not* be misunderstood (e.g. between 20 and 25% of the findings were positive in nature). Most (60%) of the findings and recommendations were minor and very minor with respect to protecting the health and safety of the worker. Most findings and recommendations related to actual practice within the procedures. This should not be considered unusual because of the uniqueness of the clean-up operation in Australia—there was only a limited body of experience to draw on, and procedures put in place at the onset of the clean-up were often adopted from other sources and needed revision in the light of local experience.

The number of findings and recommendations reflects the level of detail within which the review team operated and also its mandate to review cost-efficiency. Because many of the procedures adopted initially were based on procedures applied in facilities such as nuclear reactors and fuel reprocessing plants, they were more conservative than necessary for the radiological environment at Maralinga. A number of the findings and recommendations reflect this observed conservatism and called for greater efficiency in the application of procedures.

In addition to protecting workers from exposure to and intake of radioactive material, a number of recommendations (e.g. relating to record keeping, sensitive bioassay procedures and quality assurance programs) were directed towards protecting the Commonwealth from possible future litigation (required from the terms of reference).

Major recommendations made and referred to the Department for action

Environmental monitoring. The environmental monitoring program needs the foundation established in the *Health Physics Strategy Statement*, with concordant flowdown to procedures that provide the basis for having adequate environmental air samplers to monitor the potential dust conditions (resuspended/contaminated), and a spreading source of contamination on the haul roads. This sampling should be maintained throughout the soil moving and hauling operations. Data from this small network should provide empirical data/information/experience such that operational decisions can be planned and not require potential evacuation before determining conditions.

Designation of workers. The criteria for a designated worker need to be more rigidly enforced (i.e. the proposed worker truly must be expected to be working under conditions which give a likelihood of exceeding 1 mSv/yr).

Extension of blue area along walkway (see Figure 5.13) *to Class II vehicle cabs.* To be consistent with current practice and provide clarity for workers in the red area, the blue area should be extended from the change room, out through 'door four' along the walkway into the plant cabs. A blue line should be painted on the walkway with appropriate warning signs.

Data quality objectives. Appropriate DQO should be provided in writing to the Thermo NUtech Laboratory (TNU) in Albuquerque, containing a request to provide Level 3 standard reports. The Health Physics Auditor should arrange to receive standard urine solutions that can be returned as unknowns for increased data quality check.

Enhanced urine analysis for fitters. One different fitter sample per month should be sent for analysis, completing the cycle for all fitters each quarter. These individuals are most at risk from contamination and will be a good continuous check on the dosimetry system.

Procedure consistency check. Instructions from management at all levels should be given to all personnel in the various organisations to adjust the procedures to fit current practice or current practice should be adjusted to meet current procedures.

Personal decontamination. Guidance for skin decontamination needs to be set. The guidance needs to be based on dose in skin limits, founded from the *Health Physics Strategy Statement* down to the procedures, not in inanimate material surface release limits.

Contamination incident reporting guidance. Instrument thresholds for triggering an incident need to be developed as guidance for health physics technicians to provide consistency, prevent unnecessary alarming of workers, avoid unnecessary records and eliminate the variability created when left up to individual discretion.

Record keeping. An overall strategy and procedure for records flow, interlinking dosimetry/monitoring information from the various organisations would help clarify who is responsible, which records are to be distributed and the various dispositions. Fragments are currently held in many places, but no overall plan links this information. This is currently causing some frustration to the Environmental Monitor. The HPRT believes that one possible vehicle for this may be the draft Department document *Maralinga Rehabilitation Project – Health Physics*.

Project management. There is a need for a clear chain of command, documented in writing. The document provided by the Department titled *Maralinga Rehabilitation Project – Health Physics*, the Department project management plan and the Health Physics Procedure (see *Attachment 5.3*) entitled *Health Physics Strategy Statement*, do not clearly delineate a chain of command at the highest levels of the Project or allocate responsibilities for the development of a health physics strategy. While the Project Manager's health physics procedures apply to its own staff and its subcontractors it is not clear if these requirements apply also to organisations with contracts directly with the Department. Although this information might be contained in the details of the individual contracts, it is not summarised in any document.

Worker dose notification. One of the purposes of the dosimetry regime, as stated in the dosimetry procedure, is for personnel reassurance. The HPRT observe that no implementation of this requirement that can be defined. They believed the Health Physics Provider should have an active requirement to inform, in a timely fashion, personnel who terminate, their dose history, and every six months (because of the short duration of the Project) for the continuously employed.

5.6.2.3 Response to recommendations

The HPRT report was presented to the MARTAC committee for review during its April 1997 meeting. MARTAC endorsed the findings and recommendations of the report, with additional discussion and clarification of requirements for urine samples from fitters as the Project moved from Taranaki to the TM sites. The Health Physics Auditor during MARTAC's ninth meeting noted that *... on the whole ... workers were being excessively monitored by the health physics regime*.

Following the first audit, the Department transmitted directions to the Project Manager for implementing the recommendations of the HPRT. In its letter the Department noted that all of the recommendations listed in 'recommendations highlights' were to be implemented. In addition to the main recommendations there were many others which were to be discussed with the Department and suitable actions agreed to satisfy the requirement. Proposals for satisfying the recommendations were to be submitted to the Department for approval before being put into place.

The Departmental Engineering Advisor also provided further direction, defining the schedule and placing limits on the number of analyses of urine samples from the three fitters at Taranaki. This was to provide guidance up to the transition to the TM100/101 site, after which all samples provided by the fitters were to be analysed until completion of work at TM100/101.

The HPRT report addressed the concern that the use of personal protective clothing/equipment should be carefully controlled to limit creation of conditions of increased risk (e.g. those arising from restricted vision).

The Departmental Engineering Advisor, noted that health physics determinations had concluded that respirators were not required for vacuum cleaner operators during the final soil removal, although the Earthworks Contractor still allowed their use. The Earthworks Contractor was advised that if the practice was continued, the contractor would have to accept responsibility for any adverse health effects caused.

The same communication re-emphasised that the fitters' urine samples were to be the primary ones sent for analysis. The Project Manager reluctantly accepted the direction on urine sampling, but made it clear that it did not agree, as it felt that the Engineering Advisor was restricting too severely the number of personnel being sampled. The Project Manager further felt that it was inappropriate that the on-site Health Physics Manager was not responsible for the selection of personnel for sampling and for determining the sampling frequency.

No further communications regarding the 1997 audit recommendations appear in the record until March 1998, when the Project Manager responded to a Department request of the previous May for an implementation report on the status of the 1997 recommendations. The five-page response concluded by stating that:

> *In summary, the HPRT recommendations were implemented as agreed with the Department and the Environmental Monitor and no items within the Project Manager's scope of works were currently outstanding.*

5.6.3 SECOND AUDIT OF THE HEALTH PHYSICS REVIEW TEAM

5.6.3.1 General finding

The HPRT reported that the health physics regime implemented at Maralinga was conservative and occasionally over-restrictive but more than adequate to protect the radiological health and safety of workers.

The principal deficiency noted in the second audit related to the unsatisfactory management of the urine monitoring program. The 1997 HPRT report had made specific recommendations for improving the urine monitoring program, including:

- development and transmittal of DQO for Level 3 reporting to Thermo NUtech; and
- the purchase of a standard synthetic urine solution from Thermo NUtech that could be used by the ARL as a blank spike in a quality assurance check on the analysis.

The HPRT was critical that neither recommendation had been implemented. No reason was given by the Project Manager or the Health Physics Provider for non-action on the first recommendation. A letter from the Project Manager to the Department in March 1998 reported that because the Environmental Monitor could not prepare spiked urine samples, it had been decided not to pursue the standard solution, but to instead place reliance on a review of the Thermo NUtech quality assurance procedures (a decision that was not itself implemented). At the time of the 1997 review, the HPRT knew that the Environmental Monitor did not have the capability to create spiked or blind standard solutions, which was why it recommended that a standard solution be purchased from Thermo NUtech and shipped to the Environmental Monitor, where it could be placed in a new container and returned later to Thermo NUtech as part of a regular batch of Maralinga urine samples. This recommendation was made in part also to take into account the fact that Thermo NUtech, in participating in outside interlaboratory comparisons, did not have a ‘plutonium-in-urine’ unknown. Hence, for a complete or enhanced quality assurance check, an externally furnished unknown was considered necessary. This need was still valid.

Comments by the HPRT on the urine assay shortcomings are provided in *Attachment 5.8*.

5.6.3.2 Impact of procedures on overall OHS

It is well known that actions taken, or proposed, for the control of one workplace hazard may have a deleterious effect inasmuch as they may, if poorly thought out and implemented, increase the level of risk from another hazard. It is important not to become trapped into implementing controls that are not really necessary and actually increase total risk.

Thus, in relation to air monitoring, ‘red’ and ‘blue’ area controls, and emergency response to ‘off-normal’ events, the HPRT found non-radiological hazards to exist in the ISV operations that, if not appropriately controlled, could present significant risk to workers at the site. Health physics requirements were identified by the HPRT that could act to limit or prevent the implementation of good OHS practice by general site workers and/or the health physics staff (e.g. the routine use of respirators is a form of risk control that is low in the ‘control hierarchy’ enshrined in OHS legislation, and as a result, should not be used unless absolutely necessary—their use can limit vision and speech communication, and increase the overall risk of industrial accidents). Similarly, the health physics restriction on consuming water in the ISV control van, that required workers go to the forward area facility for a drink was counterproductive. Such an arrangement could contribute to the risk of heat stress, dehydration and poor concentration. In a worst case scenario, heat stroke could occur (a life-threatening occurrence).

The ISV Contractor and the ISV Operator jointly instigated systems that should have assured that employees had the means and training to work safely. However, it was not clear to the HPRT that health physics staff working alongside the ISV workers during ISV operations would be as knowledgeable in the OHS practices and implications of the ISV work as they should have been.

A comment made to the HPRT on several occasions was that each contractor at the site had its own OHS responsibilities and it appeared that little in the way of sharing of OHS information and practices occurred between the contractors. Given the small size of the worksite, and the fact that the Project Manager, the Health Physics Provider and the ISV employees necessarilyworked in close liaison, it was important that such sharing should take place. A joint safety committee that met on occasions attempted to achieve this.

The HPRT noted that ISV workers were in the process of documenting their safe work/permit systems at the time of the review. The team noted that it was important that such information should be provided to the Health Physics Provider and their employees trained in such systems. To maximise the likelihood that the safe work/permit systems were implemented as planned, it would be appropriate for the Health Physics Provider to amend, for example, its routine monitoring procedure to address the safe work/permit requirements for any potential entry into a confined space.

A summary of the recommendations and findings arising from the June 1998 review is included at *Appendix 5.2*. These covered the shortcomings of the urine analysis program as discussed above, the potential dovetailing of the ISV Contractor's relevant ISV monitoring results with those of the Health Physics Provider for dose assessment purposes, clarification of some work procedures, improvements to the ISV Contractor's emergency alarm systems and recognition that general OHS required an integrated site-wide approach.

5.6.3.3 Response to recommendations

The various contractors responded to the second HPRT report following its release to them in draft form by the Department in July 1998.

The Project Manager responded with an updated action plan for bioassay and dosimetry. In its response, the Project Manager pointed out that it did not share the level of concern expressed by the audit, and that the:

> *... dosimetry regime has been comprehensive and that records are sufficient to support all assertions that there has been no significant dose uptake ... and ... Lung monitoring by ARL has always been the primary technique and other techniques, such as urine sampling have supported these measurements.*

In its view ... *urine sampling has only ever formed part of an overall dosimetry regime incorporating lung monitoring, air sampling and keeping records of area visited or worked in.'*

MARTAC recommended a urine sampling schedule for both Category 1 and 2 workers, and provided a discussion of the quality assurance requirements to achieve:

- an MDA of 200 µBq/sample;
- the use of external blind samples;
- preservation of urine samples; and
- requested QA Level 3 reports from the analytical laboratory.

The Department confirmed funding to ensure the integrity of the urine monitoring regime by recounting the earlier urine samples that had not achieved the specified MDA, and to provide resources to secure Level 3 QA reporting and the purchase of materials necessary to create blind QA samples for the laboratory. The Department concluded by affirming that urine samples for the ISV phase of the Project should be treated with the same level of specification and QA as the samples about to be re-analysed.

The Health Physics Provider responded with comments that, in summary, stated:

- 48 urine samples had been shipped for analysis;
- environmental samplers were not used for personal dose calculations;
- no worker had been denied information about their skin contamination or any of their personal records;
- the misunderstanding was coming from the fact that workers' personal files were being denied to the Project Manager's representatives, as the Health Physics Provider viewed this as a breach of confidence between the worker and the health physics organisation; and
- training and self-frisking that was being instituted for the control staff would allow the introduction of food and drink into the control room.

On 14 July 1998, the ISV Contractor submitted a response to the Department that explained why the stack monitor and sampler was never intended to provide health physics-related data. Its sole purpose was to provide process control data. Clarifications were made concerning the control zone or exclusion area around the ISV hood—a total health and safety, rather than just radiological, exclusion zone. Clarifications were made about monitoring vehicles in and out of the red area, stating that vehicles travelling in and out of the red area stayed in the forward area and did not travel to the village. The ISV Contractor challenged the view that 'off-normal' conditions warranted considerations of evacuation and an emergency response for release of gases as monitored by the stack air monitors. It considered that the emissions at the stack were only an indicator of potential hazards on the ground from the dispersed plume and where workers are located. The ISV Contractor preferred that all releases should be individually considered and the personnel be moved when appropriate. The ISV Contractor further clarified that workers rarely if ever entered the hood during hood dismantling, and never during operations.

In July 1998, a conference call between the members of the HPRT was held to review the comments received by the contractors who had been given the opportunity to review the audit report in draft. Minor changes were made to correct findings of fact, but little change was made to the recommendations and the report was finalised and issued.

Late in July 1998, the Project Manager provided further comments on the draft HPRT report. It noted some inaccuracies in the report and the actions taken to address recommendations. It was suggested by the Project Manager that there had been earlier confusion about implementing previous bioassay recommendations, and it was now noted that the Department's position on bioassay had altered significantly since that time. The Project Manager confirmed that:

- the air monitoring regime had been finalised;
- ISV Contractor alpha monitors were not part of the environmental air sampling program; and
- the array of environmental air sampling units operated by the Health Physics Provider were fully adequate to establish a sufficient data bank for environmental air samples.

Personal air samplers had now been included in procedures. Workers had been briefed about their skin contamination results.

All vehicles used in central Taranaki were being monitored prior to return to the village. It was the ISV Contractor's decision to not eat and drink in the control trailer, and health physics procedures called for self-frisking to maintain cleanliness.

The Project Manager advised that it was withholding final personal dosimetry information from individual workers until revised wording was agreed with the Department and the Environmental Monitor. This would assist employees in the interpretation of their assessed exposures.

Actions that would summarise all significant Project records had been taken to develop a structure and contents list for their report to MARTAC:

- an action plan for bioassay was developed and submitted to the Department;
- action was taken to add more health physics staff;
- a range of meetings held at the site were believed to facilitate communication; and
- health physics briefings had been provided to workers and routine monitoring procedures had been refined and documented from initial ISV operational experience.

In October 1998, the Project Manager formally advised that all recommendations had been implemented, apart from one suggesting resampling for those samples that had leaked during transport.

The Health Physics Manager also made regular presentations to subsequent MARTAC meetings. These provided the only way the committee had to monitor the implementation of its and the HPRT recommendations. Reports were also received by the Department from the Environmental Monitor, acting in its role as the Health Physics Auditor, although MARTAC did not receive copies. Beginning at the MARTAC meeting on 13 January 1999, the Health Physics Auditor joined MARTAC at its meetings and participated in the briefing received by the Health Physics Manager.

Brief excerpts covering health and safety issues addressed at subsequent MARTAC meetings in discussions with the Health Physics Manager are given in *Appendix 5.4*.

5.7 AUDITS—OHS

In 1999, the Project Manager commissioned an independent audit of OHS at the site. This was divided into two parts:

- a general overview of OHS management at Maralinga; and
- a 'legislative audit' that aligned field practices to the specific requirements of the *Occupational Health Safety and Welfare Act 1986* (SA) and *OHSW Regulations 1995* (SA).

The auditor found that the Project Manager was well aware of its responsibilities and was fulfilling its obligations. However, it was noted that the situation of multiple contractors, not all of whom were answerable to the Project Manager, led to variable attention to OHS requirements and to less than desirable communication between them. In the legislative audit, attention was drawn to numerous points of detail where practices were not in strict compliance with regulations and recommended appropriate corrective action. Many of these were basically minor in nature, and had frequently been corrected by the time of the final report. A copy of the audit report is provided as *Attachment 5.9*.

With respect to the ISV Contractor, the auditor found that its site plan was appropriate but pointed out that it did not include a risk assessment related to the possible explosion and the potential outcomes and consequences.

5.8 INCIDENTS AND EMERGENCIES

A major incident occurred on 21 March 1999, when a sudden release of gases occurred during the final stages of the treatment of pit 17 at Taranaki by the ISV process. This resulted in the ejection of large quantities of gases and molten material from the pit that, in turn, resulted in the panels of the hood structure falling in on the pit and to a fire on top of the structure. The radiological implications of the incident were minor, with no exposure to personnel or spread of contamination outside controlled areas. Some molten material flowed over the base of the hood for approximately 1 m and glass beads were ejected mostly within 20 m, but with small quantities reaching 70 m in a north-easterly direction. These glass beads were easily identified and removed, leaving no contamination in the soil. Area monitoring carried out after the event indicated that the radioactive components had been incorporated in the melt phase and nearly all of the melt material remained within the hood and its immediate vicinity.

While no worker was hurt or exposed to radiation, the incident was nevertheless a serious accident from an OHS perspective, because of the potential physical harm it could have caused to personnel rather than from its radiological impact.

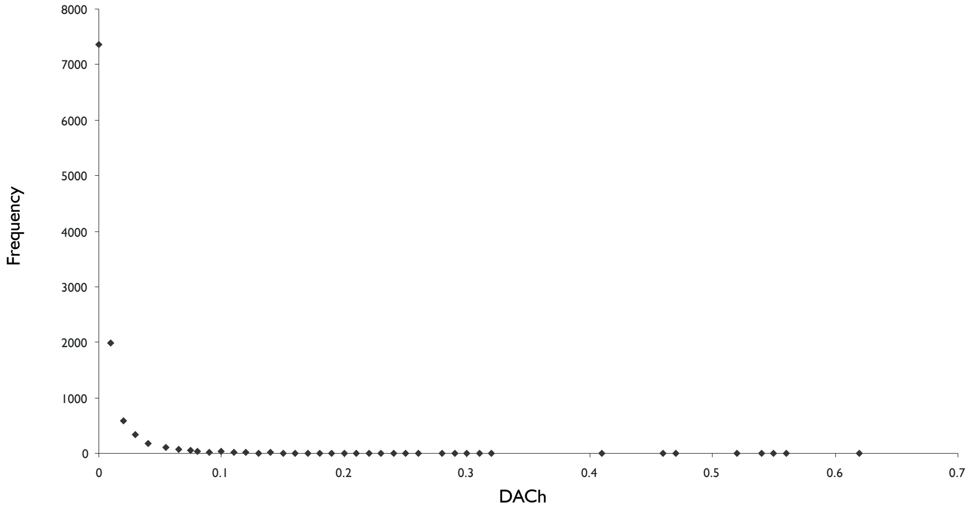
5.9 CONCLUSIONS

In general it can be concluded that the management of health and safety throughout the Project was satisfactory in its outcomes. Contractors managed OHS within their own tasks in a manner that was consistent with the site-wide *OH&S Strategic Plan* and the injury record throughout the four years of the Project was on par with Australian mining experience.

The one serious accident—the pit 17 explosion—fortunately took place at a time when no-one was nearby and was therefore without actual occupational health consequence. It did, however point to shortcomings in the design of the ISV process as applied at Maralinga. The nature of the event is discussed in three reports by the ISV Contractor, the ISV Contractor's contractor Vitchem and by EntecUK/Robsearch, commissioned by the Project Manager. These are to be found at *Attachment 4.5*.

Radiological control was thorough and occupational exposures extremely low. The overall outcome is perhaps best exemplified by the distribution of inhalation intakes for the entire designated workforce, as presented in Figure 5.14. Excluding the problematical intake of uranium by two of the three workers engaged in the hand scavenging of uranium at Kuli, average annual exposures for designated workers was 3.4 μSv with a maximum individual annual exposure of 35 μSv. These very low exposures must have been due, at least in part, to a thorough, documented and strictly applied system of written health physics procedures, supported by method of work descriptions. Reported radiological incidents were insignificant in terms of exposure and consisted mainly of failures to comply with procedures.

Figure 5.14 Distribution of inhalation intakes—all designated workers.



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APPENDICES

5.1 Summary of deliberations, first HPRT audit

5.2 Summary of deliberations, second HPRT audit

5.3 Minutes of teleconference on status of bioassays

5.4 Health and safety issues addressed at MARTAC meetings

ATTACHMENTS

5.1 Policy on radiation protection practices in the rehabilitation of former nuclear weapons test sites at Maralinga.

5.2 Facility licence issued by ARPANSA

5.3 List of health physics procedures

5.4 Summary table of mean and maximum intakes

5.5 First HPRT audit report

5.6 Second HPRT audit report

5.7 Review of non-conforming bioassays

5.8 HPRT comments on urine analysis

5.9 OHS audit report

5.10 ARPANSA audits of uranium dose to two Kuli workers

CHAPTER 6

POST-REHABILITATION STATUS AND PLANNING AT MARALINGA AND EMU

6.1 POST-REHABILITATION STATUS OF THE PROJECT

This chapter details the features of Maralinga and Emu subsequent to the completion of the Project and planning efforts for future use of the sites after handback to the traditional owners and the State of South Australia. One site (referred to as Tufi, see Figure 6.1) prepared for testing with a similar layout of ring roads and radials to those at Taranaki was not used for any testing purposes and found to be free of contamination. It will not be discussed further in this report.

Figure 6.2 shows the post-rehabilitation features of Maralinga, including the various soil removal areas at Maralinga and the burial trenches constructed during the course of the Project, as well as the sources of buried materials.

Figure 6.1 Aerial photograph showing the distinct landscape markings of the Tufi site.

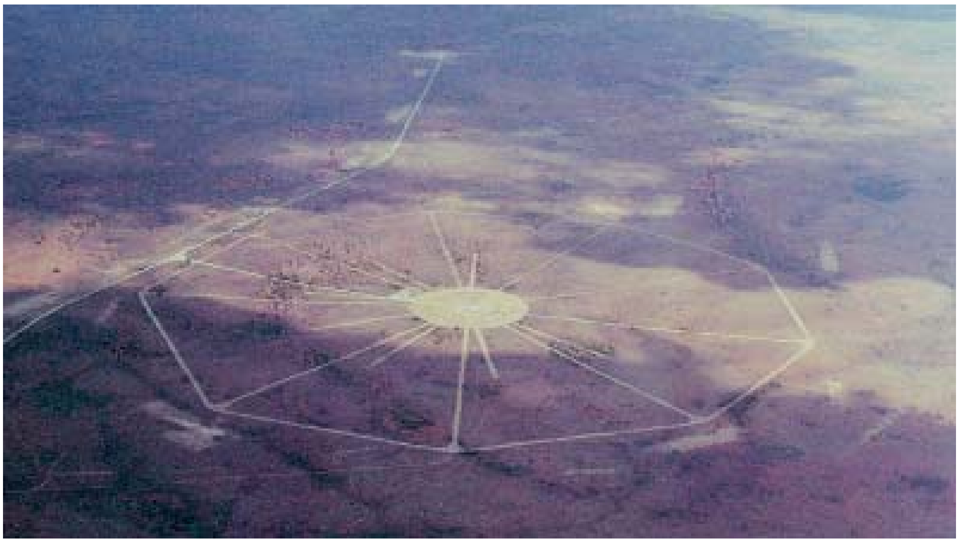


Figure 6.2 Key features constructed during the course of the Project at Maralinga.

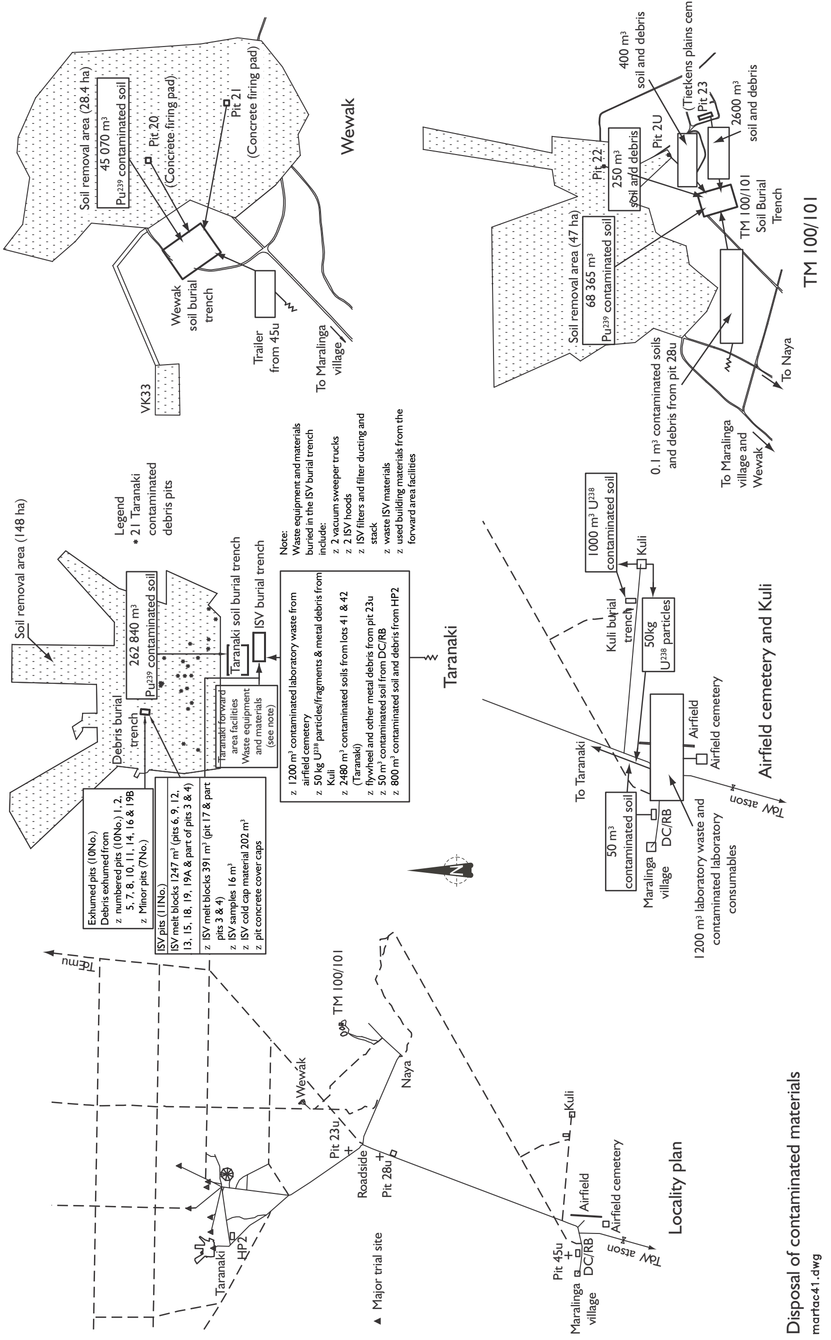
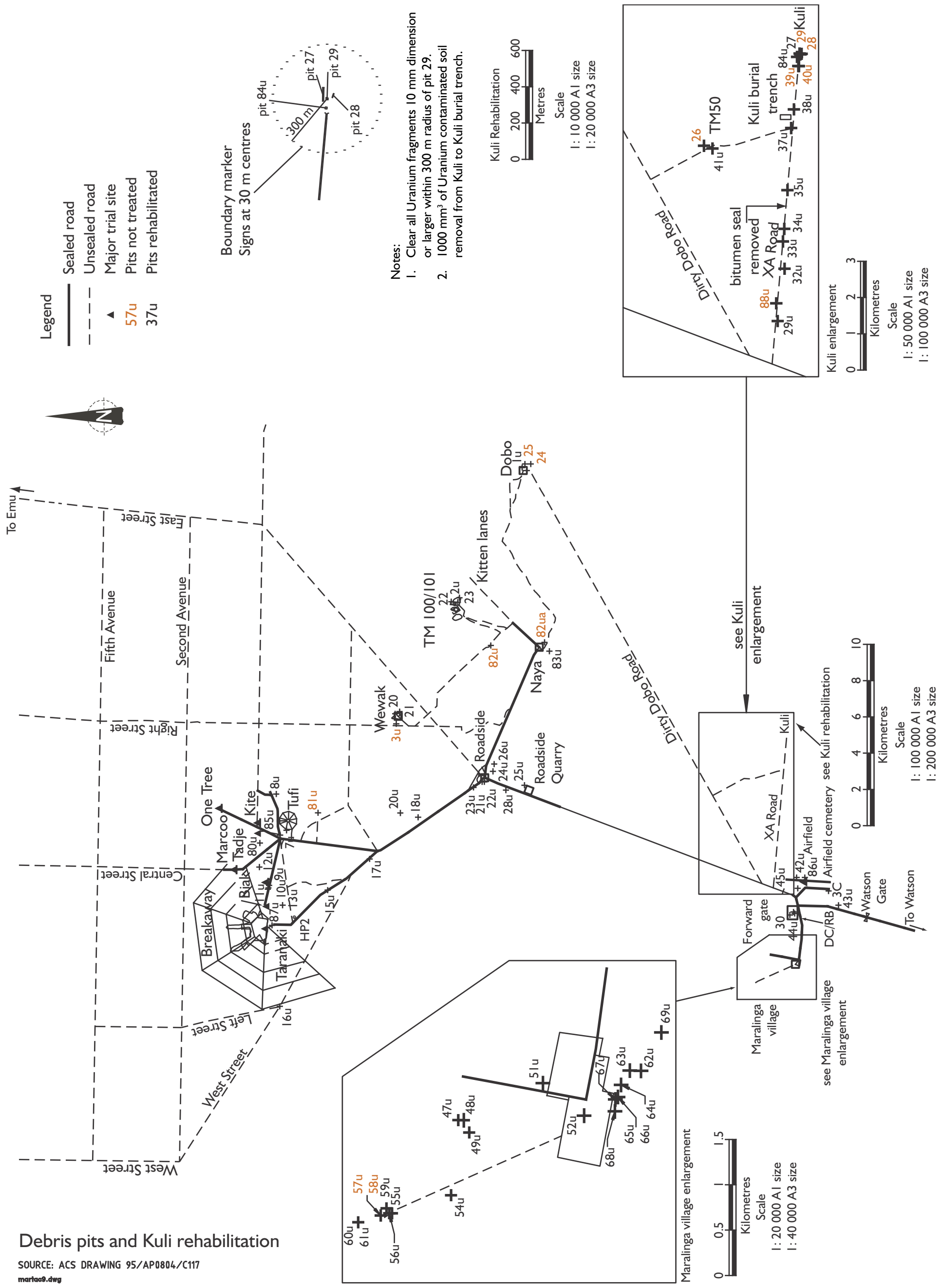


Figure 6.3 Location of the informal pits or mounds remaining from the time of the British involvement at Maralinga.



Notes:
1. Clear all Uranium fragments 10 mm dimension or larger within 300 m radius of pit 29.
2. 1000 mm³ of Uranium contaminated soil removal from Kuli to Kuli burial trench.

Debris pits and Kuli rehabilitation

SOURCE: ACS DRAWING 95/AP0804/C117

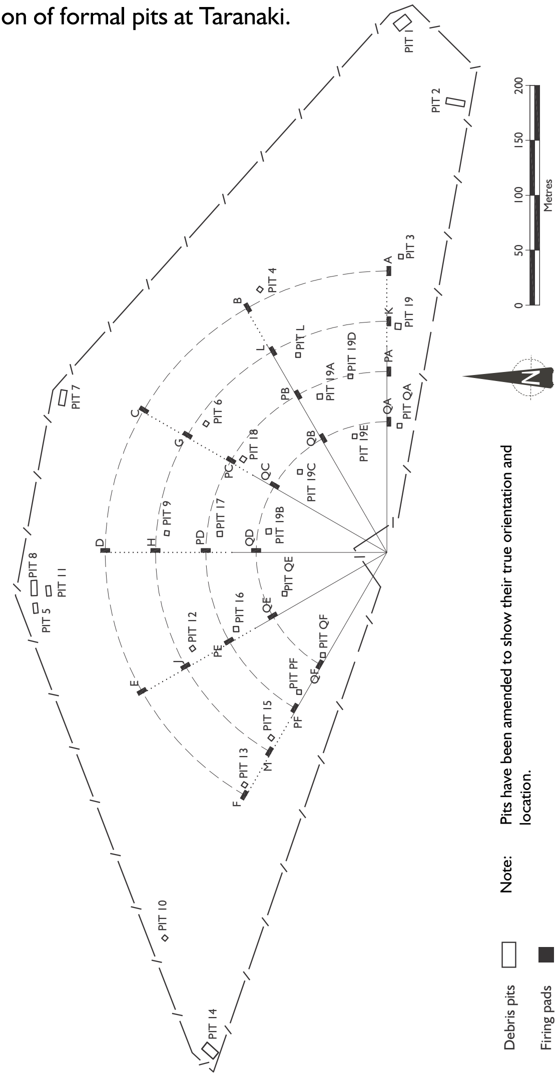
marlaa9.dwg

6.1.1 TARANAKI

The post-rehabilitation status of the Project at Taranaki is shown in Figure 4.6, indicating the positions of the soil burial trench, the ISV burial trench, the debris burial trench and where clean fill was introduced over areas approaching the clearance limit. Features of Taranaki post-rehabilitation include:

- the locations of the formal pits associated with British firings and the eight other minor debris pits which were also exhumed (Figure 6.4); and
- location of the boundary marking signs (see *Chapter 3*, Figure 3.6).

Figure 6.4 Location of formal pits at Taranaki.



Note: Pits have been amended to show their true orientation and location.

6.1.1.1 Taranaki soil removal area

As is discussed in detail in *Chapter 4*, the Taranaki soil removal area is that portion of Taranaki that has been rehabilitated by removal of a minimum of 100 mm of the soil from the surface of the ploughed areas (approximately 1.5 km^2). The Taranaki soil removal area was determined by the Environmental Monitor through a series of contamination surveys conducted prior to the soil removal operations. This process is detailed in *Sections 3* and *4* of this report and in specific ARPANSA reports.

The layout of the Taranaki lots is illustrated in Figure 4.5 and the coordinates of their corners are reported in *Appendix 6.1*[28], Table 6.1.1. This contaminated soil was placed at least 3 m below the ground's surface in a burial trench (the Taranaki soil burial trench, 206 m x 141 m at grade level and 15 m deep). The soil was then covered by a minimum of 5 m of clean fill that included some mounding over the trench. An aerial photograph of the remaining features surrounding the soil removal area is shown in Figure 6.5. *Appendix 6.1*, Table 6.1.2 contains the lot clearance summaries for the 42 lots where soil removal operations were conducted and then cleared by the Environmental Monitor.

6.1.1.2 Soil removal boundary verification

As is discussed in *Section 4.2.4*, OKA measurements were conducted around the perimeter of the soil removal boundary at distances of 100 m, 350 m and 600 m from the soil removal area. These show clearly that the dispersed activity in the area directly surrounding the Taranaki soil removal area is well below the 40 kBq/m^2 Am^{241} criterion.

A composite representation of the residual activity left in the Taranaki area, based on all of the ground-based measurements carried out by the Environmental Monitor, is presented in Figure 6.6, taken from *Attachment 6.5*. The resuspension characteristics of the cleared land and the changes in them over time, are provided in *Attachment 6.3.*

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[28] Coordinates are given relative to the Australian coordinate system, Geocentric Datum of Australia (GDA). The transformations from GPS to GDA are described in *Attachment 6.6*.

Figure 6.5 Aerial view of Taranaki soil removal area and surrounds.

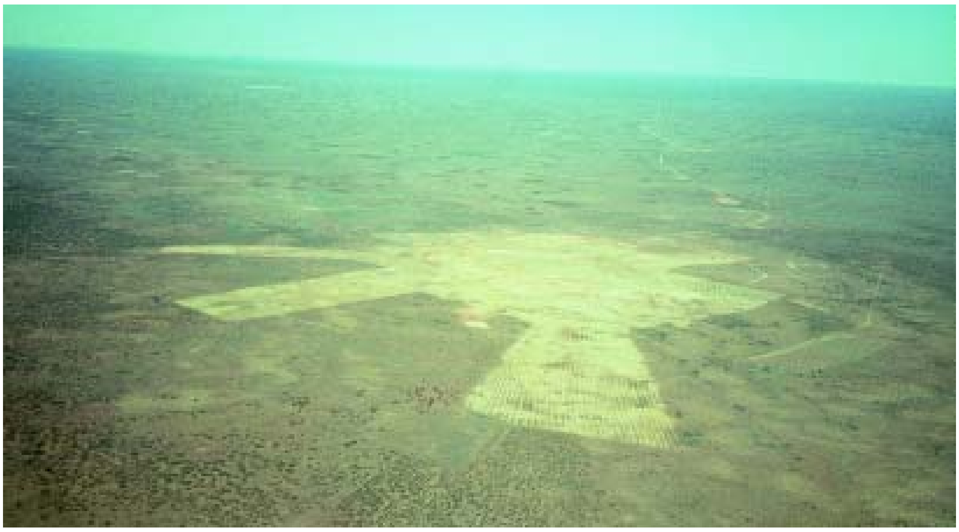
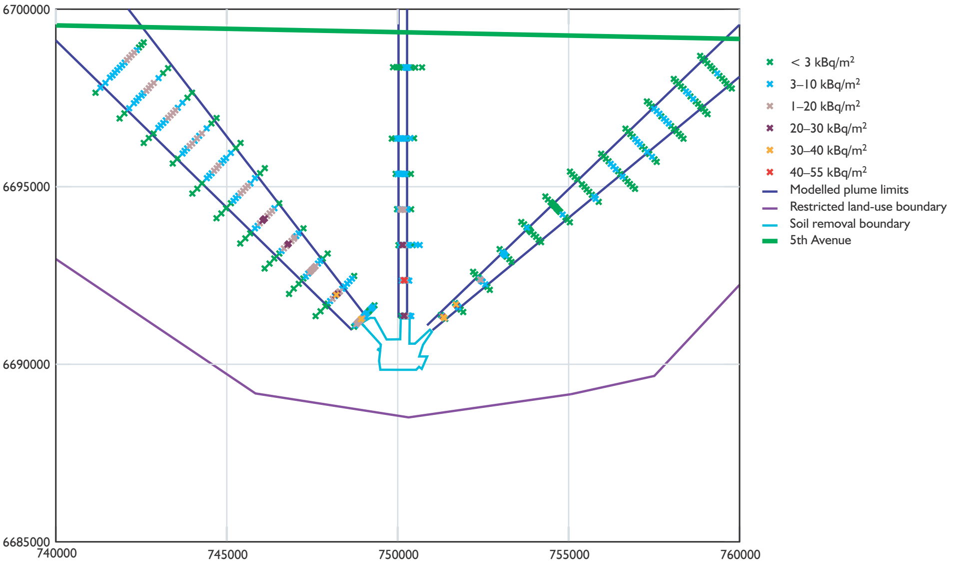


Figure 6.6 Residual contamination at Taranaki.



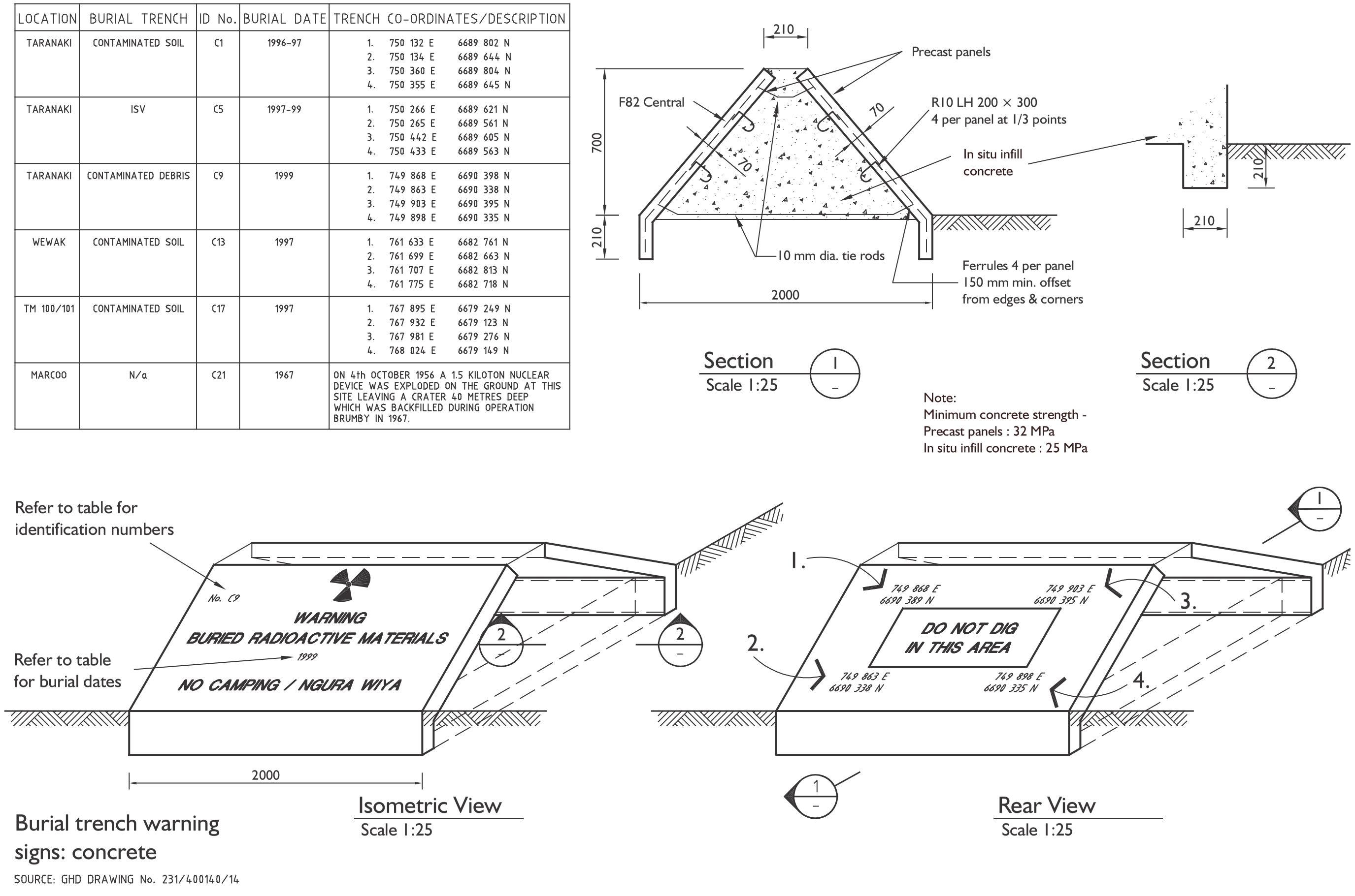
6.1.1.3 Taranaki soil burial trench

The Taranaki soil burial trench is marked by a concrete plinth in the most southerly corner of the trench. The other three corners of the trench are marked with metal signposts. These burial trench warning signs contain information about the contents of the trench, time of burial, and warnings regarding digging in that area. Figures 6.8 and 6.9 describe the physical attributes of these warning signs. The soil removal trench at Taranaki was operational from 1996 through to 1997. It was closed on 3 October 1997. The trench contains contaminated soil from the Taranaki soil removal area, some steel plates (*Section 4.2.3.3*) and miscellaneous debris, a total volume of 262 840 m^3. A photograph of a metal warning sign with the burial trench cap in the background is shown in Figure 6.7.

The coordinates of the corners of the Taranaki soil burial trench are provided in *Appendix 6.1*, Table 6.1.3. A longitudinal cross-section of the Taranaki soil burial trench is at Figure 6.10.

Figure 6.7 Metal warning sign at Taranaki soil burial trench.

Figure 6.8 Design of trench warning plinth.



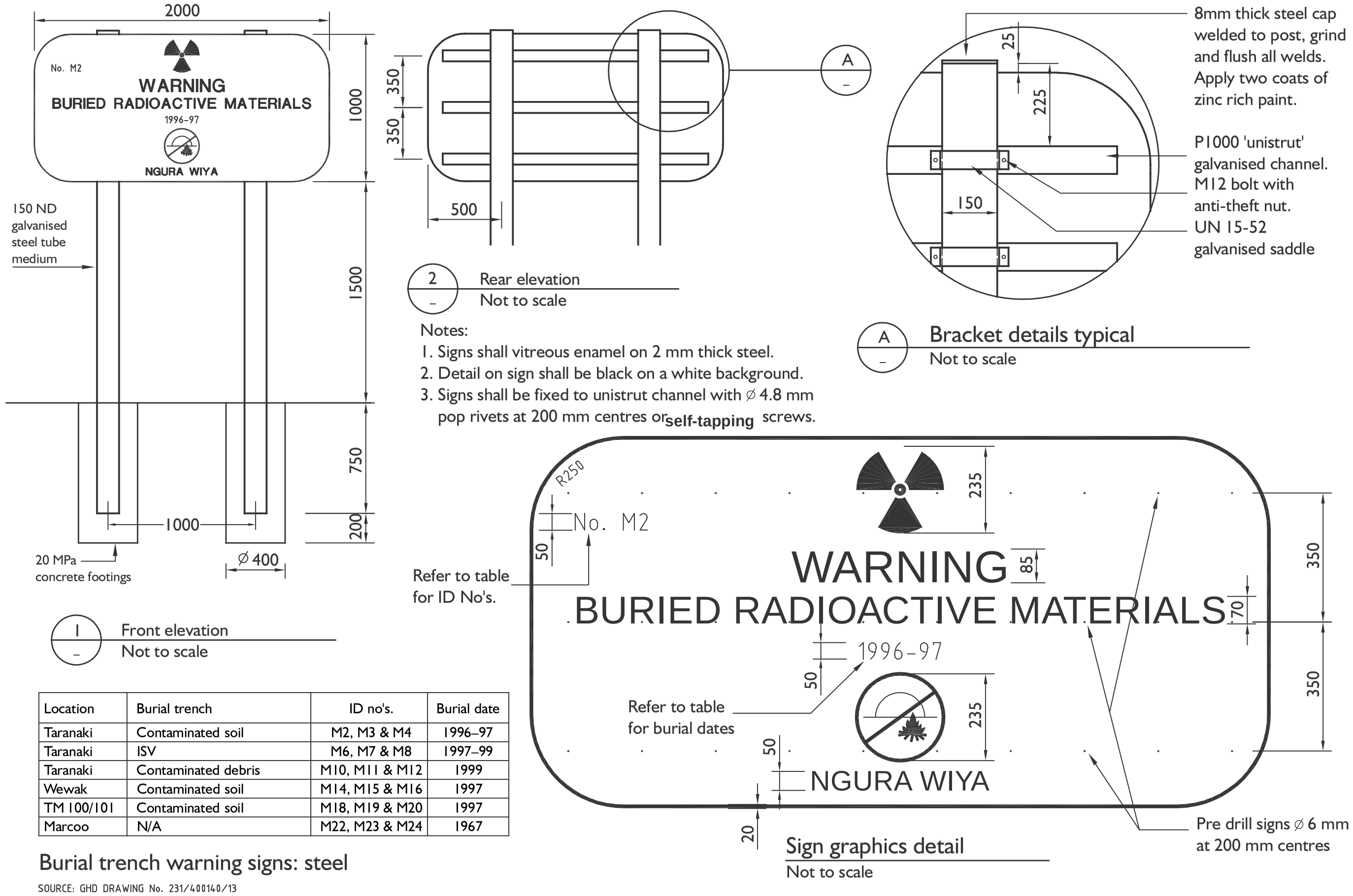
LOCATION	BURIAL TRENCH	ID No.	BURIAL DATE	TRENCH CO-ORDINATES/DESCRIPTION
TARANAKI	CONTAMINATED SOIL	C1	1996–97	1. 750 132 E 6689 802 N 2. 750 134 E 6689 644 N 3. 750 360 E 6689 804 N 4. 750 355 E 6689 645 N
TARANAKI	ISV	C5	1997–99	1. 750 266 E 6689 621 N 2. 750 265 E 6689 561 N 3. 750 442 E 6689 605 N 4. 750 433 E 6689 563 N
TARANAKI	CONTAMINATED DEBRIS	C9	1999	1. 749 868 E 6690 398 N 2. 749 863 E 6690 338 N 3. 749 903 E 6690 395 N 4. 749 898 E 6690 335 N
WEWAK	CONTAMINATED SOIL	C13	1997	1. 761 633 E 6682 761 N 2. 761 699 E 6682 663 N 3. 761 707 E 6682 813 N 4. 761 775 E 6682 718 N
TM 100/101	CONTAMINATED SOIL	C17	1997	1. 767 895 E 6679 249 N 2. 767 932 E 6679 123 N 3. 767 981 E 6679 276 N 4. 768 024 E 6679 149 N
MARCOO	N/a	C21	1967	ON 4th OCTOBER 1956 A 1.5 KILOTON NUCLEAR DEVICE WAS EXPLODED ON THE GROUND AT THIS SITE LEAVING A CRATER 40 METRES DEEP WHICH WAS BACKFILLED DURING OPERATION BRUMBY IN 1967.

Note:
Minimum concrete strength -
Precast panels : 32 MPa
In situ infill concrete : 25 MPa

Burial trench warning signs: concrete

SOURCE: GHD DRAWING No. 231/400140/14

Figure 6.9 Design of burial trench warning signs.



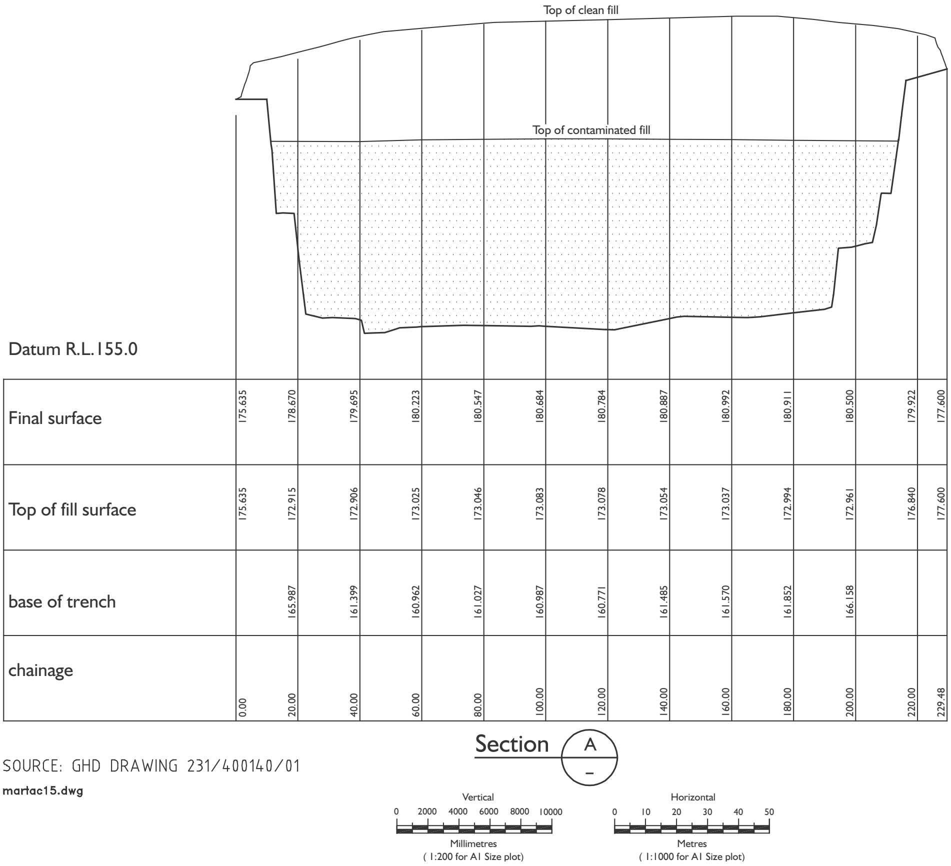
Notes:
1. Signs shall vitreous enamel on 2 mm thick steel.
2. Detail on sign shall be black on a white background.
3. Signs shall be fixed to unistrut channel with Ø 4.8 mm pop rivets at 200 mm centres or self-tapping screws.

Location	Burial trench	ID no's.	Burial date
Taranaki	Contaminated soil	M2, M3 & M4	1996–97
Taranaki	ISV	M6, M7 & M8	1997–99
Taranaki	Contaminated debris	M10, M11 & M12	1999
Wewak	Contaminated soil	M14, M15 & M16	1997
TM 100/101	Contaminated soil	M18, M19 & M20	1997
Marcoo	N/A	M22, M23 & M24	1967

Burial trench warning signs: steel

SOURCE: GHD DRAWING No. 231/400140/13

Figure 6.10 Longitudinal cross-section through the soil burial trench at Taranaki.



Final surface	175.635	178.670	179.695	180.223	180.547	180.684	180.784	180.887	180.992	180.911	180.500	179.922	177.600
Top of fill surface	175.635	172.915	172.906	173.025	173.046	173.083	173.078	173.054	173.037	172.994	172.961	176.840	177.600
base of trench		165.987	161.399	160.962	161.027	160.987	160.771	161.485	161.570	161.852	166.158		
chainage	0.00	20.00	40.00	60.00	80.00	100.00	120.00	140.00	160.00	180.00	200.00	220.00	229.48

SOURCE: GHD DRAWING 231/400140/01

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6.1.1.4 Taranaki formal disposal pits

Figure 6.4 shows the location within Taranaki of the Taranaki formal disposal pits, inner, outer and the eight minor, used by the British to dispose of debris from their testing program at Maralinga. In all there were 29 pits of various shapes and sizes containing this debris at Taranaki. Of these, 21 pits were designated for rehabilitation by use of the ISV technology, while the eight minor pits were discovered at the end of the inner and outer pit rehabilitation. Eleven of the 21 pits were treated in 13 melts by the ISV process. A more detailed account of this part of the program is to be found at *Section 4.6*. After a severe transient of the melt at pit 17 in March 1999, and subsequent notification by the ISV Contractor that no further ISV work would be conducted, the remaining ten pits were exhumed and their contents of debris and soil disposed of in the debris burial trench. The ISV blocks were subsequently removed from the 11 pits treated by ISV, broken up and examined, and the ISV block fragments disposed in the debris burial trench. Pit 17 and portions of pits 3 and 4 were disposed of in the ISV burial trench.

Although the pits are shown in Figure 6.4, they are now indistinguishable from the rest of the soil removal area (both physically and radiologically) and are considered to be clean. A photograph of the central Taranaki area where these pits were located, as it is post-rehabilitation, is shown in Figure 6.11, where the windrows laid as native seed traps are clearly evident.

Figure 6.11 Post-rehabilitation aerial view of central Taranaki.

After the pits had been exhumed they left potentially contaminated empty holes in the ground. Figure 6.12 is a photograph of the exhumed pit 17. Clearance of these areas required different criteria than that for the rest of the soil removal area. Because the pits were to be re-filled with clean material, it was not necessary for them to be as scrupulously clean as surrounding surface areas but, nevertheless, it was not desirable that significant amounts of contamination should remain, buried in a casual fashion in these pits. It was considered that a suitable criterion was that the inside surfaces of the pits should not be more contaminated than those areas remaining at the boundaries of the soil removal area. This corresponded to dispersed contamination of 20 kBq/m^2.

Details of clearance of individual pits are kept in pit clearance folders and individual Maralinga field trip reports on file at ARPANSA (Lower Plenty Road, Yallambie, Victoria, Australia). The coordinates of the 21 formal debris pits and the eight pits discovered later at Taranaki are provided in *Appendix 6.1*, Table 6.1.4.

6.1.1.5 Debris burial trench

The debris burial trench is the trench established in 1999, sized initially for disposal of soil and small debris (less than 100 mm in size) from the eight outer pits at Taranaki. It was subsequently extended for interim storage in separate stockpiles of the large exhumed debris from the eight outer Taranaki pits pending a decision

Figure 6.12 Exhumed pit 17 in central Taranaki prior to backfill.

between proceeding either with the ISV 'hybrid' option, or with the alternative of permanent burial. In the event, the debris burial trench was used both for the disposal of the Taranaki formal disposal pits debris and most of the vitrified pit melts. The location of the trench is shown in Figure 4.6. Its dimensions and design are detailed in *Chapter 4*. The trench contents are covered with uncontaminated rock and soil cover to a minimum depth of 5 m. The contents of the debris burial trench and their distribution within the trench are described in *Attachment 4.4*, *Section 11.9*. The trench is marked by a concrete plinth at the southerly corner and by three metal signposts at each of the other corners. Figure 6.13 shows a long-section view of the location of the debris within the trench.

Coordinates of the pit debris burial trench are provided in *Appendix 6.1*, Table 6.1.5.

6.1.1.6 ISV burial trench

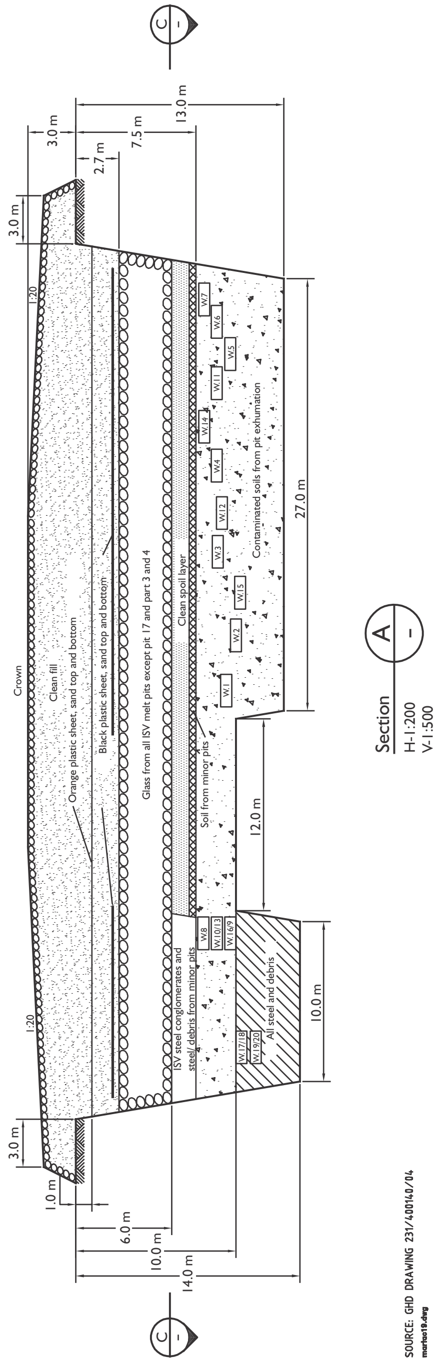
Any non-contaminated debris associated with the ISV phase was buried in a third trench—the ISV burial trench.

During operations of the ISV plant, it was necessary to plan to dispose of contaminated materials that were generated during operations. These materials consisted of used electrodes, contaminated filters, and other operational waste generated during the treatment of the Taranaki formal disposal pits. The ISV burial trench was in use from 1997 through to 1999 and its location is identified in Figure 6.2 as the ISV burial trench. It is marked similarly to the Taranaki soil burial trench with a concrete plinth in the southerly corner of the trench and with metal warning signs at each corner of the trench. The ISV burial trench contains, inter alia:

- 391 m^3 of ISV melt block from pits 17, 3 and 4;
- 16 m^3 of ISV samples;
- 202 m^3 of ISV cold cap materials;
- the pit concrete covers;
- 1200 m^3 of contaminated laboratory waste from the airfield cemetery;
- surface soil from lots 41 and 42 at Taranaki;
- particles and fragments from the Kuli site;
- ISV equipment; and
- building materials from the forward area facilities.

A photograph of the ISV burial trench plinth in front of the trench cap is shown in Figure 6.14. Coordinates of the corners of the ISV burial trench are provided in *Appendix 6.1*, Table 6.1.6.

Figure 6.13 Long section of Taranaki pit debris burial trench, showing disposition of contents.



SOURCE: GHD DRAWING 231/400140/04
martac19.dwg

Figure 4.19 shows a cross-section through the trench including the location of the various components of the material buried there, while *Appendix 6.1*, Table 6.1.7 summarises its contents.

6.1.1.7 The outer perimeter boundary

An outer perimeter boundary (see Figure 3.6), largely following existing roads, encloses the plumes to include all areas where full-time occupancy would lead to annual doses, which MARTAC had taken from TAG to be 5 mSv, but which are now assessed to be less than 1 mSv. The basis of this revision downwards lies in more definitive recent measurements of the surface activity concentration and a revision of the dose conversion coefficients for the relevant radionuclides (*Attachment 6.2*, ARL inhalation dose assessment). Land-use restriction is still necessary however, to eliminate the ingestion pathway for infants. This boundary consists of a series of marker poles that carry a warning that areas within it are not suitable for camping. Hunting and passage through the area are however acceptable practices. The total length of the perimeter boundary is approximately 80 km. Figure 3.5 shows a typical boundary marker sign.

Figure 6.14 The post-rehabilitation ISV burial trench.

6.1.2 TM 100/101

6.1.2.1 Soil removal area and windrows

The soil removal area of TM 100/101 was divided into 14 lots prior to rehabilitation, with an additional lot (lot 12A) defined during the rehabilitation process, after it was found that the soil removal boundary area was not correctly surveyed for rehabilitation. The GPS coordinates of these 15 lots are provided in *Appendix 6.1*, Table 6.1.8 and the entire soil removal area for TM 100/101 is shown in Figure 4.12. This area was remediated to a level not to exceed 1.8 kBq/m^2 of Am^{241} for the TM100 area and a level of 4.0 kBq/m^2 for the TM101 area. All particles detected with activities greater than 30 kBq/m^2 of Am^{241} were removed and no visible fragments were remaining (*Attachment 4.3*). Clean soil was added to the soil removal area to form windrows for the acceleration of revegetation. These windrows are clearly visible at the site. *Appendix 6.1*, Table 6.1.9 summarises the lot clearance data for the lots at TMs.

Soil was removed from each lot generally to a depth of at least 100 mm although where there were elevated rock levels it occasionally may have been less. This contamination was placed at least 3 m below the ground surface in a burial trench 130 m x 87 m (at grade level) and 16 m deep. A detailed trench survey drawing may be found in *Attachment 4.4*, *Appendix B*, Figure 16. The soil was then covered by a minimum of 5 m of clean fill.

Clearance documentation has been retained by the Environmental Monitor, and can be referenced through *Attachment 4.3*.

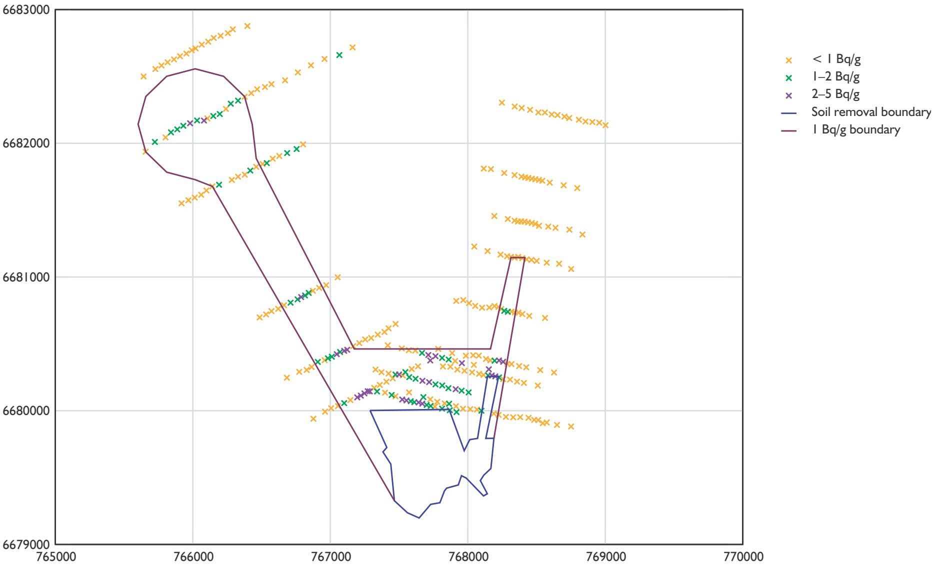
Figure 6.15 Aerial view of the TMs site after rehabilitation—with trench cap in background.

A composite representation of the residual activity left in the TMs area, which is based on all of the ground-based measurements carried out by the Environmental Monitor (*Attachment 6.5*), is presented in Figure 6.16.

Two pits were excavated at the main TM100/101 site on lots 10 (pit 2U) and 11 (pit 22). A larger pit was also excavated at the Tietkens Plain cemetery site (pit 23), to the south-east of TM 101, together with a smaller adjacent pit 23A, that had not been listed by Pearce (1968). The process of pit exhumation is summarised in *Section 4.5* and details of the measurements conducted over the pit are in the Environmental Monitor's pit clearance folders.

The coordinates of these exhumed pits are given in *Appendix 6.1*, Tables 6.1.10, 6.1.11 and 6.1.12.

Figure 6.16 Residual contamination at TMs.



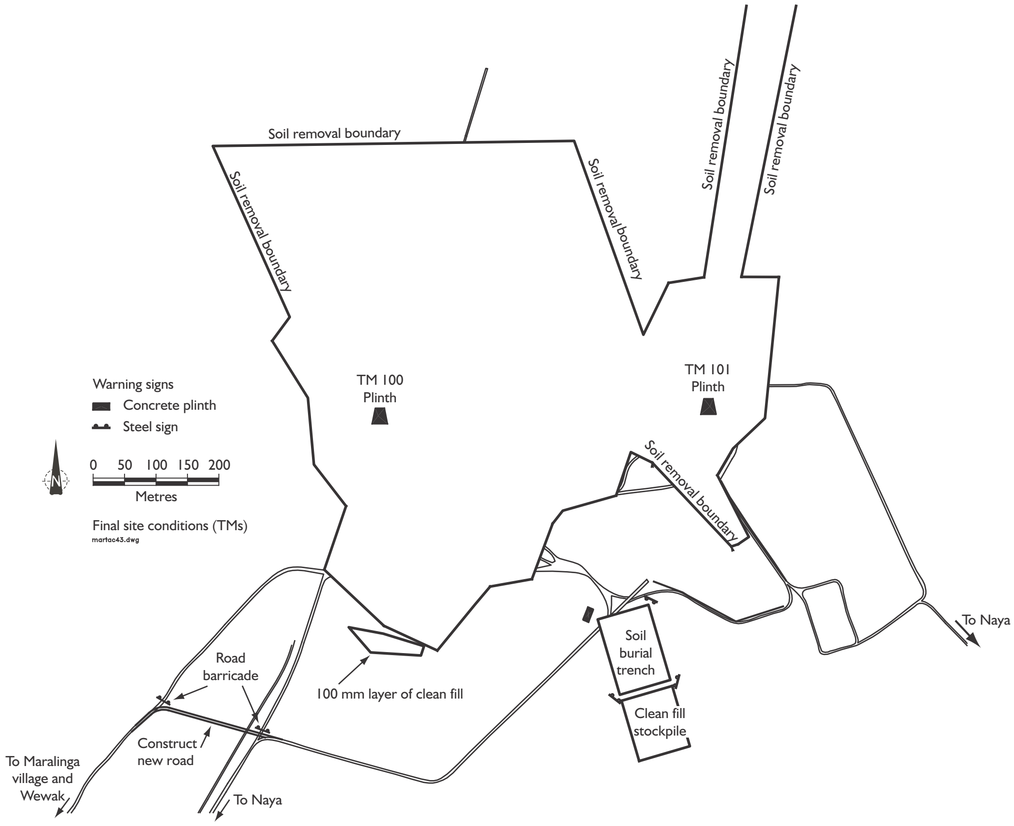
6.1.2.2 TM100/101 trench

The location of the TM100/101 trench is shown in Figure 6.17. The trench is marked by a plinth on the southerly corner of the trench and metal signposts at the other corners. These warning signs are described in Figures 6.8 and 6.9.

The coordinates of the TMs burial trench are provided at *Appendix 6.1*, Table 6.1.13.

The trench contains contaminated soil from the TM soil removal area, 47 ha (68 365 m^3 of plutonium contaminated soil), the contents of formal disposal pit 22 (600 m^3 of soil and debris), informal pit 2U (550 m^3 of soil and debris) and the Tietkens Plain cemetery formal pit (23 500 m^3 of soil and debris) and pit 23A. The trench was in use during 1997.

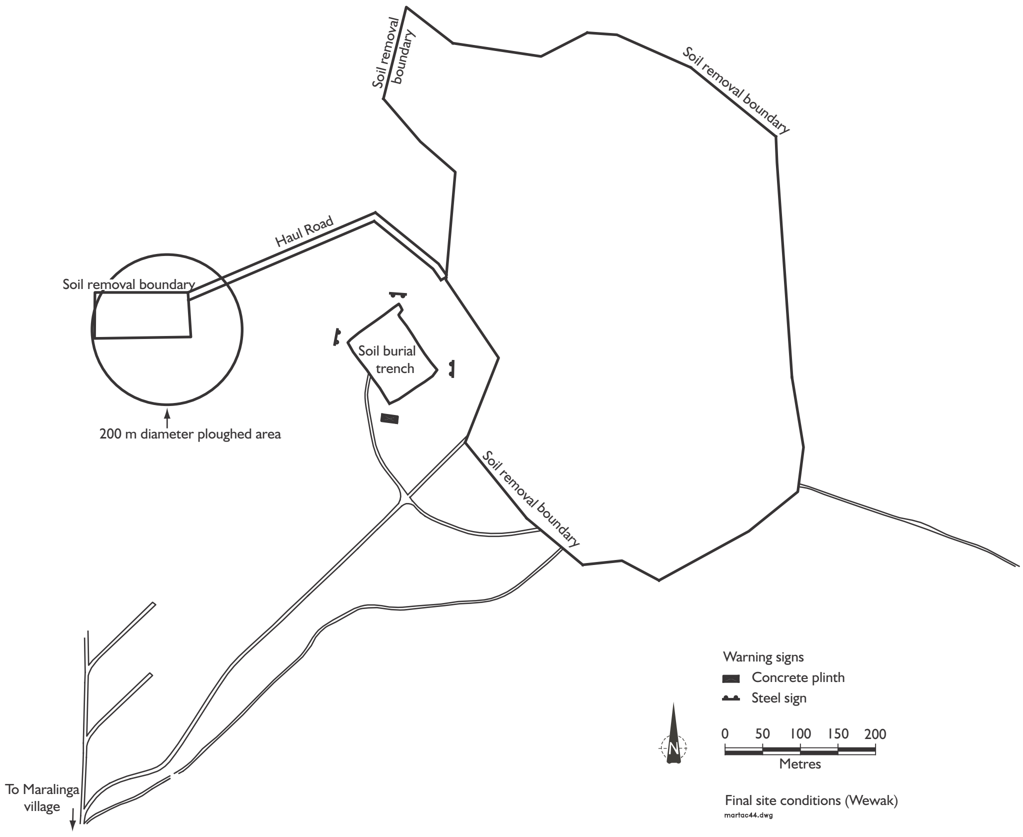
Figure 6.17 Final state plan of TMs.



6.1.3 WEWAK

Figure 6.18 is an enlargement of the Wewak part of the diagram of the entire Maralinga site post-rehabilitation shown in Figure 6.2. This figure shows the general size of the soil removal area, the relative locations of the soil removal trench, and the separate soil removal area at British trial site VK33.

Figure 6.18 Plan of Wewak after rehabilitation.



6.1.3.1 Lots

The Wewak soil removal area was divided into eight lots, approximately between 0.7 and 5 ha in size, for treatment and subsequent monitoring. The cleared area on Emu Road was not given the title of a lot and was treated by pushing the surface soil back from the road for a distance of 100 m on each side. ARPANSA's monitoring of the Emu Road area, following treatment, was identical to monitoring of cleared lots. The coordinates for each of the Wewak lots are given in *Appendix 6.1*, Table 6.1.14.

The Earthworks Contractor subdivided the site into the lots and removed the soil from each, generally to a depth of at least 100 mm unless prevented by underlying rock. Once soil removal was completed, the Health Physics Provider assessed each lot for compliance with end-state criteria. Once this had been reached, access was granted to ARPANSA for final verification monitoring. Handover documentation including details of the lot coordinates, means of transport to and from the lot, and any other relevant information were given to ARPANSA. Clearance verification can be found in *Attachment 4.3*.

6.1.3.2 Wewak trench

The Wewak site was part of the minor trials program at Maralinga carried out as part of the *Vixen A* trials. The location of the Wewak site can be found in Figures 6.2 and 6.3. The Wewak trench contains the contaminated soil from the lots in the Wewak soil removal area (28.4 ha and 45 070 m^3 of soil) as well as the contents of the concrete firing pads designated in British documents as pits 20 and 21. Each of these lots was then dealt with individually during soil removal and verification. This contamination was placed at least 3 m below the ground's surface in a burial trench, on average 100 m x 70 m and 11 m deep (see *Attachment 4.4*, *Appendix B*, Figure 17 for further detail). The soil was then covered by a minimum of 5 m of clean fill.

The coordinates of the burial trench, with the plinth in the southwest corner and warning signs at each of the other corners, are given in *Appendix 6.1*, Table 6.1.15.

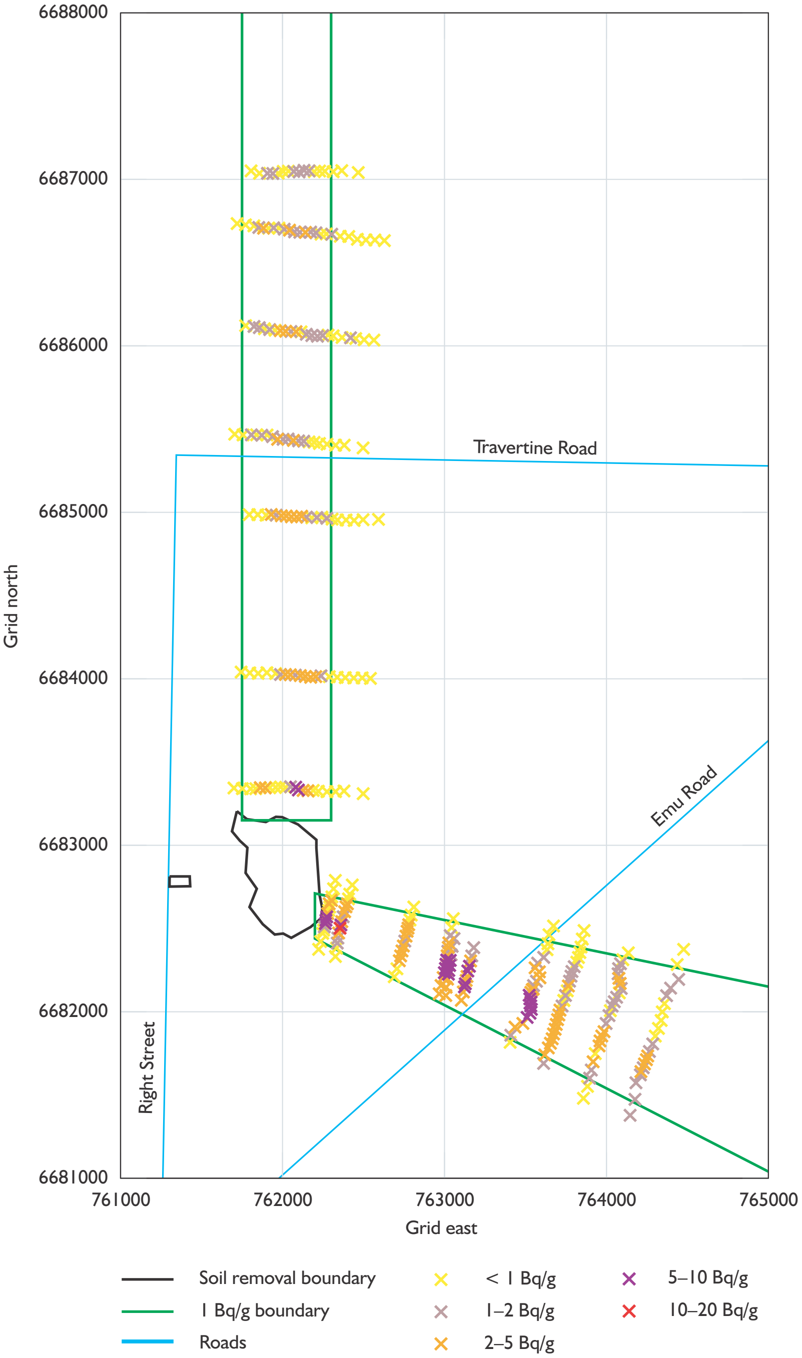
The plutonium contamination at Wewak consisted of fragments, particles and dust. The resulting remediated area had no contamination exceeding 1.8 kBq/m^2 of Am^{241}, no particles with a contamination level of greater than 30 kBq, and no visible fragments in the soil removal area. *Appendix 6.1*, Table 6.1.16 provides the lot clearance data for the Wewak soil removal area and Emu Road.

The trench is marked with a concrete plinth at the southerly corner of the trench and metal signposts at each of the other corners. Descriptions of the signs are found in Figures 6.8 and 6.9. The soil removal area has been recontoured and revegetated. Details of the design and construction of the trench as well as the operations of clean-up can be found in *Chapter 4*. An aerial photograph of the Wewak area showing the recontoured and revegetated soil removal area is shown as Figure 6.19.

A composite representation of the residual activity left in the Wewak area, which is based on all of the ground-based measurements carried out by the Environmental Monitor (*Attachment 6.5*), is presented in Figure 6.20.

Figure 6.19 Aerial view of Wewak site after rehabilitation—with trench cap on right.

Figure 6.20 Residual contamination at Wewak.



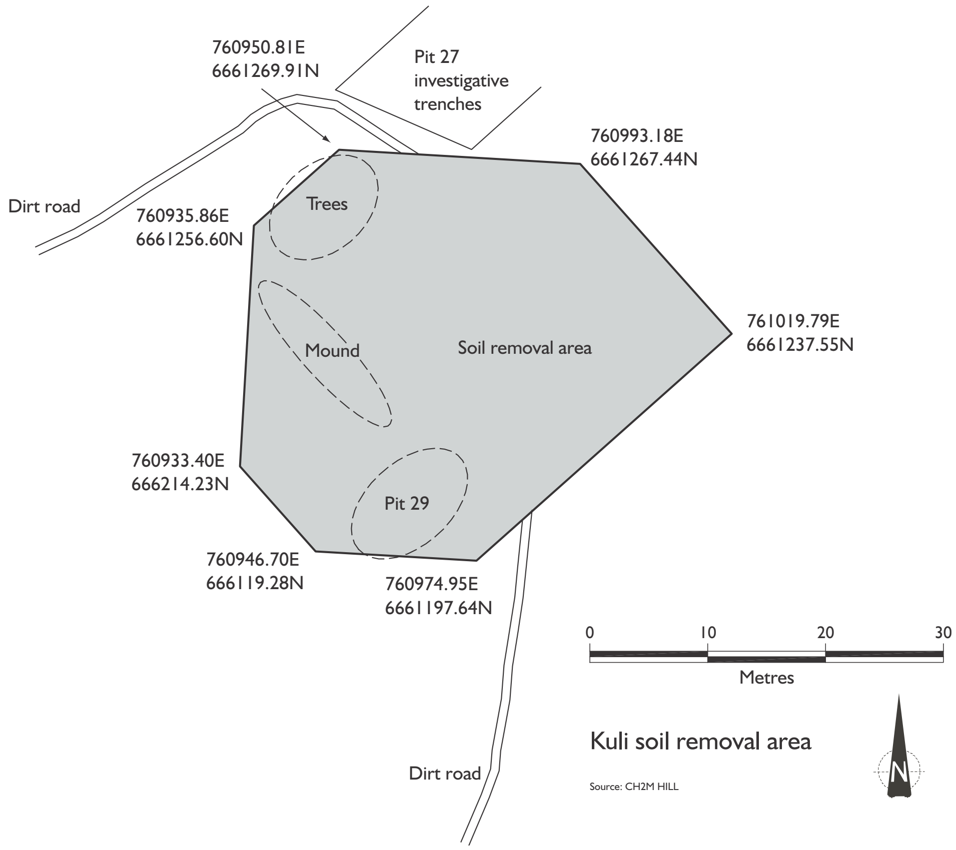
6.1.4 KULI

The Kuli area, showing the soil removal boundary, is shown as Figure 6.21.

6.1.4.1 Kuli soil removal area

Kuli was the location used by the British for many series of development trials called *Tims*. In the *Tims* trials, natural or depleted uranium was used in lieu of plutonium or enriched uranium. Beryllium was also present. These trials gave rise to three hazards—chemical explosion, particulate beryllium and particulate uranium. The trials and the operations for rehabilitation of Kuli can be found in detail in *Chapter 4* of this report. Uranium fragments were abundant in the Kuli area when initially surveyed in 1985. These fragments posed a scavenger hazard and it was agreed that this site should have a restricted occupancy. Formal scavenging of the Kuli site by operations personnel was conducted.

Figure 6.21 Kuli soil removal area.



Kuli soil removal area

Source: CH2M HILL

Initial recommendations for the rehabilitation of Kuli were that the site be recontoured and re-seeded in order to control the erosion potential of the surface. The surface was later stripped of the contaminated soil in an area in the central part of Kuli and this soil was buried approximately 1.5 km west of Kuli in the Kuli soil disposal trench. The post-rehabilitation status of Kuli is that the soil removal area is enclosed by boundary markers that delineate a surface activity of uranium of 5 kBq/m^2. This boundary excludes the possibility of family units camping in this area. The bitumen surface of the access road has been removed for the entire length of Kuli Road, the soil removal area has been recontoured with clean soil and the area has been re-seeded. An aerial photograph of the Kuli site is shown in Figure 6.22.

6.1.4.2 Kuli soil burial trench

The Kuli soil burial trench is marked by warning signs similar to those that mark the 300 m boundary at the Kuli soil removal area and surrounding area. The coordinates of the burial trench are given in *Appendix 6.1*, Table 6.1.17[29].

Figure 6.22 Aerial view of Kuli, after rehabilitation.

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[29] In October 2002, the Environmental Monitor carried out a further survey in which the Nissan measurement system was used to investigate the surface density of fragments of 60 kBq or greater as a function of distance from the firing pad (see *Attachment 6.7*). This survey established that the surface density diminishes exponentially with distance, and that 1 km distance is approximately 2–3 particles per 10 000 square metres.

6.1.5 AIRFIELD CEMETERY

A plan view of the airfield cemetery is shown in Figure 3.14. This figure shows the location of the untreated pits within the airfield enclosure. An aerial photograph of the airfield is at Figure 6.23 with the airfield cemetery to the south-west of the airfield.

6.1.5.1 Formal debris pit exhumation area

The airfield cemetery was arranged with three classes of waste.

- Category 1 was the most active. The wastes were predominately the short-lived Th^{228} and Co^{60}.
- Category 2 wastes were lesser activities of Co^{60} and Th^{228} and with some burials involving Pu^{239}.
- Category 3 wastes were low level.

A total of 18 debris pits were located at the airfield cemetery. The contents of all Categories 1 and 2 pits and Category 3 pit C were exhumed, with pits 3A, 3B, and 3D being undisturbed. The exhumed pits were backfilled with radiologically clean soil and concrete rubble from pit caps. The debris was placed in the ISV burial trench. The airfield cemetery has no markings of the remaining pits and the remediated pits are indistinguishable from the surrounding area. The cyclone wire mesh fence has been left at the site as an historic item.

Figure 6.23 Maralinga airfield—looking towards the north-east, airfield cemetery is located near south-western end of airfield.

6.1.5.2 Unexhumed debris pits at the airfield cemetery

The unexhumed debris pits have no markings. The area of the airfield cemetery has background levels of contamination. The details of the operations at the airfield cemetery can be found in *Chapter 4* of this report. The locations of the untreated debris pits are listed in *Appendix 6.1*, Table 6.1.18.

6.1.6 *MARCOO* CRATER

Marcoo was a ground detonation of a weapon with approximately 1.5 kton yield. The crater formed by the detonation had a volume of approximately 6000 cubic yards, the diameter being approximately 50 m and depth 12 m surrounded by a rim of ejected material from the crater as a result of the explosion.

6.1.6.1 Markings, recontouring and revegetation

The filled in *Marcoo* crater has been marked by a plinth on the southerly corner of the site, and three warning signs placed at the one quarter points on the perimeter of the crater. The warning signs and concrete plinth are similar to those at the burial trenches. The top 5 m of the crater has been backfilled with uncontaminated clean soil.

A photograph of the *Marcoo* crater area showing the plinth identifying the ground zero for the *Marcoo* detonation and the surrounding recontoured area is shown in Figure 6.24.

Figure 6.24 Marcoo after rehabilitation.

6.1.7 GROUND ZERO MARKERS

The coordinates of the ground zeros for the seven British nuclear explosions at Maralinga and the two nuclear explosions at Emu are tabulated in *Appendix 6.1*, Table 6.1.19.

The plinths marking the locations of these detonations are typical of the *Marcoo* plinth. It must be noted that these plinths only indicate locations and do not imply that any remedial action was taken at these ground zero locations. The remaining radiation levels at these ground zeros arise from neutron activation of the soil, and now derives predominantly from residual Eu^{152}, with a 16 year half-life. Glazing, which occurred at the ground zeros, stemmed from the detonation itself. Although small bits of glazing (glass made by the heat of the detonation on the sand of the desert) still remain at most sites, most glazing was removed and disposed of during *Operation Brumby* in 1967.

6.1.8 DC/RB (DECONTAMINATION/RADIOBIOLOGICAL LABORATORY) AREA

The formal disposal pit 30 was remediated by driving heavy equipment over the pit followed by filling subsidence areas and revegetating. Access to this site was reduced by roadworks that made the roads leading to the site difficult to traverse. There are no markers designating the location of the pit. A photograph of the DC/RB area is shown in Figure 6.25. Operations at this site are detailed in *Chapter 4*.

Figure 6.25 DC/RB Area after rehabilitation.

6.1.9 KULI ROAD

Concrete slabs remaining after demolition and removal of storage buildings along the Kuli Road (LA and XA areas) were left in place. These locations are uncontaminated.

6.1.10 MARALINGA VILLAGE AND ENVIRONS

The village layout is shown in Figure 6.27. This diagram shows the relative locations of the original village and the new construction camp facilities. An aerial photograph of the Maralinga village area is shown in Figure 6.26.

Figure 6.26 Maralinga village, looking east, airfield in background (circa 1998). Only about five of the original British buildings remain.

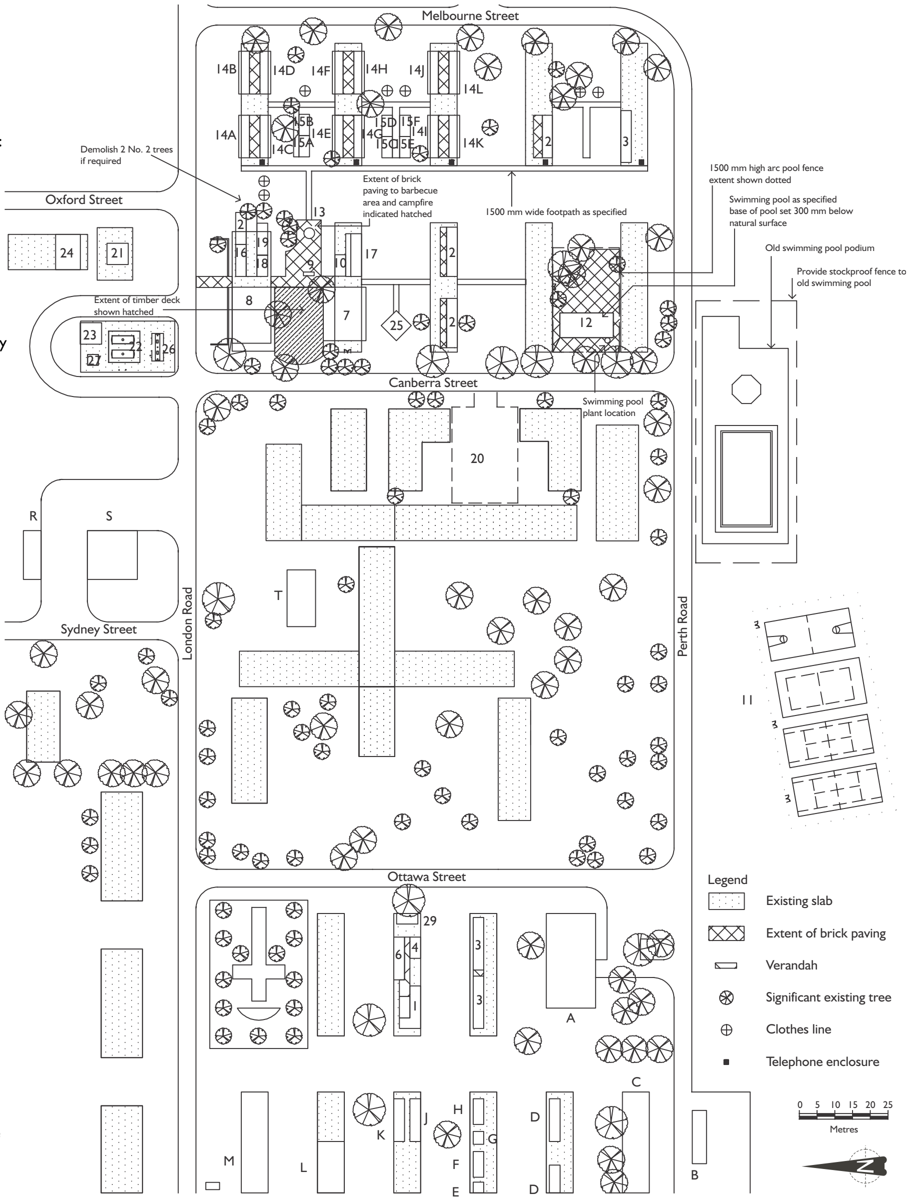
Figure 6.27 Plan of Maralinga village 1995–2000.

Existing buildings

- A. APS Headquarters
- B. Telecom accommodation demountable
- C. VIP building
- D. ISR accommodation: 4 room units
- E. Male ablution demountable
- F. Laundry/female demountable
- G. Dry food store demountable
- H. Mess demountable
- J. ANSTO laboratory
- K. ARPANSA laboratory
- L. Generator shed
- M. Bedding store
- R. Storage shed
- S. Maintenance workshop (fire station)
- T. Flammable store

New Buildings

1. GHD office
2. Accommodation: 2 room ensuite
3. Office/ensuite accommodation
4. GHD ablutions
6. Health physics store and workshop
7. Mess
8. Recreation room
9. BBQ area
10. Mess/recreation ablutions
11. Sports courts
12. Swimming pool
13. Camp fire area
14. Accommodation: 4 room units
15. Ablution block
16. Camp operators office
17. Medical centre
18. Linen Store
19. Bedding laundry
20. Carpark
21. Camp operators maintenance workshop
22. Fuel storage
23. Oil and grease store
24. Generation shed
25. Gymnasium
26. Fuel Bowsers
27. Waste oil storage



6.1.11 HAZARD SURVEY

A hazard survey of the Maralinga village area was conducted in 1999. This hazard survey was conducted by the Project Manager and is documented as the *Maralinga Village Hazard Survey, September 1999* (GHD 1999).

This survey covered the village area proper, the rifle range, the quarry and areas around the airfield. At the start of the Project and during the establishment of the construction camp, some hazard reduction was undertaken in the vicinity of the camp and to a level appropriate for the type of person accommodated in the camp to work on the rehabilitation project. Numerous hazards remained in the village and surrounds (e.g. concrete and steel upstands; debris pits—generally containing rusted steel, wire and concrete rubble; crumbling concrete structures; and deep manholes and pits). Leaving these hazards to exist after the turnover would make the village unsuitable for the uncontrolled movement of other groups of the general population and, in particular, children.

Figure 6.29 defines the limit of the area surveyed. The area was divided into a grid similar to the various soil removal areas. The survey area limits were established to encompass those areas which were the most accessible from the village along existing roads and tracks and therefore the most likely areas to be accessed by future Maralinga residents.

The survey was conducted as though all the current infrastructure was to remain at Maralinga, including:

- water supply including tanks, pumps and reticulation system;
- power supply including generators, cabling and diesel storage;
- all buildings including roads and upgraded recreational facilities; and
- sewage system including pipework, manholes, treatment plant and ponds.

Figure 6.28 Village reverse osmosis water plant—supplies fresh water to Maralinga village.

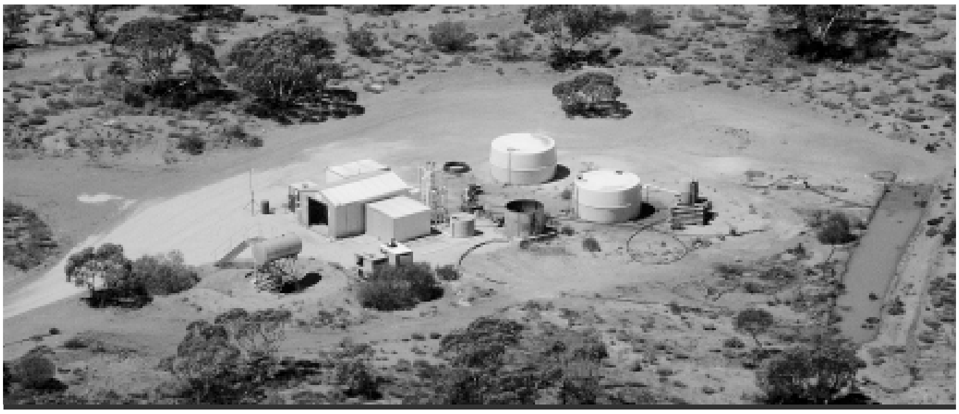
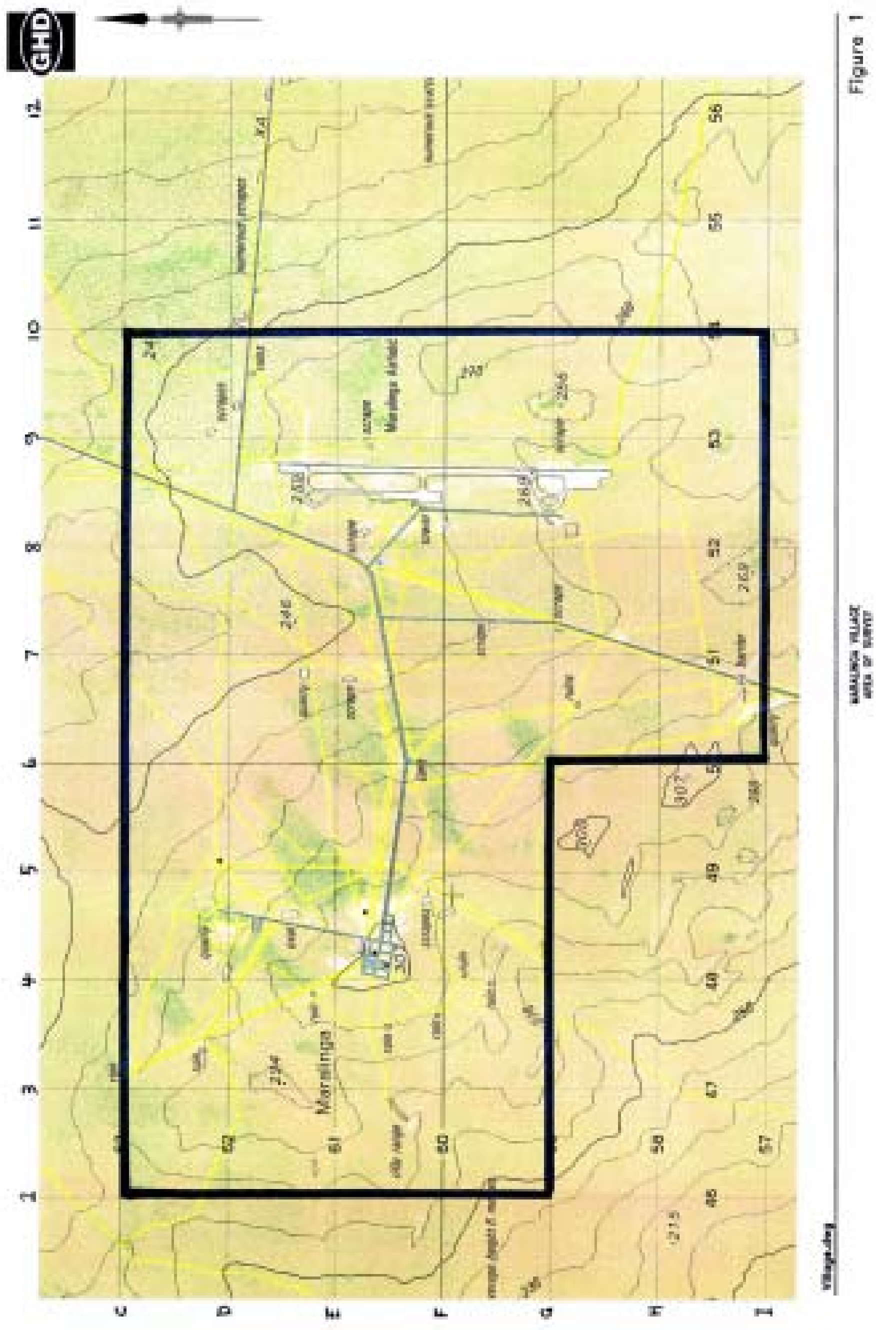


Figure 6.29 Area encompassed by the hazard survey.



Hazards were considered to be:

- dangers associated with unaccompanied infants and teenage children;
- condition of equipment, plant and buildings that may cause a potential hazard within a few years; and
- hazards that could cause significant injuries or death.

The survey kept a photographic record of most of the hazards identified, and these are contained in the referenced Hazard Survey by the Project Manager. *Appendix 6.1*, Table 6.1.20 provides a list of the hazards identified outside the village and those identified within the village area.

Proposals were made to mitigate or remediate all identified hazards. Treatment of these hazards is described briefly below and in more detail in the Project Manager's report—*Hazard Reduction Works, Maralinga village and Environs, June 2000.*

- *Open pits, manholes, tanks and holes.* Pit lids were removed and buried, pit and manhole bases were broken to facilitate drainage, then filled with granular material to 100 mm above ground level.
- *Concrete slabs.* Protrusions were cut at the base, plinths that were in poor condition were broken out, service penetrations were filled, cable trenches were filled, tank foundations were broken out and buried, fill was introduced to even the ground and reduce trip hazards.
- *Sewage works.* The airport sewage works was completely demolished, the village sewage works was made safe by filling all tanks and surrounds, pump and valve spindles were left in place.
- *Asbestos.* Asbestos existed in the form of asbestos cement pipe and fittings in all areas of the village and airfield. The pipe was laid both above ground and in trenches. Asbestos was collected from around the village and disposed of in an approved burial trench outside the village.

A more detailed account of the works performed are contained in the Project Manager's report (*Attachment 4.4*, *Section 12.10*), including photographs of the rehabilitated areas.

The coordinates for the asbestos burial pit in the village are given in *Appendix 6.1*, Table 6.1.21 and a list of hazards cleared in *Appendix 6.1*, Table 6.1.20.

Figure 6.30 illustrates the rifle range as it is currently, following the hazard reduction exercise.

6.1.12 ROAD SYSTEM

MARTAC's recommendation regarding the road system at Maralinga was to reduce the accessibility of the site through the ripping up of road surfaces. The end-state of the road system is that they have remained intact, with the exception of the XA Road (see *Section 4.4.1.3*).

6.1.13 EMU

The Emu site was found not to have significant contamination apart from residual activation around the ground zeros and was handed over to Maralinga Tjarutja in 1996. For details of the studies and decision processes used, refer to *Chapter 3* and *Chapter 4*. However, the *Totem 1* and *Totem 2* detonations are each marked with a plinth similar to the *Marcoo* plinth. Most of the glazing was removed and disposed of as part of *Operation Brumby* in 1967 with a follow-up collection by HydroGen after a MARTAC recommendation.

Figure 6.30 Abandoned rifle range—Maralinga village.

6.1.14 DEBRIS PITS AT THE END OF THE PROJECT

Figure 6.3 is a diagram of the Maralinga area and includes the locations of untreated, unexhumed debris pits remaining at the site. *Appendix 6.1*, Table 6.1.22 provides a summary of the Section 400 (Maralinga) debris pits remaining at the completion of the Project. Those pits that were exhumed during the project are not included. Subsequent to discussions with members of the Maralinga Tjarutja community it was agreed that current marker signs would be left on the numbered pits in the village area.

A photograph of a typical pit and marker sign is shown in Figure 6.31.

Figure 6.31 Marker sign at a typical undisturbed Maralinga informal pit.

6.2 MARALINGA RISK ASSESSMENT—POST-REHABILITATION

During the latter stages of rehabilitation at Maralinga, MARTAC took up the question of determining the end-state of the Maralinga range. Of first importance was a clear statement of the Department's knowledge of the condition of the range, including the various levels and location of remaining contamination (e.g. Table 6.1 provides an approximate distribution for the plutonium contamination within Section 400 at the end of the rehabilitation program). MARTAC also emphasised that the location of the many places where rehabilitation was not recommended nor performed should be accurately recorded so that these areas will be able to be identified in the future.

MARTAC recommended that the Department, the State of South Australia, Maralinga Tjarutja and ARPANSA should reach agreement on the range of potential risk scenarios that are to be considered and agree to the boundaries that would be placed on the assessment of risks for the future. MARTAC considered that the actual risk assessment was a technical matter and that it would be best carried out by an agency such as ARPANSA, after agreement by the parties on the bounds of the assessment.

6.2.1 RESULTS OF ASSESSMENT BY THE ENVIRONMENTAL MONITOR

The Environmental Monitor carried out a revised dose assessment for the inhalation pathway—by far the dominant contributor to overall dose following rehabilitation (*Attachment 6.2*).

The Environmental Monitor used the same methodology as had been applied for the TAG studies (Williams 1990) but made use of the revised ICRP dosimetric model (ICRP 1994) and new post-rehabilitation measurements of contamination levels. Table 6.2 summarises the estimated age-dependent annual dose commitments for full-time residents at a variety of locations after rehabilitation. It should be noted that the values in Table 6.2 represent conservative upper limits as it is difficult to envisage circumstances that would lead to 100% occupancy within the confines of the remaining contamination.

Table 6.1 Approximate distribution for the plutonium contamination within Section 400 following rehabilitation.

Location	**Sources of plutonium content**		**Pu content**
	Major	Minor	(g) (rounded up)
Soil disposal trench	Cleared soil from Taranaki	Some featherbed components originally near the surface	3000
ISV disposal Trench	ISV block from pit 17	Some ISV block material from pits 4 and 19A. Cold caps from all ISV melts and airfield cemetery contents	150
Debris disposal trench	All other ISV blocks & excavated pit contents	–	600
TM trench	Cleared soil from TM 100/101 & TM disposal pits	Pit 2u	300
Wewak trench	Cleared soil from Wewak	Two firing pads	100
Plume remnants	Taranaki VB series		50
Total			**4 200**

Table 6.2 Estimated committed effective doses (mSv/yr) from inhalation for full-time Aboriginal residents following rehabilitation at Maralinga.

	Adults	**Children** (10 years)	**Children** (5 years)	**Infants** (3 months)
Taranaki restricted zone				
Taranaki – non-residential boundary	0.73	0.81	0.60	0.25
Taranaki – non-residential boundary	1.1	1.2	0.92	0.37
NW plume – worst 3 km^2	3.2	3.6	2.7	1.1
N plume – worst 3 km^2	2.06	2.9	2.1	0.87
NE plume – worst 3 km^2	1.7	1.9	1.4	0.56
Non-plume areas within restricted zone	0.03	0.04	0.03	0.01
Total non-residential zone	0.23	0.26	0.19	0.08
Taranaki—beyond restricted zone				
NW plume – Am^{241} EG&G 'A' contour	0.69	0.77	0.57	0.23
N plume – Am^{241} EG&G 'A' contour	0.78	0.87	0.65	0.26
NE plume – Am^{241} EG&G 'A' contour	0.88	0.97	0.72	0.29
25th Avenue (N plume)	0.32	0.36	0.27	0.11
Giles Flat Tops (N plume)	0.08	0.09	0.07	0.03
West Street (NW plume)	0.93	1.04	0.77	0.31
Western Avenue (NW plume)	0.35	0.39	0.29	0.12
Oak Valley Road (NW plume)	0.09	0.10	0.07	0.03
Wewak				
Wewak 2.4 kBq/m2 – Am^{241} (N plume)	0.32	1.47	1.09	0.44
Wewak 3.5 kBq/m^2 – Am^{241} (SE plume)	1.93	2.14	1.59	0.64
Wewak 4.9 kBq/m^2 – Am^{241} (worst ha)	2.70	2.99	2.23	0.90
Wewak VK33 0.9 kBq/m^2 – Am^{241}	1.40	1.56	1.16	0.47
TM100/101				
TM100 1 kBq/m^2 – Am^{241} (NW plume)	0.56	0.63	0.47	0.19
TM100 2 kBq/m^2 – Am^{241} (35.5 ha)	1.13	1.25	0.93	0.38
TM101 1.5 kBq/m^2 – Am^{241} (3 km^2)	0.36	0.40	0.30	0.12
TM101 4.8 kBq/m^2 – Am^{241} (0.3 km^2)	1.16	1.29	0.96	0.39
Tadje				
Pu contaminated area – NNE of *Tadje*	0.88	0.98	0.73	0.29

Doses were estimated for casual visitors for a number of scenarios such as digging, driving behind a vehicle on a dusty road and repairing a puncture. In all these situations, estimated dose rates and potential doses are acceptably low.

It is now impossible for casual visitors making intermittent forays to the area (e.g. tourists, geological prospectors and surveyors) who do not engage in abnormal dust raising or large-scale soil-disturbance activities to receive a committed effective dose by inhalation of anything approaching 1 mSv. The estimated doses received during ambient (calm) conditions are very low and exposure to the substantial dust loadings observed during times of severe dust storms also results in doses that are essentially insignificant.

6.2.2 RESULTS OF THE AEA TECHNOLOGY'S RISK ASSESSMENT

A study was undertaken by AEA Technology (AEAT), initially to address the safety of the disposal of plutonium-contaminated material in the near-surface burial trenches at Maralinga in relation to their potential for inadvertent human intrusion.

This study (*Attachment 6.4*) investigated a range of potential intrusion scenarios in which doses may arise to individuals living or working in the vicinity of the Maralinga trenches. This study was based upon scenarios considered previously in the Maralinga program and by those normally considered by the Nuclear Energy Agency of the OECD. The study attempted to estimate the frequency of a number of different intrusion events through a combination of fairly pessimistic assumed scenarios and the application of expert judgment. The study also drew on a knowledge of prior and current normal practice in the region. Effective doses for the different scenarios were estimated using simple linear models.

The following scenarios were considered:

- excavation using manual or mechanical digging in the course of archaeological or scientific investigations or as a result of the investigation of near-surface resources;
- construction of a road over a burial trench so that contaminated material is disturbed;
- obtaining core samples of near-surface materials and removing them to a laboratory for examination—this could occur for the same motives as the first scenario;
- exposure to contaminated material that is distributed on the surface as a result of any of the above activities; and
- consumption of roots or water derived from roots that have drawn in contaminated water.

Deliberate intrusion was not considered, as it is normally assumed that a deliberate intruder is aware of potential hazards.

Results of assessment

The calculated doses using best estimate parameters are generally significantly below the principal dose limit of 1 mSv/yr for members of the public for continuing practices. However, taking uncertainties into account, it is possible that doses could significantly exceed this limit. Doses that exceeded 1 mSv/yr were calculated for the scenario involving digging into the trenches. Risks for those events that are not certain to occur are significantly below the risk limit of 5 x 10^{-5}/yr (for a site in an arid region for which no other potential artificial sources of exposure exist for members of the critical group).

It was recommended by AEAT that consideration be given to recording the location and characteristics of the site in a number of different ways (e.g. in libraries and possibly with some local markers). This would then conform to international best practice and would contribute towards minimising the radiological consequences that might arise from the trenches. It was also recommended that further consideration be given to the potential impacts of climate change at the site.

MARTAC's review of this initial assessment indicated that it was too narrowly focused upon inadvertent intrusion and proposed that the study be expanded to include the final state of the entire site, not just where intrusion may occur.

A subsequent expanded version:

- repeated the assessment of the radiological consequences of inadvertent human intrusion into the disposal structures containing plutonium using revised data on the quantities of plutonium in the structures;
- widened the scope of the assessment to include uranium in the Kuli disposal structure (the assessment for uranium addresses both potential radiological and potential toxicological consequences);
- assessed, at the request of MARTAC, the toxicological consequences of the disposal of lead oxide in the Taranaki ISV burial trench;
- widened, at the request of stakeholders, the scope of the assessment to include two additional scenarios;
- considered the potential impact on third parties from intentional human intrusion with the intention of embarrassing the Australian Government (intentional intrusion is not normally addressed in assessments); and
- made a very simple scoping assessment of the potential impact of climate change leading to agricultural use of the land at Maralinga—assessment of the impact of climate change also scopes the potential impact of erosion exposing contaminated material, were this to occur for reasons other than climate change.

Conclusions

For only one scenario and one disposal structure were the effective radiological doses that might result from inadvertent human intrusion into the disposal structures at Maralinga calculated to be greater than 1 mSv: an archaeological dig into the Taranaki debris burial trench. In this case, the predicted dose rate was calculated to be approximately 10 mSv/yr. The estimated risk for this case, however, at 5 x 10^{-8}/yr, was well below the risk limit, because of the low estimated probability of the intrusion event.

To assess the impact on third parties from an intentional intrusion, the effective dose to a child playing in contaminated material taken from the disposal structures and deposited in or near habitation such as Maralinga village was estimated. The highest calculated dose for material taken from the different disposal structures for a child assumed to play for two hours a day for seven days was calculated to be approximately 0.2 mSv. Assuming a frequency of 10^{-2}/yr, this gives an illustrative risk of 1.5 x 10^{-7}/yr. There are great uncertainties about the exact nature and likelihood of such an intentional intrusion, but the results indicate that, in many cases, the resulting doses and risks would not be very high if the time of exposure were limited.

The chemical hazards presented by the uranium and lead were calculated using similar methodologies to the calculations of radiological dose. The chemical hazard presented by the uranium in the Kuli soil disposal trench was calculated to be negligible. The estimated kidney burdens for all types of intrusion were at least three orders of magnitude smaller than the expected ‘no effects’ threshold of 57 mg/kg body weight (*Australian Drinking Water Guidelines*, NHMRC and ARMCANZ 1996). For the lead oxide buried in the Taranaki ISV burial trench, the data provided suggest that an intrusion into the lead oxide containers themselves could lead to blood levels of lead that would be in excess of safe levels. For longer-term use of the land following intrusion, blood levels of lead were calculated to be twice the recommended action level of 50 µg/dL. The lead oxide was disposed of in the ISV trench in concentrated form over a small cross-section of the trench. The probability of intrusion is likely therefore to be very small with a low risk of serious consequences for an individual.

Calculations were performed to scope the radiological consequences that might arise if climate were to change in such a way that agricultural practices might be possible in the Maralinga region. It is not clear whether the agricultural practices assumed as a basis for the calculations are realistic or not. The doses estimated are below the dose rate limit of 1 mSv/yr, assuming that members of the critical group obtain their food requirements from an area of 1 km^2, which is larger than the contaminated area of the disposal structures. Doses of up to 20 mSv/yr might arise if undiluted water from the disposal structures provided all required drinking water; however, it is not clear that this would be feasible and such an event is likely to have a low probability (*Attachment 6.4*).

6.3 LONG-TERM MANAGEMENT OF POST-REHABILITATION MARALINGA

MARTAC considered many alternatives in debating the issue of a long-term site management strategy. The Environmental Monitor assessment was considered by MARTAC as the foundation for the plan that followed. This risk assessment would identify the status of the site, the risks, an assessment of whether the risks would need to be managed, and some recommendations for the long term management of the risks. It was apparent that all parties would have to be a part of the final plan to manage the residual risks at the site, and that a formal long-term management plan for the site would be required.

The airfield has been a tremendous asset as part of the transportation infrastructure of the project and is considered to have many more years of service to the site. The management plan will address this aspect of maintaining the airfield and perhaps maintaining the airfield reception building (Figure 2.9) as a functioning, if not historical, resource for the future use of the site. The many roads that have provided the site with the ability to have a transport infrastructure in support of the site will continue to provide service to the management of the site once handover to the traditional owners is complete. It is this infrastructure that will allow the monitoring and maintenance of the site for future generations.

Figure 6.32 Halfway tank which stores rainwater collected from the airstrip.

In addition to the transport infrastructure, Maralinga village has the capacity to serve the traditional community for many generations. Figure 6.26 provides an aerial view of the post-rehabilitation Maralinga village. *Appendix 6.2* provides a number of views of the many different types of buildings and infrastructure items that remain at Maralinga village.

6.3.1 MARTAC RECOMMENDATIONS

MARTAC summary recommendations regarding future management

- To perform a risk assessment of the final condition of the site, based upon an agreement between the Commonwealth, the State of South Australia, and Maralinga Tjarutja.
- To identify from the risk assessment the risks that require long-term management via a land and environment management plan.
- To prepare an agreed ‘roles and responsibilities agreement’ for the execution of the management plan.
- To create an oversight group that would track the execution of the plan and allow for dialogue when it is needed to resolve issues that may arise subsequent to handover.
- To ensure that there is a mechanism to allow the Department to request additional funds for unforeseen problems arising at the site.

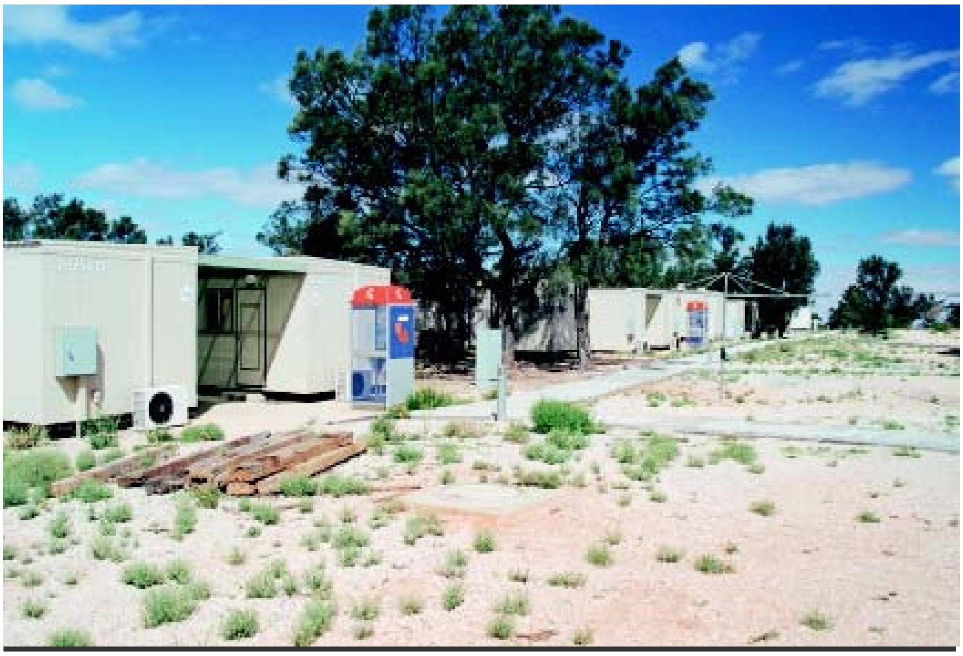
Essential objectives of the management plan

- Ensuring that there are no changes in the containment of the radioactive materials that would increase the level of risk to current and future generations above that existing at the time of completion of the rehabilitation and handover to the traditional owners of the land.
- Ensuring that any exposures or discoveries of potentially contaminated materials are reported to an appropriate authority for investigation and action.
- Ensuring that the area is managed in a manner which is consistent with not disturbing the contained contaminants and that land use restrictions are adhered to.
- Ensuring that the records on the final disposal of all contaminated materials are stored for long-term preservation and are readily retrievable.
- Ensuring that the historical record of events and structures of the testing period and subsequent rehabilitation programs are maintained in accordance with the site management plan.

6.3.2 DEPARTMENT/CONSULTATIVE GROUP PLANNING AND INVOLVEMENT

The *Maralinga Land and Environment Management Plan*, jointly drafted by the Commonwealth and South Australian Governments, and Maralinga Tjarutja will be the governing plan for post-rehabilitation management of the resources at Maralinga and Emu.

Figure 6.33 Accommodation blocks at Maralinga village.



MARALINGA LAND AND ENVIRONMENT MANAGEMENT PLAN

- *Institutional management* puts in place an institutional structure for implementing the *Maralinga Land and Environmental Management Plan*. This structure has the responsibility for the oversight of the implementation of this plan.
- *Records management* puts in place an operational system for the management of records and documents that form the basis for the continued management of the site. This portion outlines how records will be maintained, stored and retrieved.
- *Maintenance of hazards reduction measures* puts in place a system to ensure that a proper monitoring regime is developed to enable detection of any changes in the buried contaminated materials or the site warning signs.
- *Radiological safety assessment* puts in place a system for assuring the protection of workers and the public from radiological hazards at the site, and will be based upon current standards of the time.
- *Conservation management* addresses measures to be put into place that will ensure that the heritage significance of the Maralinga and Emu sites is preserved.
- *Revegetation of soil removal areas* forms the basis for monitoring the natural flora and fauna of the site and encouraging its re-establishment.
- *Auditing* provides measures that provide verification of compliance at the site with the policies, objectives, commitments and management tasks of the *Maralinga Land and Environmental Management Plan*, including verification that the measures being taken are effective and efficient.
- *Contingency planning* will monitor and manage unanticipated events at the site which could pose a risk to the public or on-site workers.

6.4 LICENCING OF THE FACILITY

In late 1998, the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cwlth) was enacted, followed shortly thereafter by the enactment of the *Australian Radiation Protection and Nuclear Safety Regulations 1999* (Cwlth) (the ARPANS Regulations). This legislation required the Department to apply for a 'facility licence' to cover the rehabilitation work remaining to be done at Section 400 (Maralinga) from mid-1999 onwards.

Although MARTAC made no input to the facility licence application that the Department submitted to cover the remaining work at Maralinga, MARTAC was kept informed by the Department of its development of the licence and its subsequent assessment by ARPANSA's Regulatory Branch. The licence application included:

- a general description of the site;
- arrangements for maintaining effective control of the site;
- information on safety management, radiation protection and radioactive waste management;
- strategies for the ultimate 'decommissioning, disposal or abandonment' of the site;
- information on security and emergency response;
- operational/design criteria applying to the rehabilitation;
- safety analysis reports;
- operational limits and conditions; and
- workplace procedures and other arrangements.

The facility licence application was made to the Regulator in accordance with the ARPANS Regulations on 4 August 1999.

The Regulator subsequently issued a facility licence (licence number FV0043) to the Commonwealth of Australia, through the Department, to 'operate' the Maralinga 'facility' on 30 October 2000. Included at *Attachment 5.2* is a copy of this facility licence. In an associated statement, the CEO of ARPANSA noted that the work carried out at Maralinga was an 'intervention', and that the licensing process carried out by ARPANSA was *... essentially* [an] *historical exercise in that the relevant provisions of the ARPANS Act are 'catching up' with the historical circumstances applying to the project.*

The Regulator included in its statement several conditions to the existing licence. All of the licence conditions were met and the only ongoing conditions are that visitor access to the site must be controlled and that the Department periodically monitor the watertable below the five burial trenches for radioactive contamination.

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APPENDICES

6.1 Tables

6.2 Views of Maralinga village

ATTACHMENTS

6.1 Project Manager's assessment of compliance with CMP

6.2 ARPANSA inhalation dose assessment

6.3 Studies of plutonium aerosol resuspension

6.4 AEAT intrusion assessment (expanded)

6.5 Locations of Pu^{239} surface contamination at Maralinga following the 1995–2000 rehabilitation

6.6 Geographical coordinate transformations from GPS to GDA

6.7 ARPANSA Maralinga Rehabilitation Project Field Trip Report 2002 (Survey of Uranium Fragments at Kuli)

GLOSSARY

Aboriginal people
The homelands of a number of Aboriginal peoples border or cross the Maralinga and Emu Ranges. Those mentioned in this report are mainly members of the Maralinga Tjarutja living at the Oak Valley and at Yalata. Details of the various Aboriginal peoples formerly occupying these lands are given in *Appendix B* of the *Report of the Royal Commission on British Nuclear Tests in Australia*.

Activation
Some of the neutrons released in fission are captured by atoms in the surrounding materials (e.g. soils, structural materials or atmospheric gases). Many of the resulting atoms are radioactive and are known as activation products. This process of producing radioactive materials is known as activation.

Aerosol
A suspension of particles dispersed in a gas as vapour or mist.

Alpha radiation
Some radioactive elements, particularly those with a high atomic number, decay by emitting a positively charged particle, the alpha particle, which is identical with the nucleus of a helium atom. Alpha radiation has very little penetrating power, but it may present a serious hazard if alpha emitters are inhaled or ingested.

Annual limit of intake (ALI)
The activity of a radionuclide which on its own would irradiate a person, represented by 'reference person', to the limit set by the ICRP for each year of occupational exposure.

Becquerel
The unit of radioactivity, corresponding to one disintegration per second. The older historical unit (Curie) is equal to 3.7×10^{10} Becquerel.

Berm
As used in ISV discussions, a wall structure containing and supporting the assembly of equipment and the materials melted in the ISV process.

Berylliosis
A lung disease caused by the inhalation of finely divided beryllium.

Biological half-life
The time required for the amount of a specified element that has entered the body (or particular organ) to be decreased to half of its initial value as a result of natural biological elimination processes.

Calcium to silica ratio; Ca:Si ratio or Ca:Si
In MARTAC documents, this term generally means the ratio of basic to acidic oxides in the ISV material, specifically including Ca:Si = $(CaO + MgO)/(SiO_2 + Al_2O_3)$. Geosafe maintain that their own use includes other silica network modifiers such as Na_2O and K_2O.

Calcrete
Calcrete (or caliche) is a rock or rocky layer predominantly of calcium carbonate ($CaCO_3$ or limestone).

Contamination
The deposit of radioactive material on or within structures, land, people or animals following dispersal of the radioactive material (e.g. by a nuclear explosion of dust-raising capabilities).

Critical group
The group of individuals likely to be subject to the highest exposures from a specified radiation source. Used in setting constraints to control the exposures of members of the public.

Decay product
The substance formed by a radioactive decay of a radioactive nuclide. Some radionuclides (e.g. U^{238} which decays through a sequence of steps) have associated with them many successive decay products.

Decontamination
The removal or reduction of contaminating radioactive material from persons, equipment, structures or areas.

Detonation point
See *ground zero*.

Dolomite
A carbonate rock with magnesium as well as calcium (Mg, Ca) $C0_3$.

Dose
The amount of energy delivered to a mass of material by ionising radiation passing through it.

Dose conversion coefficient
The numerical factor, recommended by ICRP, to convert the intake of radioactive material (Bq) to the dose (Sv) which will be delivered to a person by that intake. Its SI units are therefore Sv/Bq.

Dose rate
The rate at which ionising radiation delivers energy to a mass of material through which it is passing.

Dosimetric modelling
The definition of exposure pathways and conditions used in dose assessment.

Encased, encapsulated
Terms used synonymously to describe the nature of the distribution of the oxide phase of the melt around unmelted or partially melted steel components in the ISV process. Use of the term 'encased steel' would imply that a continuous layer of strong, crystalline or non-vesicular glassy oxide phase material surrounded the steel. Encased steel would not be open to weathering processes.

Engineered trench
A burial trench containing engineered features to delay or prevent radionuclide migration from the trench into the surroundings.

Environmental transfer factors
Numerical factors used to transfer the measured concentration of radioactive contamination on the ground to its concentration in grasses and vegetables and further to its concentration in animal tissue which may be eaten by humans. It thus allows the estimation of intake by a person eating foods from a contaminated area and the corresponding dose (from the dose conversion coefficient).

Exposure route
The combination of sequential biological and physical processes that transfer the initial contamination to a subject for whom harm may result. For the Maralinga Tjarutja, a significant but not major exposure route is plutonium deposition, plant uptake, burning of plant material in cooking fire, ash resuspension/inhalation and ash including during damper preparation/consumption by infants.

Fallout
The descent to the Earth's surface of particles contaminated with radioactivity, following the dispersion of radioactive material into the atmosphere by an explosion. The term is applied both to the process and, in a collective sense, to the particulate matter. The early fallout consists of the particles that reach the Earth's surface within 24 hours. The delayed fallout consists of smaller particles that may be carried by wind to great distances and even completely around the earth many times before descent.

Featherbed
The steel structure supporting the experimental assemblies in the *Vixen B* trials.

Fission
The process whereby the nucleus of a heavy element (e.g. uranium or plutonium), splits into two nuclei of lighter elements (fission products) accompanied by the release of substantial amounts of energy.

Fission products
The complex mixture of substances produced in the process of nuclear fission. The primary fragments produced in fission are themselves radioactive, and decay through a succession of radioactive isotopes until a stable form is reached.

Frequency rate
Used in occupational health assessments to indicate the degree of occupational hazard in a given industry. Numerically given by the number of occupational injuries and diseases multiplied by 1 000 000 and divided by the number of hours worked.

Gamma radiation
Most radioactive elements emit electromagnetic radiation called gamma rays from the nucleus. Gamma radiation is penetrating and can cause radiation exposure many tens of metres from external sources. It is also the radiation that is most readily measured by monitoring equipment such as film badges and dosimeters.

Glazing
Glassy substance formed from alumino-silicates in soil as a result of heating by a nuclear explosion.

Glove box
A sealed container with clear viewing panels containing apparatus that can be manually manipulated by the operator inserting his hands in arm-length gloves sealed into the container.

Ground zero
The point on the ground surface at, or directly below, the initiating point of a nuclear explosion. A specialised term for the detonation point when the detonation is nuclear.

Grouting
Filling interstices between rocks and/or aggregate with cement.

Hand-held Rascal/PG-2
See *PG-2 low energy gamma detector*.

HGPe detector
Device for detecting gamma radiation. Much more for defining radioactive species, but much less sensitive than a Rascal/PG-2 detector.

Induced radioactivity
The radioactivity of nuclides produced from naturally stable nuclides, as the result of nuclear reactions with neutrons. Radioactivity is induced in materials close to a nuclear explosion by the absorption of the neutrons given off by the explosion.

Inhalation pathway
The intake route leading to radiation exposure arising from the inhalation of radioactive material.

In-situ vitrification (ISV)
A process developed by Battelle Pacific Northwest Laboratory using a large electric current through the soil to convert contaminated soil into a stable glass and crystalline complex.

Ionising radiation
Electromagnetic radiation (gamma rays or X-rays) or particulate radiation (alpha particles, beta particles, neutrons) capable of producing electrically charged particles, directly or indirectly in its passage through matter.

Isotopes
Forms of the same element having identical chemical properties but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties (e.g. radioactivity, fission).

Karstic limestone
A mixed dolomite/limestone rock. Fairly easily dissolved by the rain and therefore prone to erosion and the formation of sinkholes which allow rainwater to penetrate.

Limit of detection
Generally, the lowest concentration or level of a contaminant which may be reliably detected.

Melt product
The high strength crystalline or glassy ISV melt product arising from solidification of melted oxides of silica, aluminium, calcium, magnesium, barium, iron, etc.

Mesothelioma
A chest wall tumour associated with asbestos exposure.

Microsievert
The one-millionth part of the unit of dose equivalent, the sievert.

Millisievert
The one-thousandth part of the unit of dose equivalent, the sievert.

Monitoring
The procedure or operation of measuring radioactive contamination using survey instruments that can detect and measure ionising radiations.

Monolith, monolithic
Term used by Geosafe to describe the ISV melt blocks. However, the blocks generally comprised several smaller blocks separated by penetrative cracks. The cracks are assumed to be tension cracks generated on cooling

Natural uranium
Uranium, as it occurs in nature, is made up of 99.3% U^{238} and 0.7% U^{235} with 56 ppm of U^{234}.

Nephrotoxicity
The capacity of a material to cause kidney damage.

Neutron
A nuclear particle having no charge and a mass approximately equal to that of a proton. Neutrons are present in all atoms except those of the lightest isotope of hydrogen. Neutrons are produced in large numbers in nuclear explosions and are very penetrating.

Nuclear radiation
Particulate and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations, from the weapons stand-point, are alpha and beta particles, gamma rays, and neutrons. All nuclear radiations are ionising radiations, but the reverse is not true (e.g. X-rays are included among ionising radiations, but they are not nuclear radiations since they do not originate from atomic nuclei) (see *ionising radiation*).

Nuclear reaction
Any event involving a change in the nucleus of an atom.

Nuclide
An atomic species characterised by its mass number, atomic number and energy state.

Outstation
In the 1970s, Indigenous owners of lands moved away from the townships originally established as mission sites and established their own discrete settlements on their homelands. These new settlements were called outstations and are inherently remote. The inhabitants of outstations are highly mobile between outstation and other communities and within the geographical structure of the outstation itself. Outstations have few amenities (no water supply or permanent buildings) and few if any permanent services (heath, communication, schooling, supply stores). Community behaviour is governed through a mixture of European trappings (rifles, a few vehicles, canvas, cooking utensils) and cultural requirements (dietary components, damper preparation, dressing of kangaroo carcasses). For this report the characteristics of an outstation lifestyle are taken as those of Oak Valley residents in 1986/87 and reported by Parmer and Brady in their report to TAG. Oak Valley, in 2002, is a township.

Occupational exposure
An exposure to radiation measured while the recipient is working on materials pertaining to or at the site of his or her normal place of work.

Pathway
An exposure route along which radioactivity or toxicity may be transferred to body organs or tissues. The three main pathways are ingestion, inhalation or skin penetration.

Pedestal
In ISV discussions, the soil material remaining beneath the steel masses once the melt material has been removed from around them. Sometimes the pedestal could be emphasised where in situ geological materials have been removed from beneath the level of the melt base or steel base level.

PG-2 low energy gamma detector
A device for detecting gamma radiation using a sodium iodide detector.

Plume
The wind-borne envelope of combustion products and contaminants leaving the source after combustion or detonation.

Radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an (unstable) isotope. As a result of this emission the radioactive isotope is converted (or decays) into the isotope or a different element that may (or may not) also be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (non-radioactive) end product is formed.

Radioisotope
A radioactive isotope.

Radionuclide
A radioactive nuclide.

Sievert
The SI unit of radiation dose.

Sodium iodide detectors
A radiation detector employing the fluorescent compound sodium iodide.

Soil concentration
The amount of radioactivity contained in a unit mass of soil.

Specific activity
The amount of radioactivity per gram of material. Its units are Bq/g.

Tjarutja
Indigenous word meaning community.

Transuranic elements
Elements with atomic number above 92 produced by artificial means such as by the irradiation of uranium with neutrons. Transuranic elements include neptunium (93), plutonium (94) and americium (95).

Transfer factor
The arithmetic relationship between the source of the contamination and the end point of a component or series of components that go to make up the exposure route.

Uncertainty analysis
A mathematical procedure to estimate the reliability of a calculated quantity such as radiation dose. It takes into account the uncertainties implicit in the quantities and models used.

Wiltja
A lean-to shelter, a brush shelter. A term used widely by Aboriginal people mentioned in this report.

Willy-willy
Small whirlwinds that prevail in Australian desert regions.