The Nautilus Institute for Security and Sustainability

The SIGINT Satellites of Pine Gap: Conception, Development and in Orbit

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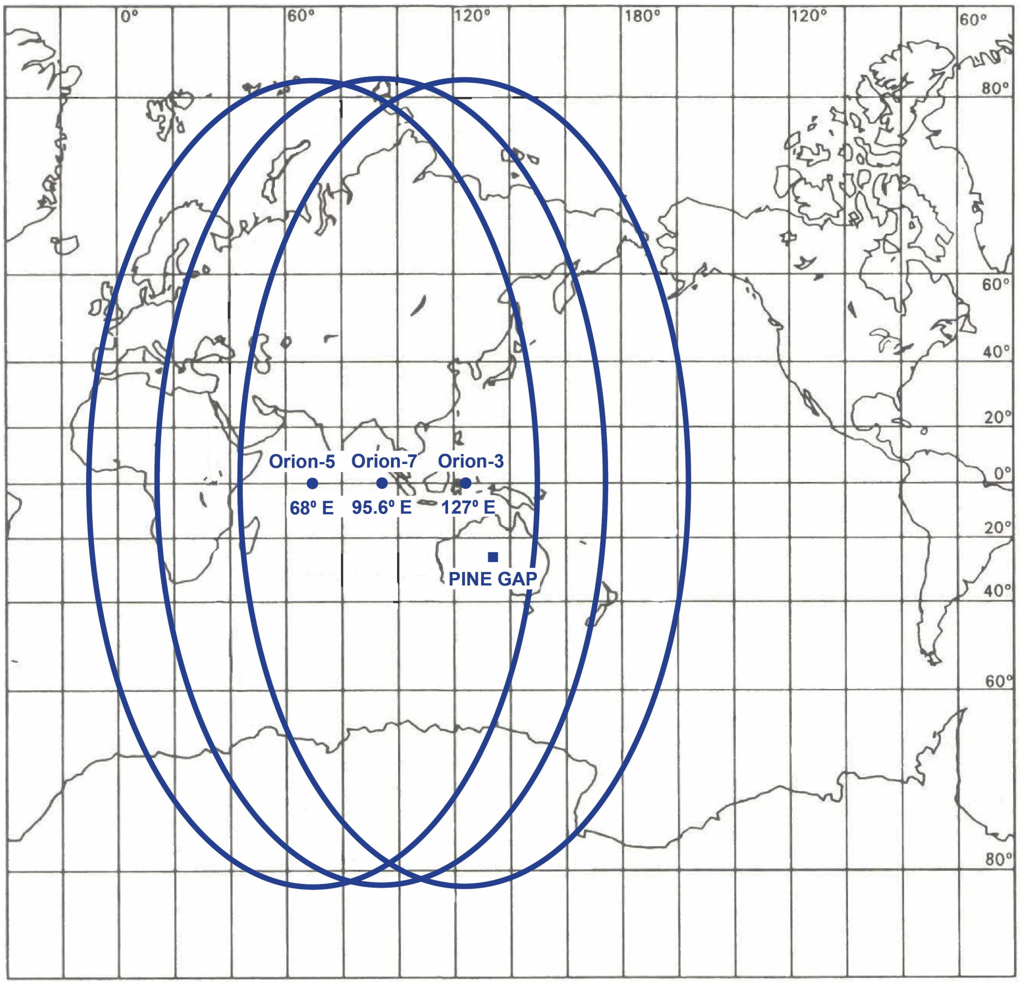

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Summary

Pine Gap's initial and still principal importance to the United States lies in its role as a ground control and processing station for geosynchronous signals intelligence satellites. Nine geosynchronous SIGINT (signals intelligence) satellites have been operated by Pine Gap over the past 45 years. That role has grown as the satellites and their associated ground systems have developed in size, capacity and range of applications far beyond what was envisaged half a century ago – or understood by the host government that accepted the base at that time. During the ground station site selection process in 1966, one of the main criteria was that the horizon angle from the floor of the selected location and over the surrounding hills 'should not exceed six degrees'. From Pine Gap's latitude of 23.80° S and longitude of 133.74° E, this would allow connectivity (for both command and control and for data reception) with satellites stationed as far west as 60° E (or as far east as 153° W if ever required). The stations of the current three Orion SIGINT satellites controlled by Pine Gap make possible the collection of a wide range of signals across more than half the surface of the planet outside the polar regions – every continent except the Americas and Antarctica, and every significant region of contemporary US military concern. There is now just one US highly integrated geosynchronous signals intelligence satellite system, with comparable satellites operated by Pine Gap and Menwith Hill, with much greater capacities and much more focussed military roles than their Cold War equivalents

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Contents

Figures

Tables

Glossary

ABM	anti-ballistic missile
ACMA	Australian Communications and Media Authority
AOR	Area of Responsibility
CIA	Central Intelligence Agency
COMINT	communications intelligence
COSPAR	Committee on Space Research
DDS&T	Deputy Director for Science and Technology
ELINT	electronic intelligence
ESA	European Space Agency
ESL	Electromagnetic Systems Laboratory
EST	Eastern Standard Time (US)
ICBM	intercontinental ballistic missile
ITU	International Telecommunications Union
IUS	Inertial Upper Stage
LV	launch vehicle
MIT	Massachusetts Institute of Technology
NRO	National Reconnaissance Office
NROL	NRO Launch
NSA	National Security Agency
OD&E	Office of Development and Engineering
OEL	Office of ELINT
OSI	Office of Scientific Intelligence
OSO	Office of SIGINT Operations
OSP	Office of Special Projects
PSAC	President's Science Advisory Committee
RF	radio frequency
ROB	radar order of battle
RV	re-entry vehicle
SIGINT	signals intelligence
STS	Space Transportation System
TEBAC	Telemetry and Beacon Analysis Committee
TELINT	telemetry intelligence
UHF	ultra high frequency
USAF	United States Air Force
USIB	United States Intelligence Board
VHF	very high frequency

The principal mission of the Joint Defence Facility Pine Gap in Central Australia is to operate three US geosynchronous signals intelligence satellites, which sit in an orbit above the Equator at an altitude of about 36,000 km.[1] These three satellites are controlled and commanded by operators at Pine Gap, and the wide range of electronic signals they collect are downlinked to Pine Gap for processing and analysis. These signals from the Earth's surface or in the air above it include missile telemetry, radar and other military emissions, radio communications, microwave transmissions, satellite phone transmissions, and cell phone transmissions. The three satellites Pine Gap currently operates sit above the western Indian Ocean (Orion-5 or USA 171 at 67.9° E), the western tip of Sumatra (Orion-7 or USA 223 at 95.6° E), and eastern Indonesia west of Sulawesi (Orion-3 or USA 110 at 126.9° E). Each of these satellites can receive transmissions originating from or close to the surface of the Earth and the oceans over more than 160° of longitude at the Equator, giving Pine Gap operational control over US geosynchronous signals intelligence satellite coverage in all areas of contemporary US critical strategic concern, from west Africa to the mid-Pacific Ocean, including all of Russia and China, the Middle East, the Indian subcontinent and its oceans, and all of Southeast and East Asia. (See Table 1 and Figure 1.)

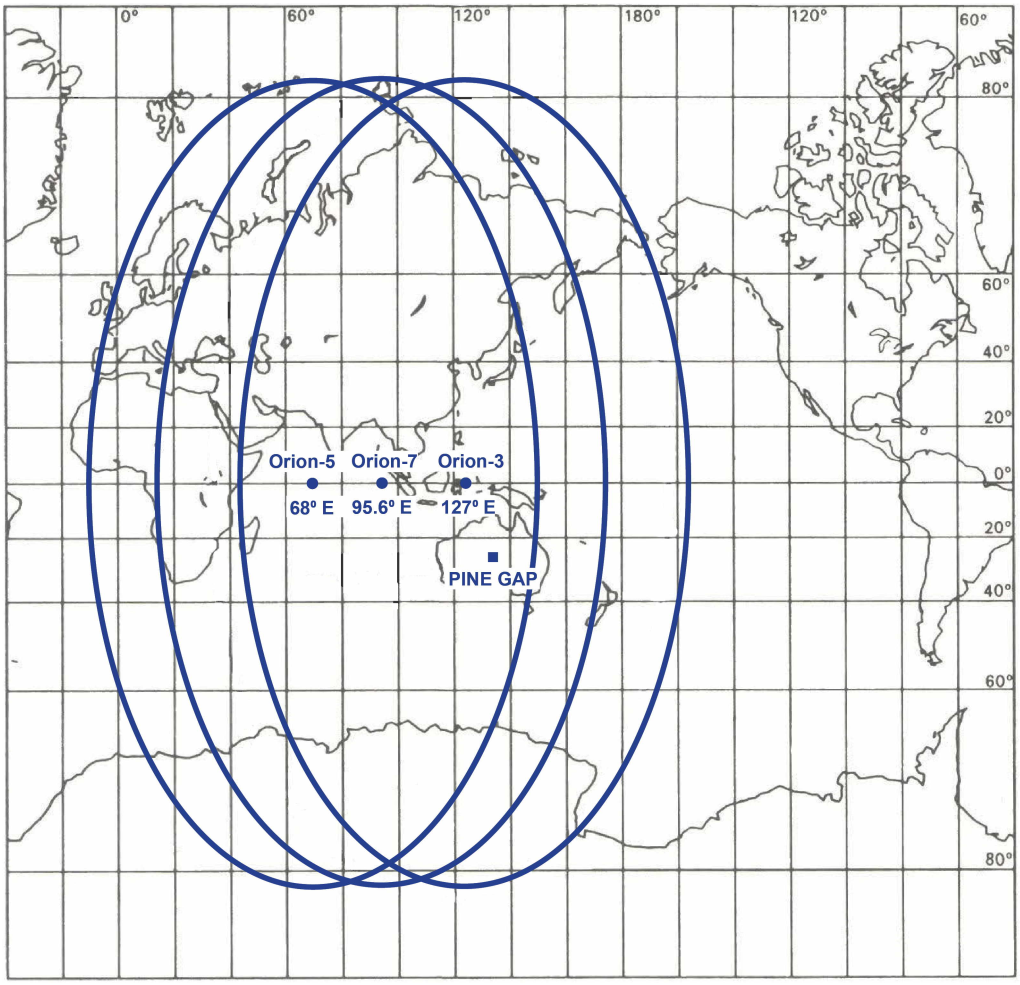
Table 1. Geosynchronous SIGINT satellites controlled from Pine Gap, 2015: longitude and inclination

	Orion-3 (1995-22A) (USA 110)	Orion-5 (2003-41A) (USA 171)	Orion-7 (2010-63A) (USA 223)
Longitude	126.9° E	67.9° E	95.6° E
Inclination	12.6°	7.7°	3.8°

Source: T. Flohrer, European Space Operations Centre, *Classification of Geosynchronous Objects*, Issue 17, 28 March 2015.

[1] Satellites in geosychronous orbit (GEO) have an orbital period equal to one earth sidereal day (23 hours 56 minutes). Satellites in circular geosynchronous orbits that are aligned to the plane of the equator appear to an observer on the ground to sit in one place in space, and are called geostationary satellites. Those in geosynchronous orbits inclined with respect to the equatorial plane will typically appear to move in figure-of-eight patterns above and below fixed points on the equator each day, thereby allowing greater coverage of either or both of the two hemispheres. (See Appendix 2.)

Figure 1.
Pine Gap–controlled Orion SIGINT satellite stations, 2015



Pine Gap's nine SIGINT satellites, 1970-2015

Nine geosynchronous SIGINT (signals intelligence) satellites have been operated by Pine Gap over the past 45 years. A 2-satellite constellation of Rhyolite and successor satellites was maintained from 1973 until 1995, followed by a 3-satellite constellation from 1995 to 2003 and a 4-satellite constellation from 2003 until the launch of Orion-7 in November 2010. With the arrival of Orion-7 the number of operational satellites may briefly have gone as high as five, but it quickly dropped again to three with the retirement of Orion-1 and Orion-2 in 2013.[2] Many of these satellites have exhibited amazing longevity. (See Tables 3 and 4, and Appendix 3.)

[2] Names are assigned to satellites in a number of different and confusing ways. Some are systematic, and others idiosyncratic; some are official, others informal; some are public and some secret. All satellites today

All of the National Reconnaissance Office's (NRO's) Orion-class geosynchronous SIGINT satellites since Orion-1 launched in January 1985 have been officially designated numerically, from Orion-1 to Orion-8, launched in June 2012.[3]

Rhyolite, the US government identifying codeword for the first of the Pine Gap signals intelligence satellites was changed to Aquacade after the Rhyolite program was made known to the Soviet Union by Christopher Boyce.[4] The first satellite of what became the Orion series was initially officially called Magnum-1, but, according to Richelson, by the time that satellite was launched from the Space Shuttle on 24 January 1985, the name had been changed to Orion-1.[5] The US government has retained the codename Orion for all geosynchronous SIGINT satellites controlled by Pine Gap launched since 1985. Some of the Orion satellites have had other codenames attributed to them at different stages through their development, such as Mentor and Advanced Orion. Many commentators have used the name Advanced Orion to refer to Orion-3 (also referred to as Mentor-1) and its successors, which aptly distinguishes them from their smaller and less capable predecessors.[6] (See Table 2 for a list of alternative satellite names.)

The nine geosynchronous SIGINT satellites that have been controlled from Pine Gap since 1970 in the Rhyolite, Aquacade and Orion series are listed in Table 3.

During the ground station site selection process in 1966, one of the main criteria was that the horizon angle from the floor of the selected location and over the

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have an identification number issued by the Committee on Space Research (COSPAR) of the International Council for Science. COSPAR numbers identify the year the satellite was launched, its order amongst those launched in that year, and a letter indicating which payload, possibly among several on the same launcher. The satellite launched on 21 November 2010 has the COSPAR number 2010-63A, indicating it was placed into orbit following a launch in 2010 by a rocket which was the 63rd launch that year, and the SIGINT satellite was identified as the first payload from that launch. COSPAR numbers are sometimes shortened by omitting the first two numerals: e.g. 2010-63A becomes 10-63A. Orion-7 was also identified as NROL-32, indicating it is National Reconnaissance Office Launch-32, although not all NRO launches have been identified. It is also known by its unclassified US military name of USA 223. (See Tables 2 and 3.)

[3] 'FY 2013 Congressional Budget Justification: Volume 1, National Intelligence Program Summary', February 2012, p. 167.

[4] In the mid-1980s. other SIGINT satellite codenames were changed as they became compromised by becoming publicly known or thought to be known by adversary states. According to Jeffrey Richelson, this practice seems to have ended for SIGINT satellites in the late 1980s. Richelson notes that after he wrote about the Orion satellites, using that codename, in the second edition of his *The US Intelligence Community*, the name did not in fact change. (Letter from Jeffrey Richelson to the authors, 21 September 2015.)

[5] Jeffrey T. Richelson, *The Wizards of Langley: Inside the CIA's Directorate of Science and Technology*, (Westview Press, Boulder, Colorado, 2001), p. 234.

[6] The Mentor and Advanced Orion 'codenames' are used in this paper where it seems appropriate to retain historical usage.

surrounding hills 'should not exceed six degrees' (see Figure A.2).[7] From Pine Gap's latitude of 23.80° S and longitude of 133.74° E, this would allow connectivity (for both command and control and for data reception) with satellites stationed as far west as 60° E (or as far east as 153° W if ever required). At any given time since 1973, one of the satellites controlled from Pine Gap has invariably been stationed at around 65-70° E longitude.

The first three Orion satellites were all operated from Pine Gap, but from the early 1990s the Orions were envisaged as a multi-purpose SIGINT satellite to succeed both the Central Intelligence Agency's (CIA) Rhyolite/Aquacade system controlled from Pine Gap and the National Security Agency's (NSA) similar Chalet/Vortex/Mercury system, controlled from Menwith Hill in Yorkshire, UK. Until around 1977-78, these were essentially autonomous programs, only loosely coordinated by the NRO (and then mainly with issues such as budget priorities and access to launch vehicles rather than the respective CIA and NSA SIGINT missions).

The major reorganisation of the NRO in 1997 established a SIGINT Directorate superimposed above the single Orion program, as well as collaborative operational, management and reporting processes at the Pine Gap and Menwith Hill stations. Orion-4, launched on 9 May 1998 and the first to be controlled from Menwith Hill, as well as Orion-6 launched on 19 January 2009 and also controlled from Menwith Hill, are evidently no different to Orion-3 or Orion-5 controlled from Pine Gap. There is now just one highly integrated US geosynchronous signals intelligence satellite system, with comparable satellites operated by Pine Gap and Menwith Hill, with much greater capacities and much more focussed military roles than their Cold War equivalents.

It does seem that Orion-7, launched on 21 November 2010 and controlled from Pine Gap, and certainly Orion-8, launched on 29 June 2012 and controlled from Menwith Hill, were each successively larger than their predecessors and have each carried more advanced capabilities.[8] However, this should not be regarded as reflecting any organisational or operational divergence within the program, but rather as involving the

[7] 'Cable dated 18 January 1966', National Archives of Australia (NAA), 'Joint Defence Space Research Facility: Policy 1965-1984', Series A1945, Item 227/1/131.
[8] William Graham, 'Delta IV Heavy Launches with NROL-32', *NASA Spaceflight.com*, 21 November 2010, at http://www.nasaspaceflight.com/2010/11/live-delta-iv-heavy-launch-with-nrol-3/; and Jonathan McDowell, *Jonathan's Space Report*, No. 661, 1 July 2012, at http://planet4589.org/space/jsr/back/news.661.

incorporation of evolving technological developments and responding to changing strategic priorities within a standard spacecraft design.

Albert ('Bud') Wheelon and the conception of the Rhyolite geosynchronous SIGINT satellite program

The geosynchronous SIGINT satellites that were originally conceived by Albert ('Bud') Wheelon and his colleagues in the CIA's Directorate of Science and Technology in 1963-65, soon to become the RAINFALL program and the satellites to be called Rhyolite, were intended for one primary purpose, viz., the collection of telemetry (TELINT) generated in Soviet strategic weapons systems tests, and, more specifically, to 'continuously look down on Tyuratam and Sary Shagan', respectively the Soviet Union's main launch site for testing liquid-fuelled ICBMs and its main anti-ballistic missile (ABM) test centre, and respectively located at 46° North latitude and 63.3° East longitude and 46.4° N latitude and 73° E longitude. The Rhyolite spacecraft had already been designed by the CIA's engineers and negotiations were already underway with the Australian Government concerning the establishment of the RAINFALL ground station at Pine Gap when, in late 1965, agreement was reached for the NSA to join the program and the CIA accepted an NSA proposal 'that COMINT [communications intelligence] become an ancillary mission'.[9]

An official NSA history later recorded, perhaps with some jaundice, that the CIA 'gave NSA the job of collecting what COMINT [communications intelligence] they could from a bird whose job was TELINT, not COMINT'. It also noted that the NSA was allowed to install 'a COMINT processing subsystem and an ELINT [electronic intelligence] subsystem' at the RAINFALL ground station, that the NSA paid for these subsystems, and that 'eventually, it provided all the COMINT staff and about half of the TELINT crew.'[10]

Organisationally, the RAINFALL program and the Rhyolite satellites comprised the SIGINT satellite component of the NRO's Program B, but it operated as a quasi-autonomous CIA entity. Until the major re-structuring of the NRO in the mid-1990s, the

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[9] Thomas R. Johnson, *American Cryptology During the Cold War, 1945-1989. Book II: Centralization Wins, 1960-1972*, (Center for Cryptologic History, National Security Agency, 1995), pp. 409-410, at http://www2.gwu.edu/~nsarchiv/NSAEBB/NSAEBB441/docs/doc%201%202008-021%20Burr%20Release%20Document%201%20-%20Part%20A2.pdf.

[10] Thomas R. Johnson, *American Cryptology During the Cold War, 1945-1989*, pp. 409-410.

CIA effectively determined the collection priorities, and hence the satellite design parameters and even the geosynchronous vantage points for the satellites.[11]

Albert Wheelon, the father of the Rhyolite program, was appointed Deputy Director of the CIA for Science and Technology (DDS&T) in August 1963. He obtained his PhD in physics from MIT in 1952, and had then worked at TRW for nine years, including as director of TRW's Radio Physics Laboratory in 1960-62, which was primarily concerned with the design and development of 'guidance systems for long-range ballistic missiles and satellites'.[12] He joined the CIA as head of the Office of Scientific Intelligence (OSI) in June 1962, when he was just 33 years old, 'awfully young' for that job. He has described himself as being, at that time, 'brash', 'very demanding' and impatient. His most important mission was to develop and employ advanced technical systems to collect and analyse intelligence concerning Soviet strategic weapons system developments. The telemetry generated by Soviet missile tests and the emissions of ABM radars were the key ingredients for analysis of the respective offensive and defensive sides of these developments.[13]

In July 1963, as Wheelon was preparing to take up his appointment as DDS&T, he read an article on the front page of the *New York Herald Tribune* about the launch of the Syncom-II experimental communications satellite, the first satellite to be placed into a geosynchronous orbit, a major purpose of which was to demonstrate attitude control of the satellite for antenna-pointing and station-keeping. Wheelon wondered whether it might be possible to build a geosynchronous satellite for intercepting signals from 'key targets' in the Soviet Union, and particularly telemetry signals from the missile test ranges at Tyuratam and a few other places and ABM radar data from Sary Shagan, and then downlinking the intercepted signals to a US ground station.[14]

Wheelon 'assembled some key CIA officials to explore such ideas'. These included George C. Miller, the founding chief of the Office of ELINT (OEL), which was formed in 1962 to provide technical support for CIA SIGINT stations located in

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[11] Desmond Ball, Bill Robinson and Richard Tanter, *The Higher Management of Pine Gap*, Nautilus Institute, Special Report, 18 August 2015, at http://nautilus.org/wp-content/uploads/2015/08/The-Higher-Management-of-Pine-Gap.pdf.
[12] Jeffrey T. Richelson, 'From JAM SESSION to the PFIAB: Albert Wheelon and U.S. Intelligence', *Intelligence: Journal of U.S. Intelligence Studies*, Fall/Winter 2013, p. 23.
[13] Ed Dietel, 'Charting a Technical Revolution: An Interview with Former DDS&T Albert Wheelon', *Studies in Intelligence*, 17 October 1998, p.35, at http://www.foia.cia.gov/sites/default/files/DOC_0000863247.pdf.
[14] *Ibid.*, p. 39; Jeffrey T. Richelson, *The Wizards of Langley*, pp. 109-110.

West Germany, Norway and Iran; Carl Nelson from the Office of Communications, who had been involved in a variety of covert COMINT collection projects; Leslie C. Dirks, a young scientist who had joined the CIA in 1961 with degrees from MIT and Oxford University; and Lloyd K. Lauderdale, a graduate of the US Naval Academy with a PhD from Johns Hopkins University, who joined the CIA in 1963 and worked in OSI on the Soviet ABM program, trying to make sense out of the limited amount of technical intelligence concerning activities at the ABM test centre at Sary Shagan.[15]

Figure 2.
Albert 'Bud' Wheelon,
Deputy Director for Science and Technology,
Central Intelligence Agency, 1963-1966

Source: 'Dr. Albert D. "Bud" Wheelon, Ph.D,
January 1929 - September 27, 2013', Roadrunners Internationale, at
http://roadrunnersinternationale.com/wheelon.html.

The initial discussions raised many technical issues, of which two were paramount. These concerned the feasibility of extracting SIGINT of interest, and specifically TELINT, from the multitude of other VHF (very high frequency; 30-300 MHz) and UHF (ultra high frequency; 300-3000 MHz) signals emanating from within the Soviet Union; and the practicality of designing and deploying the 'immense antenna' that was required in space. The official NSA account of the beginnings of the

[15] Jeffrey T. Richelson, *The Wizards of Langley*, p. 110.

RAINFALL/Rhyolite program has noted that 'a scientist calculated that it [the main intercept antenna] would have to be at least seventy-five feet [23 metres] in diameter, the largest such object ever unfurled in space'.[16]

Wheelon asked Lloyd Lauderdale to study the antenna issue, including possible mechanisms for unfurling the massive antenna once the satellite reached orbit. Wheelon stated in an interview in 1998 that 'Lloyd Lauderdale gets a lot of the credit' for the antenna design. Wheelon also said:

> I will never forget the day when they finally came in with a model and manually cranked it up – the thing actually deployed. I said "Come on, let's go up and see [CIA Director John] McCone". We showed it to him, and he agreed to go forward.[17]

Wheelon also sought technical advice from engineers in the private aerospace/electronics sector. For example, he consulted Frank W. Lehan, an electrical engineer, who had been Wheelon's boss at TRW in the late 1950s, who was a member of the President's Science Advisory Committee (PSAC), and who 'advised the NRO and Program B on overhead reconnaissance systems'.[18] In the late 1950s, Lehan had invented an electronic antenna scan system which 'automatically searches for and then locks-on to a signal source target'.[19] In 1972 he produced a study on the implications of the Space Shuttle for 'future military space activity', in which he noted that there had been 'frequent studies in the past of employing multiple, low altitude satellites for SIGINT applications as opposed to a few synchronous-altitude satellites', and that 'the trades have tended to lean in favour of the few high altitude satellites as opposed to the many low altitude satellites for a combination of cost and technical reasons'.[20] Lehan was honoured by the NRO in 2000 for his role at the beginning of the Rhyolite program. The NRO stated that Lehan had provided 'service to national reconnaissance' from 1965 to 1975, that he 'was instrumental in the decision to proceed with an important high altitude

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[16] Thomas R. Johnson, *American Cryptology During the Cold War, 1945-1989,* p. 409.
[17] Ed Dietel, 'Charting a Technical Revolution: An Interview with Former DDS&T Albert Wheelon', p. 39; Jeffrey T. Richelson, *The Wizards of Langley*, p. 111.
[18] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 123, at https://fas.org/irp/nro/review-2008.pdf; Jeffrey T. Richelson, *The Wizards of Langley*, (p. 132
[19] F. W. Lehan et al, 'Electronically Scanning Antenna Employing Plural Phase Locked Loops to Produce Optimum Directivity', (Patent US3036210, 2 November 1959), at http://www.google.com.au/patents/US3036210.
[20] Letter from John S. Foster, Jr., to Carl Duckett, 9 August 1972, at http://nsarchive.gwu.edu/NSAEBB/NSAEBB509/docs/nasa_43.pdf.

signals intelligence satellite system', and that he had 'contributed to the reflector design for that system'.[21]

William J. Perry, a mathematician who 'advised the NSA and CIA on programs to intercept and evaluate Soviet missile telemetry and communications intelligence', played a critically important role during the origins of the Rhyolite program.[22] Wheelon and Perry had first worked together on a Telemetry and Beacon Analysis Committee (TEBAC) in 1958-60, a joint NSA-CIA project which involved analysis of telemetry recorded from test launches at Tyuratam by NSA and CIA SIGINT stations in Turkey and Iran, as well as signals transmitted by Soviet Sputnik satellites. Perry had also advised OEL on Soviet ABM radar developments.[23] In 1964, Wheelon asked Perry, who had just set up his own company in Palo Alto called Electromagnetic Systems Laboratory (ESL) Inc., to study the technical feasibility of extracting worthwhile SIGINT/TELINT from the radio frequency (RF) background. As Wheelon noted in an interview in 1998, the problem was that, from geosynchronous altitude, 'you will hear everything in addition to what you are looking for. The question is, would the other transmitters that we were not interested in swamp out what we were interested in?'.[24] According to Wheelon:

> We gave that job to Bill Perry…. I went to Bill, for whom I had a high regard, and said: "The key question in this project is whether or not we can do this. Will you please go off to one side and work with NSA to see what the background data look like. Please tell us whether we are on the right track? There is no point building this system and having it be a flop".[25]

Perry reported back to Wheelon after about six months. 'The answer', he said, was 'yes, we could make it work'. Wheelon has recorded that 'On that basis we proceeded'.[26] Perry subsequently chaired the 'Perry Panel', which 'advised the CIA on all overhead signals collection' programs, including the successors to the Rhyolite satellites,[27] and served as Secretary of Defense from 1994 to 1997.

Perry's study persuaded both John McCone, the Director of the CIA, and Lieutenant General Marshall Carter, the Deputy Director (who became Director of the

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21 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 123, at https://fas.org/irp/nro/review-2008.pdf.
22 'National Reconnaissance Office Review and Redaction Guide', p. 127.
23 Ed Dietel, 'Charting a Technical Revolution: An Interview with Former DDS&T Albert Wheelon', p. 34; Jeffrey T. Richelson, *The Wizards of Langley*, pp. 49, 90.
24 Ed Dietel, 'Charting a Technical Revolution: An Interview with Former DDS&T Albert Wheelon', p. 39.
25 *Ibid.*, p. 39.
26 *Ibid.*
27 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 127.

NSA several months later) that the project was feasible and worth supporting.[28] However, neither Perry's study nor other technical studies that Wheelon had commissioned said much about the cost of any such geosynchronous SIGINT satellite system. The NSA account of the beginnings of the RAINFALL/Rhyolite program noted not only that 'the project was fraught with tremendous risk', but also that 'it would be hideously expensive, the most costly intelligence system ever mounted'.[29] Brockway McMillan, the Director of the NRO from March 1963 to October 1965, accepted Perry's analysis concerning its feasibility, but 'questioned whether such a system would be worth the expense'. The NRO provided little funding for the development of the first Rhyolite satellites.[30] On 30 September 1965, McMillan wrote to the Secretary of Defense, Robert McNamara, arguing that building a geosynchronous satellite just to collect telemetry data was unjustifiable. He stated that:

> This requirement [for a Rhyolite satellite] cites a prior USIB [United States Intelligence Board] requirement for collecting telemetry from boosters from the time they go into operation on the pad. [Deleted] It is hard for me to believe that a rational analysis of the usefulness of telemetry data, in comparison say, to the direct usefulness of the ROB [radar order of battle] data to be gotten by other SIGINT activities, would justify so large an expense. In any case, no alternative collection schemes were compared, and no ways, other than SIGINT, for getting the basic information desired – booster sizes – were considered.[31]

The development of the Rhyolite satellite was approved within the CIA in 1965, with Lloyd Lauderdale appointed Manager of the new program.[32] Wheelon has said that he 'had no faith that McMillan or the NRO would give RHYOLITE a fair hearing', and that the CIA used its own funds to initiate the program. Indeed, the CIA preferred to keep the NRO ignorant about the program. The NRO Comptroller, John Holleran, reportedly 'kept trying to get a handle on money for RHYOLITE and never was able to'.[33]

Lauderdale was appointed Assistant DDS&T on 5 June 1967, where he remained until he left the CIA on 21 March 1969, continuing to serve through that period as

[28] Jeffrey T. Richelson, *The Wizards of Langley*, p. 111.
[29] Thomas R. Johnson, *American Cryptology During the Cold War, 1945-1989*, p. 409.
[30] Jeffrey T. Richelson, *The Wizards of Langley*, p. 111.
[31] Brockway McMillan, Memorandum for the Secretary of Defense, 'Subject: Comments on NRO and NRP', 30 September 1965, pp. 8-9, cited in Jeffrey T. Richelson, *Civilians, Spies, and Blue Suits: The Bureaucratic War for Control of Overhead Reconnaissance, 1961-1965*, (National Security Archives, Washington, D.C., January 2003, p. 45, at http://nsarchive.gwu.edu/monograph/nro/nromono.pdf.
[32] Jeffrey T. Richelson, *The Wizards of Langley*, pp. 110-111.
[33] *Ibid.*, pp. 111-112.

Rhyolite Program Manager, effectively seeing the project through construction of the first satellite. He then joined E-Systems in Dallas, Texas, where he became Vice President for Research and Engineering.

In 2000, some 35 years after the bitter bureaucratic struggles between the NRO and the CIA over the Rhyolite program, the NRO acknowledged Lauderdale as one of the 'pioneers of national reconnaissance'. It stated that he had been 'Program Manager for the CIA Program B team that developed an advanced signals intelligence satellite from concept through first launch'.[34] In April 2007, to mark its 50th anniversary, the CIA honoured a select group of 'Trailblazers'. These included Lauderdale. His citation read that he had worked for the CIA from 1963 to 1969, and that:

> Mr. Lauderdale developed an innovative solution to one of the Intelligence Community's most critical technical collection problems. His proposal was risky and was one of the most ambitious space initiatives undertaken by CIA. The program was successful and greatly enhanced the nation's national technical means.[35]

Many other scientists and engineers in NRO Program B/CIA DDS&T were also directly involved in the design and development of the original Rhyolite satellites. Several of them were recognised by the NRO as 'pioneers of national reconnaissance' in 2000. John J. Crowley, the Director of the Office of Special Projects (OSP) from September 1965 to November 1970, oversaw the program within DDS&T. He 'is credited with establishing a true partnership between the CIA and Department of Defence agencies, including the NRO, NSA and USAF, which from the outset strongly opposed the CIA program.[36] John N. McMahon, the deputy head of OSP, and later the Director of OEL (1971-73), was also involved in many issues.[37] John T. Bennett, the chief engineer for contractors in Program B, made 'design improvements that greatly improved overhead SIGINT reconnaissance'.[38] Forrest H. Stieg, an engineer and spacecraft operations specialist in Program B, 'devised a process for selecting an optimum orbit that balanced

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[34] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 122.
[35] Central Intelligence Agency (CIA), '"Trailblazers" and Years of CIA Service', at https://www.cia.gov/news-information/press-releases-statements/press-release-archive-1997-1/trailblazers.html.
[36] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 114.
[37] Jeffrey T. Richelson, *The Wizards of Langley*, p. 156.
[38] Tom Nath, Kathryn Sieh and Cherie Jones, 'Pioneer 2000: Recognizing Personal Contributions', *Center for the Study of National Reconnaissance Bulletin*, (No. 2001-1), Winter-Spring 2001, p. 14, at handle.dtic.mil/100.2/ADA391673.

signals collection with vehicle [satellite] longevity', and which 'saved the NRO a great deal of money'.[39]

Thomas W. Conroy, who joined the CIA in August 1968 and served in DDS&T until December 1993, was involved in the development of several of the CIA's geosynchronous SIGINT satellites, especially after he moved to OD&E in 1976. He had initially directed the development of wide-bandwidth recorders in OD&E, but 'later helped develop, test, deploy, and operate special purpose collection systems', and 'was subsequently appointed deputy director, SIGINT Program Group, where he assisted in the development, launch, and operation of a significantly enhanced satellite collection system' (i.e., the first Orion or Magnum satellites), departing that position in 1986.[40] Conroy moved to the NRO in the 1990s, where 'he managed several major reconnaissance satellite programs'. After leaving the NRO, he became Vice President of Intelligence Programs at Northrop Grumman Corporation.[41]

Julian Caballero managed the Aquacade program in the late 1970s and early 1980s. He was an electronic reconnaissance and electronic warfare engineer who had joined the CIA in March 1965, where he worked initially as a SIGINT analyst in OSP. He was appointed director of the Special Program Group in November 1978, but had evidently been in charge of the Aquacade program for some substantial period by January 1979.[42]

TRW Inc, Redondo Beach, California

The Rhyolite satellites were produced by technicians and engineers at the Defense and Space Systems Group of TRW Inc, in close cooperation with the CIA project design team, headed by Lloyd K. Lauderdale under the direction of Carl E. Duckett, Wheelon's successor as DDS&T, and John T. Bennett, Program B's contact

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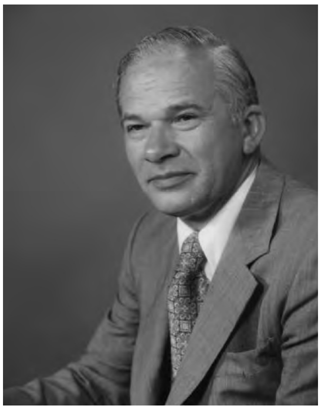
[39] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 132; and Tom Nath, Kathryn Sieh and Cherie Jones, 'Pioneer 2000: Recognizing Personal Contributions', p. 14.
[40] Clayton D. Laurie, 'Leaders of the National Reconnaissance Office, 1961-2001: Directors, Deputy Directors, Staff Directors, Program Directors, Chiefs of Staff, Directorate and Office Managers', (Office of the Historian, National Reconnaissance Office, Washington, D.C., 1 May 2002), pp. 52-53, at http://www.nro.gov/foia/docs/foia-leaders.pdf.
[41] 'Profile: Tom Conroy is Vice President of Intelligence Programs at Northrop Grumman', *IntelliBriefs*, 17 May 2007, at http://intellibriefs.blogspot.com.au/2007/05/profile-tom-conroy-is-vice-president-of.html; and 'Mr. Tom Conroy Joins Deep Water Point's IC Team', *PRWeb*, 17 February 2015, at http://www.prweb.com/releases/2015/02/prweb12517834.htm.
[42] Jeffrey T. Richelson, *The Wizards of Langley*, p. 212.

Figure 3. Carl E. Duckett
Director of Program B,
National Reconnaissance Office,
14 January 1967 – 28 May 1976



Source: Clayton D. Laurie, 'Leaders of the National Reconnaissance Office, 1961-2001: Directors, Deputy Directors, Staff Directors, Program Directors, Chiefs of Staff, Directorate and Office Managers', (Office of the Historian, National Reconnaissance Office, Washington, D.C., 1 May 2002), p.87, at http://www.nro.gov/foia/docs/foia-leaders.pdf.

Figure 4. Leslie C. Dirks
Director of Program B,
National Reconnaissance Office,
6 June 1976 – 2 July 1982

Source: Clayton D. Laurie, 'Leaders of the National Reconnaissance Office, 1961-2001: Directors, Deputy Directors, Staff Directors, Program Directors, Chiefs of Staff, Directorate and Office Managers', (Office of the Historian, National Reconnaissance Office, Washington, D.C., 1 May 2002), p.82, at http://www.nro.gov/foia/docs/foia-leaders.pdf.

Figure 5. Robert Kohler
Director of the Office of Development and Engineering,
Directorate for Science and Technology,
Central Intelligence Agency

Source: 'Robert Kohler', *377 Omega*, at http://www.377omega.com/www/234-2/

Figure 6. Marvin Sidney Stone,
TRW payload systems engineer
on Program B

Source: 'Obituary: Marvin Sidney Stone', *Los Angeles Times,* 15 September 2014, at http://www.legacy.com/obituaries/latimes/obituary.aspx?pid=172475713.

person for contractors.[43] TRW was awarded the contract to build four Rhyolites in 1966, with the first of them to be ready for launch around 1970. The satellites were assembled and prepared for launch in TRW's Building M at One Space Park in Redondo Beach, Los Angeles.[44]

Many TRW personnel contributed to the successful development of the Rhyolite satellites and their successors. According to an NRO citation, John P. Bennett, TRW's chief engineer in support of Program B, 'conceived the spacecraft design, including the reflectors, used in signals intelligence satellite systems'.[45] Paul W. Mayhew 'served as TRW's payload project manager and system engineer for two unprecedented signals intelligence satellite systems', presumably being the first two Rhyolite satellites.[46] He became Vice President and Deputy General Manager for Programs in TRW's Space & Technology Group in 1990, where he was responsible for managerial oversight of technical progress with regard to spacecraft, payloads, instruments and launch support requirements. William S. Carlson, TRW's Chief Scientist, was also involved with the development of Program B's SIGINT satellites. He was appointed Director of Special Projects at TRW in late 1965.[47] Marvin Sidney Stone, who joined TRW in 1967, 'served as a TRW payload systems engineer and project manager on Program B electronic intelligence satellite programs'. He 'introduced algorithms that improved data-processing ten-fold'.[48] He became General Manager of TRW's Electronics and Technology Division in 1988, retiring from the company in 1997.[49] Frederick H. Kaufman 'directed the TRW team that produced two important Program B signals intelligence satellites, including the first communications cross-link system in space', which suggests that the first two Orion satellites (Magnum-1 and Magnum-2) had some limited data relay capability.[50]

Daniel Saul Goldin, who joined TRW in 1965 and worked there on classified satellite programs for the next 25 years, finishing as Vice President and General Manager

[43] Desmond Ball, Bill Robinson, Richard Tanter, and Philip Dorling, *The corporatisation of Pine Gap* Nautilus Institute, Special Report, 24 June 2015, pp. 8-12, at http://nautilus.org/wp-content/uploads/2015/06/The-corporatisation-of-Pine-Gap.pdf.
[44] Des Ball, *Pine Gap: Australia and the US Geostationary Signals Intelligence Satellite Program*, (Allen & Unwin, Sydney, 1988), chapter 2.
[45] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 110.
[46] *Ibid.*, p. 124.
[47] Leslie A. Hromas, 'The Legacy of TRW and Space Park: A Summary with Key Dates and Milestones', October 2005, pp. 5, 20, at http://tra-spacepark.org/docs/TRW_History.pdf.
[48] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 132; and Nath *et al*, 'Pioneer 2000: Recognizing Personal Contributions', p. 14.
[49] 'Obituary: Marvin Sidney Stone', *Los Angeles Times*, at 15 September 2014, at http://www.legacy.com/obituaries/latimes/obituary.aspx?pid=172475713.
[50] 'National Reconnaissance Office Review and Redaction Guide', (Version 1.0, 2008), p. 120.

of TRW's Space and Technology Group, was involved to greater or lesser extents with the development of successive Rhyolite and Magnum satellites. He enjoyed a close relationship with Anthony H. Sabelhaus, another NRO 'pioneer of national reconnaissance'. Sabelhaus worked at the Goddard Space Flight Center in the late 1960s and early 1970s, where he was responsible for the design and development of gravity gradient stabilisation control systems for large spacecraft, later used on the Magnum satellites. As 'a government employee' in 1979-82, presumably working in the CIA's Program B, he 'ran a classified contract' at TRW, for which Goldin served as program manager, undoubtedly being the Magnum program. Sadelhaus retired from the government in the early 1980s and joined TRW, where he 'took a high salary position working for Mr Goldin'.[51] Goldin later served, from 1992 to 2001, as head of the National Aeronautics and Space Administration (NASA).

Northrop Grumman

TRW was acquired by Northrop Grumman in 2002, and the corporate grounds are now known as the Northrop Grumman Space Park. Northrop Grumman took over all TRW's responsibilities with respect to the geosynchronous SIGINT satellite program, including operational support at the mission ground stations.[52] One satellite, Orion-5, was almost ready for launch in 2002, although it was delayed by technical problems until September 2003.

It is likely that Orion-6, Orion-7 and Orion-8, launched in January 2009, November 2010 and June 2012, retained essential elements of their TRW legacy, but they undoubtedly also incorporated more advanced technologies and better capabilities than their TRW predecessors, especially with respect to interception of cellular telephone transmissions.

The NRO budgets for the Orion-7 and Orion-8 satellites in fiscal years 2011-2013 comprise a final payment of $9.13 million in FY 2011 for Orion-7, and payments amounting to $350.63 million for Orion-8 in the three-year period ($182.277 million, $130.383 million, and down to $37.967 million in FY 2013).[53] (Construction of the

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[51] *Ibid.*, p. 130; and Letter from 'a TRW employee' to Senator Al Gore, 17 March 1992, at http://jowilson.org/nasa/goldinletter.html.
[52] Desmond Ball, Bill Robinson, Richard Tanter, and Philip Dorling, *The corporatisation of Pine Gap*, Nautilus Institute, Special Report, 24 June 2015, pp. 8-12.
[53] 'FY 2013 Congressional Budget Justification: Volume 1, National Intelligence Program Summary', February 2012, p. 167.

Orion-8 spacecraft must have been completed in 2011, and with the greater part of the cost presumably paid off before then).

The Rhyolite satellites

The first Rhyolite satellite, identified by the Committee on Space Research (COSPAR) as 1970-46A, designated satellite 7601 by the NRO, and known colloquially as 'Bird 1' by Pine Gap personnel, was launched into orbit from Cape Canaveral on 19 June 1970. It reportedly weighed 700 kg with full fuel, and 350 kg when empty at geosynchronous altitude. The diameter of the main intercept antenna is generally reckoned to have been around 20 metres, or 60-70 feet. (It may have been slightly larger than this, as a study commissioned by Wheelon in 1965 had suggested that it 'would have to be at least seventy-five feet [23 metres] in diameter').[54] It was initially positioned at a longitude of about 105 degrees East, from where, at an altitude of nearly 36,000 km, it was able to monitor both Tyuratam and Sary Shagan.[55] (See Tables 3 and 4.)

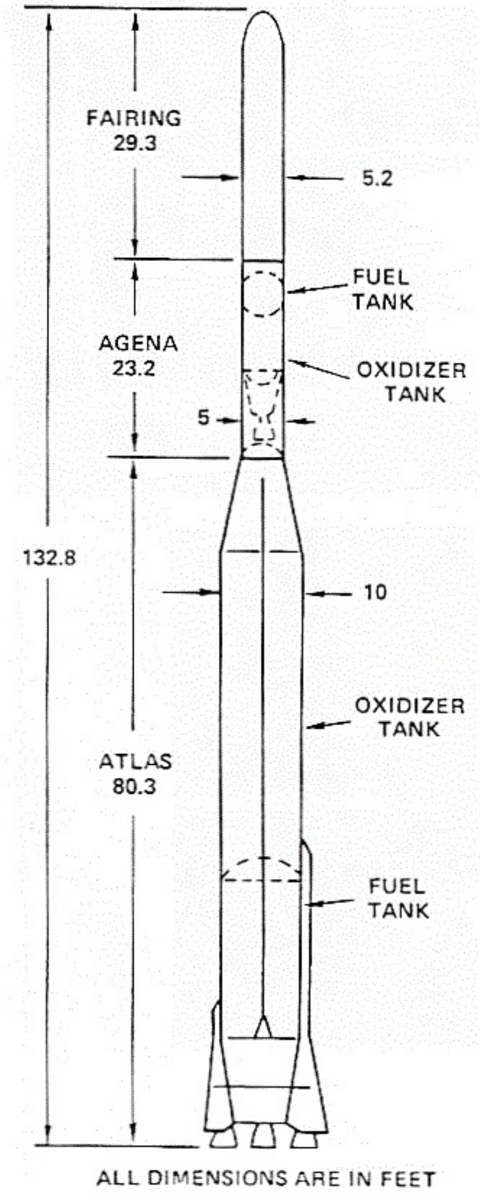
Rhyolite-1 had unexpected longevity, especially given that during the 33 months in which it was the CIA's only operational geosynchronous SIGINT satellite, it was repositioned several times in order to monitor different areas of interest. The primary mission of Bird 1 was to intercept the telemetry and other signals associated with Soviet strategic systems developments, but in 1971 it was repositioned to monitor the India-Pakistan War, and on several occasions it was directed to monitor the Vietnam theatre. Following the launch of the second Rhyolite satellite in 1973, Rhyolite-1 was re-directed towards China and Vietnam on a long-term basis. It remained operational for more than five years. It was still operational when Christopher Boyce was briefed on the Rhyolite program at TRW on 15 November 1974, and former computer operators at Pine Gap have stated that it was still operational through the end of 1975.[56]

Rhyolite-2 (1973-13A) was launched from Cape Canaveral on 6 March 1973, and reportedly placed at 70º E. According to one account:

> [1973-13A was] parked over the Horn of Africa. From this aerie, Rhyolite could eavesdrop on microwave transmissions from western Russia as well as intercept telemetry signals transmitted from liquid-fuel ICBMs launched from the

[54] Thomas R. Johnson, *American Cryptology During the Cold War, 1945-1989,* pp. 409-410.
[55] Des Ball, *Pine Gap*, pp.16-19; and Jeffrey T. Richelson, *The Wizards of Langley*, p. 157.
[56] Des Ball, *Pine Gap*, pp. 16-18.

Figure 7. Atlas Agena launcher used for Rhyolite satellites



Source: Photo from Joel Powell, at Blackstar, 'Reply #134, Re Titan-Agena, Titan-Agena, Historical Spaceflight, Forum', *NASASpaceFlight.com*, 16 March 2009, at https://forum.nasaspaceflight.com/index.php?topic=16017.msg376042#msg376042.

Source: Blackstar, 'Reply #122, Re Titan-Agena, Titan-Agena, Historical Spaceflight, Forum', *NASASpaceFlight.com*, 16 March 2009, at https://forum.nasaspaceflight.com/index.php?topic=16017.msg376042#msg376042.

> Tyuratam missile-testing range and solid-propellant missiles, like the SS-16 and intermediate-range SS-20, launched from Plesetsk.[57]

Rhyolite-3 (1977-114A), also referred to as Aquacade-1, was launched on 11 December 1977. (The codename was changed from Rhyolite to Aquacade earlier that year, following the discovery that Christopher Boyce had provided details of the Rhyolite program to the Soviet Union).[58] It was reportedly stationed at 70º E, replacing Rhyolite-2, which after nearly five years in service may have ceased operating, or was re-located to a secondary position. The diameter of the main intercept antenna on the Aquacade satellites has not been reported. However, TRW had submitted a design for 'a one-hundred-foot-wide [30 metres] concave antenna' to the CIA in July 1973, and the main antenna developed for the planned follow-on satellite from Rhyolite, the cancelled Argus program, was about 40 metres in diameter, so it is likely that the antenna on the Aquacades was at least 40 metres in diameter.[59]

Rhyolite-4 (1978-38A), or Aquacade-2, was launched on 7 April 1978. It was reportedly placed at 115º E, to monitor the re-entry telemetry from Soviet test ballistic missile re-entry vehicles (RVs) impacting around the Kamchatka Peninsula. It also monitored other signals in the central and east USSR.[60]

In December 1982, *Washington Post* columnist Jack Anderson reported that 'Only two high-altitude telemetry satellites' were then in operation, and both, he wrote, were 'dying'.[61] The two satellites were presumably Rhyolite-3 and Rhyolite-4, although the report of their imminent demise seems to have been exaggerated, as it is likely that one or both remained in service at least until the advent of the Magnum satellites.

The Magnum satellites (Orion-1 and Orion-2)

Orion-1 (1985-10B), initially called Magnum-1, was launched from Cape Canaveral aboard the Space Shuttle *Discovery* (Mission 51-C) on 24 January 1985.[62] (The

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[57] James Bamford, *The Puzzle Palace: A Report on America's Most Secret Agency*, (Penguin Books, Harmondsworth, Middlesex, 1983), p. 254.
[58] Jeffrey T. Richelson, *The Wizards of Langley*, p. 205.
[59] Des Ball, *Pine Gap*, pp. 19- 21.
[60] *Ibid.*, p. 23.
[61] Jack Anderson, "Lack of Funds Is Hampering U.S. Intelligence," *Washington Post*, 14 December 1982.
[62] James Gerstenzang, 'Shuttle Lifts Off with Spy Cargo', *Los Angeles Times*, 25 January 1985, pp. 1, 11; 'Final Launch Preparations Under Way for Signal Intelligence Satellite Mission', *Aviation Week and Space Technology*, 6 November 1989, p. 24; and Jeffrey T. Richelson, *The Wizards of Langley,* p. 234.

satellites were developed under the codename Magnum but the name was changed to Orion by the time of the first launch).[63]

Although the CIA and the Department of Defense sought to impose unprecedented secrecy on the Magnum launch, the effort served more to heighten media interest than to keep the details of the mission secret.[64] The *Discovery* Mission 51-C lifted off from Cape Canaveral at precisely 2:50 pm on 24 January 1985. Approximately 16 hours after the launch (i.e., at about 7 a.m. on 25 January US Eastern Standard Time), when the *Discovery* was stabilised at an altitude of 300 km and an inclination of 29°, a Boeing Inertial Upper Stage (IUS) booster vehicle designed to carry the Magnum to geosynchronous orbit was deployed from the *Discovery* payload bay. About 55 minutes after deployment from the Shuttle, as the IUS crossed the Equator, the first-stage motor on the booster was ignited for 146 seconds and injected the IUS into a highly elliptical orbit with an apogee of about 36,000 km. About six hours after deployment from the Shuttle and five hours after the first-stage motor was ignited, the attitude of the IUS was stabilised and the second-stage motor ignited for 103 seconds in order to successfully place the vehicle in geosynchronous orbit. Small hydrazine liquid propellant thrusters were used to refine the final positioning. The antennas and solar power arrays were unfurled as the Magnum separated from the IUS second stage.[65]

At the time of its launch, Magnum-1 was the largest spacecraft ever placed in geosynchronous orbit. It had an estimated mass of 2,200-2,700 kg, or about 3.5 times the mass of the Rhyolites. Its main intercept antenna is commonly reckoned to be about 100 metres (or about 350 feet) in diameter, making 'it possible to detect lower power transmissions, as well as to determine the position of a transmitter with increased precision', compared to the Rhyolites.[66]

According to a major report on Shuttle Mission 51-C published in the *Washington Post* on 19 December 1984, when the *Discovery* was being prepared for launch, the cost of the Magnum was $(US) 300 million; it was to be positioned to monitor 'the western

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[63] *Ibid.*, p. 234.
[64] Jeffrey T. Richelson and William M. Arkin, 'Spy Satellites "Secret", But Much is Known', *Washington Post*, 6 January 1985, pp. C1-C2; and Jack Anderson, 'Hiding Behind the Flag?', *Washington Post*, 10 February 1985, p. D7.
[65] John Noble Wilford, 'Shuttle Launched on Secret Mission', *New York Times*, 25 January 1985, pp. 1, 6; 'News Digest', *Aviation Week and Space Technology*, 28 January 1985, p. 27; 'IUS Meets Mission Objectives on Defense Dept. Shuttle Flight', *Aviation Week and Space Technology*, 4 February 1985, p. 20; and 'Defense Dept. IUS Uses Liquid Thruster Aid', *Aviation Week and Space Technology*, 18 February 1985, pp. 22-23.
[66] 'SIGINT Overview', Federation of American Scientists (FAS), at http://fas.org/spp/military/program/sigint/overview.htm.

portion of the Soviet Union' (i.e., around the 70º E station); it was designed to intercept a wide range of signals, including telemetry from Soviet missile tests; and the intercepted signals were to be transmitted 'to a receiving station outside the continental United States'.[67] According to reports in the *New York Times* the day after the launch, the satellite was 'capable of monitoring missile tests and intercepting military and diplomatic communications of the Soviet Union', and the main intercept antenna was sufficiently large and sensitive that 'it could pick up broadcasts from radios the size of a wristwatch'.[68] Other reports noted that it 'also received data from emplaced sensors in the Soviet Union and elsewhere'.[69]

Orion-2 (1989-90B, or Magnum-2) was launched aboard *Discovery* (Mission STS-33) on 23 November 1989. When *Discovery* was stabilised in a circular orbit at an altitude of 519 km, the IUS was ignited and the satellite carried up to geosynchronous orbit. It was reported that Orion-2 replaced Orion-1 at the 70º E station because, after nearly five years, the latter 'was running out of the maneuvering fuel required for keeping its station over the Indian Ocean'.[70] However, Orion-1 remained functioning for more than another two decades, probably until sometime in 2013.

The first two Orion (or Magnum) satellites had extraordinary longevity. An article in *Air & Space Magazine* in August 2009 noted that Orion-1 was 'an eavesdropping satellite for signals intelligence', and that it possessed 'a dish almost as wide as a football field is long (hence the need for the shuttle's large payload bay) to listen in on ground communications and telemetry'. It also quoted Gary E. Payton, the Payload Specialist on Mission 51-C, as saying with respect to Orion-1 that: 'It's still up there, and still operating'.[71] Indeed, it was operating at 71.3º E in early 2009.

In October 2009, NRO Director Bruce Carlson stated at a 'GeoInt Symposium' in San Antonio, Texas, that some of the SIGINT satellites were 'geriatric' but still functioning, which he attributed to 'the incredible, creative use of our ground systems'. According to a transcript of his speech, he said that:

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67 Walter Pincus and Mary Thornton, 'U.S. to Orbit "SIGINT" Craft from Shuttle', *Washington Post*, 19 December 1984, pp. A1, A8.
68 John Noble Wilford, 'Shuttle Launched on Secret Mission', pp. 1, 6; and William J. Broad, 'Experts Say Satellite Can Detect Soviet War Steps', *New York Times*, 25 January 1985, pp. 1, 6.
69 Jeffrey T. Richelson, *The Wizards of Langley*, p. 236.
70 Edward H. Kolcum, 'Night Launch of Discovery Boosts Secret Military Satellite into Orbit', *Aviation Week and Space Technology*, 27 November 1989, p. 29.
71 Michael Cassutt, 'Secret Space Shuttles', *Air & Space Magazine*, August 2009, at http://www.airspacemag.com/space/secret-space-shuttles-35318554/?all.

Figure 8.
Mission patch for Space Shuttle Mission STS -51C used to launch Orion-1, 24 January 1985

Source: 'STS-51C crew patch', collectSPACE, 30 July 2005, at http://www.collectspace.com/ubb/Forum18/HTML/000262.html.

Figure 9.
Mission patch for Space Shuttle Mission STS-33, used to launch Orion-2, 23 November 1989

Source: 'File:Sts-33-patch.png', *Wikipedia*, at https://en.wikipedia.org/wiki/File:Sts-33-patch.png.

> We have a satellite up there that is ten times older than we expected it to be. It has been up there this long [extends his arms out wide] and it has been up there this long [extends his arms out farther] and it's still working. We expected it to do a mission that had to do with strategic, long-haul communications [i.e., terrestrial microwave relay] and today it's helping us kill bad guys in the AOR [Area of Responsibility]. Now that's as specific as I can get. But we do that because of the incredible contractor and NRO team that we have that nurses that satellite along and the young people that write software to change its functionality and keep it going. I know it takes a long time but the systems that we have in orbit, I think, give the public a real bargain. The constellation is this big [holds hands out], half of it is geriatric, yet it's all functioning.[72]

Similarly, Carlson stated in 2011 that 'some of the signals collection satellites are remarkably old'. He said that 'those satellites were designed to collect Soviet long-haul communications that dealt with the Cold War,' and that 'now they're collecting phone calls or push-to-talk radio signals out of the war zone'.[73]

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[72] General Bruce Carlson, 'GEOINT Symposium, October 21, 2009, San Antonio, Texas', at http://www.nro.gov/news/speeches/2009/2009-03.pdf.
[73] Karen Parrish, 'NRO Maintains Nation's Intel Satellite Edge', *DoD News*, 16 September 2011, at http://www.defense.gov/news/newsarticle.aspx?id=65364.

Carlson was undoubtedly referring to Orion-1 and Orion-2, both of which were still functioning in 2009-11, but he was also referring to one or more Vortex (also called Chalet) satellites, controlled from Menwith Hill. Vortex-3 (1981-107A), launched on 31 October 1981, was still functioning in December 2006, when NRO celebrated the '25th birthday' of the satellite. The then Director of the NRO, Donald Kerr, stated that:

> It's extraordinary that this machine born in the analog age is still serving the country in the digital age…. It had to go to war with one of our allies shortly after launch and supported the United Kingdom in the Falklands War. It then came back, in fact to the central Asian theater, and provided notable service there. Now it's covering the sub-continent India, Pakistan, Afghanistan, still doing significant work. It had a mean mission life of three or four years. Here we are 25 years later and it's a tribute to the designers and more importantly those that have nursed it along as it displayed all of the symptoms of old age many times over.[74]

The evolution of Orion: Major upgrade or incremental advances?

In early 1985, just as the first Orion satellite (Magnum-1) became operational, Program B was embroiled in a bureaucratic battle with the NRO over the future of the Orion program. The Director of the Air Force Office of Special Projects (i.e., NRO Program A), Major General Ralph H. Jacobsen, had proposed that 'the follow-on to ORION be a far bigger system', whereas Program B, represented by Robert Kohler, Director of OD&E in DDS&T, favoured more evolutionary developments, preferring 'to take the system then in operation and modify each successive satellite', which was technically less risky and probably cheaper. To Kohler, Program A's proposal was a tactic intended to either kill any CIA follow-on to the Magnum program, or to have it taken over by Program A.[75]

Later in 1985, Wheelon, a member of the President's Foreign Intelligence Advisory Board (PFIAB), was asked by CIA Director William Casey to review the respective merits of the Program A and CIA proposals. Wheelon was then a senior

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[74] Dwayne Day, 'The Lion and the Vortex', *The Space Review*, 11 March 2013, at http://www.thespacereview.com/article/2258/1.

[75] Jeffrey T. Richelson, *The Wizards of Langley*, pp. 234-236.
After leaving the CIA in 1985 Kohler was Vice-President of Advanced Programs for the Lockheed Missiles and Space Company. Kohler went on to become Executive Vice President and General Manager of TRW's Avionics & Surveillance Group. See 'Robert Kohler', *377 Omega*, at http://www.377omega.com/www/234-2/; and
'Executive Profile: Robert J. Kohler, Member of Advisory Board, Scientific Systems Company, Inc.', *Bloomberg Business*, 9 September 2015, at
http://www.bloomberg.com/research/stocks/private/person.asp?personId=58660699&privcapId=22408520.

executive at Hughes Aircraft Company; he regarded it as 'an unwelcome assignment', which 'couldn't do the Hughes company any good'. He nevertheless examined the issue, relying on another Hughes engineer, Harold Rosen, for 'technical back-up'. Wheelon 'concluded that the extensive improvements suggested by Program A were not necessary', and that 'the CIA proposal to stay with the same basic system and same contractor (TRW) made the most sense'. He discussed the matter with Jacobsen, who 'accepted his analysis'.[76]

Casey approved the Program B proposal, with its modest upgrades, but he died in 1987, and Robert Gates, who became Acting Director, 'decided to sacrifice the program to budgetary requirements'.[77] The project lay comatose for a couple of years before being resurrected as an evolved Orion program around 1990. This resurrection was undoubtedly due to Julian Caballero, the former manager of the Aquacade program, who had been the deputy director of OD&E under Kohler during the dispute with NRO Program A over the Magnum follow-on in 1985. He succeeded Kohler as director of OS&D on 17 August 1985, where he remained until 3 October 1993. He served as Director of Program B from August 1989 to 31 December 1992.[78] It presumably also involved Thomas Conroy, who had worked with Caballero in the 1980s. Conroy served as deputy director of the Office of Special Projects in 1991-93, where he 'helped guide the development, deployment and operation of signals intelligence (SIGINT) collection systems', presumably including the first of the second group of Orion satellites.[79]

Orion-3, Orion-5 and Orion-7

Orion-3 (1995-22A) was launched from Cape Canaveral by a Titan 401A/Centaur upper stage launcher at 9:45 in the morning (EST) on 14 May 1995. It weighed 4,500-5,200 kg, double the weight of the Magnums and seven times that of the first Rhyolites. It was initially stationed at around 90-91° E (1996-97), was around 121° E in 1997-99, and has been around 127° E since 2009.

In addition to their 100-metre-diameter main paraboloid intercept antenna, the Orion satellites were equipped with a forest of secondary antennas for specialised

[76] *Ibid.*, p. 236; and Jeffrey T. Richelson, 'From JAM SESSION to the PFIAB: Albert Wheelon and U.S. Intelligence', p. 30.
[77] Jeffrey T. Richelson, *The Wizards of Langley*, p. 236.
[78] Clayton D. Laurie, 'Leaders of the National Reconnaissance Office, 1961-2001', pp. 45-46.
[79] *Ibid.*, pp. 52-53.

interception missions (including interception of mobile telephone conversations from aircraft).

The later Orion satellites were also given data relay capabilities. Initially proposed in an aborted project codenamed Kodiak in the mid-1980s, these provide much greater redundancy in critical control and data downlink elements of the system. According to Jeffrey Richelson:

> KODIAK would have consisted of four geosynchronous satellites, with one satellite in view of the Washington-area downlinks at Ft. Belvoir and Ft. Meade. That satellite would have been capable of downlinking the information in such a narrow beam as to make it virtually immune to interception. The other three satellites, in addition to their control functions, would be able to receive data from the reconnaissance satellites and then transmit the data to the downlink satellite or, via a laser crosslink, to another satellite that would then transmit the information to the downlink satellite.[80]

The Kodiak system was cancelled for funding reasons in 1987, but some of its relay capabilities were incorporated in Orion-3 eight years later, as well as in subsequent Orions.[81]

Orion-5 (2003-41A, or USA-171) was launched from Cape Canaveral by a Titan 401B/Centaur upper stage launcher at 12:29 a.m. on 9 September 2003 and arrived in geosynchronous orbit about six hours later.[82] It had originally been scheduled for launch on 28 April 2002, but was delayed seven times. According to the NRO, the slippages were due to 'issues with the satellite', evidently produced by TRW and Harris Corporation. The satellite had been under construction since the late 1990s, but 'the need for changes became apparent during the final checkout of the spacecraft'. Its initial planned launch vehicle sat on its pad at Cape Canaveral for more than six months before the Air Force decided to use it to launch another military communications satellite and to

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[80] Jeffrey T. Richelson, *The Wizards of Langley*, pp. 236-237. 287. Richelson has indicated to the authors that this planned satellite relay system may not in fact have been called KODIAK, and that that name may have belonged to a different planned system of SIGINT satellites, also abandoned – possibly the alternative to Program B.

[81] *Ibid*.

[82] The launch was also called Mission B-36 by the Air Force. The launch vehicle was nicknamed Homer, 'after LeRoy Homer, the first officer on United Airlines Flight 93, who died on September 11, 2001'. Roger Guillemette and Dwayne A. Day, 'Space Age Hieroglyphs: The Pretty Girl and the Flying Pig', *The Space Review*, 25 August 2008, at http://www.thespacereview.com/article/1197/2; and Justin Ray, 'Titan 4 Rocket Launches Cargo Cloaked in Secrecy', *Spaceflight Now*, 9 September 2003, at http://spaceflightnow.com/titan/b36/.

use another LV for the Orion-5 when it was finally ready.[83] Orion-5 was stationed around 95º E from 2003 to 2011, since when it has been located at around 68º E. There was some allusion at the time of the launch to the planned employment of Orion-5 in 'the war against terrorism', but what this might involve was never explicated.[84]

Figure 10.
Orion-3 and Orion-5 launch patches

Note: Roger Guillemette and Dwayne A. Day: 'The dragons' wings form the shape of a parabolic dish, a clear reference to the large dish-shaped antennae prominently featured on these signals intelligence spacecraft.'
Trevor Paglen: 'There's something both belligerent and weirdly self-critical about it. It's representing the U.S. as a dragon with the whole world in its clutches.'
Sources: Roger Guillemette and Dwayne A. Day, 'Space Age Hieroglyphs: The Pretty Girl and the Flying Pig', *The Space Review*, 25 August 2008, at http://www.thespacereview.com/article/1197/1; and William J.Broad, 'Inside the black budget', *New York Times*, 1 April 2008, at http://www.nytimes.com/2008/04/01/science/01patc.html?pagewanted=2&_r=0.

Orion-7 (2010-63A or USA-223), also referred to as NROL-32, was launched from Cape Canaveral at 5:58 p.m. EST on 21 November 2010. It used a Delta 4 Heavy launch vehicle, called Delta 351, the largest and most powerful US LV currently in service. NRO Director Bruce Carlson said in a speech at the Air Force Association's Air and Space Conference on 13 September, two months before the launch, that the Delta 4 would carry 'the largest satellite in the world'.[85] Carlson also said that the forthcoming launch was part of the early phase of 'the most aggressive launch campaign' that the

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83 'MENTOR [Advanced ORION]', *Global Security.org*, 17 January 2009, at http://www.globalsecurity.org/space/systems/trumpet.htm.
84 Justin Ray, 'Titan 4 Rocket Launches Cargo Cloaked in Secrecy'.
85 William Graham, 'Delta IV Heavy Launches with NROL-32'; and Tariq Malik, 'Secret U.S Spy Satellite Launches Into Orbit on Huge Rocket', *Space.com*, 21 November 2010, at http://www.space.com/9573-secret-spy-satellite-launches-orbit-huge-rocket.html.

NRO had had for 'almost a quarter of a century'. He said that the November launch and other planned launches would 'all go to update a constellation which is aging rapidly', that 'we bought most of our satellites for three, five, or eight years, and we're keeping them on orbit for ten, twelve, and up to twenty years', and that 'some of these guys are like the Energizer bunny and they have really done marvellous work'.[86]

According to one report, the NRO considered NROL-32 'to be particularly urgent'. It said that Orion-3 (USA-110), which was 'believed to be located at a longitude of 127 degrees east', probably needed replacing. It stated that 'it has been in orbit for fifteen years, and is likely to be in need of replacement'.[87] However, as old as Orion-3 was, it was 10 years younger than Orion-1 (Magnum-1) and six years younger than Orion-2 (Magnum-2). Orion-7 was initially stationed at 100.9^{o} E, but was moved in 2011 to around 95^{o} E, where it took over from Orion-5, which was moved to 68^{o} E.

It has been suggested that Orion-7 could be the first of a new generation of 'Improved Mentor' SIGINT satellites. Precisely what Carlson meant by 'the largest satellite' ever launched is unclear. Reliable estimates of its mass are unavailable. He may have been 'referring to the surface area of the spacecraft with arrays and antennae deployed'.[88] The larger payload, utilising more than seven years of advances in engineering design, could mean a larger diameter of the main intercept antenna; however, it could also mean an increase in the secondary antenna suites, or the incorporation of more advanced Kodiak-type data relay capabilities.

Recent reconfiguring of the Pine Gap constellation

According to the European Space Agency (ESA), Orion-1 and Orion-2, the two Magnum variants, were still functioning under control, conducting periodic correction manoeuvres, as at the beginning of 2013. Orion-1 was stationed at 82.154^{o} E, Orion-2 was at 89.473^{o} E, Orion-3 was at 126.976^{o} E, Orion-5 was at 67.083^{o} E, and Orion-7 was at 95.805^{o} E.[89] However, at the beginning of 2014 the ESA reported that both Orion-1

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[86] Tariq Malik, 'Secret U.S Spy Satellite Launches Into Orbit on Huge Rocket'.
[87] William Graham, 'Delta IV Heavy Launches with NROL-32'.
[88] *Ibid.*
[89] T. Flohrer, *Classification of Geosynchronous Objects*, European Space Agency (ESA), Issue 15, 25 February 2013, at http://www.astronomer.ru/data/0128/ESAclassification_Issue15.pdf.

and Orion-2 were in 'drift orbits', having been freed from ground control sometime in 2013.[90] Orion-1 was then 28 years old and Orion-2 was 24 years old.

The retirement of the two original Orions followed the positioning of Orion-7 at the 95° E station, indicating that the new satellite was now fully operational, presumably with all its novel capabilities in working order, while the reassignment of Orion-5 from the 95° E station to around 68° E to accommodate Orion-7 was evidently successful. The most recent ESA report, dated 28 March 2015, shows Orion-3 stationed at 126.924° E, Orion-5 at 67.909° E, and Orion-7 at 95.618° E.[91]

Data registered by the Australian Department of Defence with the Australian Communications and Media Authority (ACMA; previously the Australian Communications Authority, ACA) in accordance with regulations of the International Telecommunications Union (ITU), in which the geosynchronous SIGINT satellites controlled by Pine Gap are called DEF-R-SATs, provides details of the nominal satellite positions in the geosynchronous orbit.

As of 26 July 2002, three DEF-R-SAT positions were registered, these being designated DEF-R-SAT 1A, at 82° E, DEF-R-SAT 2A at 72° E, and DEF-R-SAT 3A at 93° E.[92] On 4 September 2001, the Department of Defence advised the Australian Communications Authority that it wanted a fourth position, designated DEF-R-SAT 4B, to be at either 120.5° or 121° E; this was recorded as 'advance' information in an agreement between the Australian Communications Authority and the Department of Defence in January 2002.[93] A list of 'geosynchronous orbits in the Ku-Band dated 31 March 2004 places 4B at 121° E.[94] Through the next ten years, various authorities, including the Committee on Space Research (COSPAR), ACMA, and the ITU, listed the same four DEF-R-SAT positions, i.e., 1A at 82° E, 2A at 72° E, 3A at 93° E, and 4B at

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[90] T. Flohrer, *Classification of Geosynchronous Objects*, European Space Agency (ESA), Issue 16, 27 February 2014, http://www.astronomer.ru/data/0128/ESAclassification_Issue16_.pdf.
[91] T. Flohrer, *Classification of Geosynchronous Objects*, European Space Agency (ESA), Issue 17, 28 March 2015, at http://www.astronomer.ru/data/0128/ESAclassification_Issue17.pdf.
[92] 'Pending Coordination Requests: Specific GSO FSS Receive Earth Stations, Last Update 26.07.2002', copy obtained from the International Telecommunications Union (ITU) Web-site circa 2004.
[93] 'Deed of Agreement Between Australian Communications Authority and Department of Defence for the Coordination and Radio Interference Management of a Satellite Network', January 2002, p. 34, at www.acma.gov.au/webwr/aca_home/.../deeds_of_agreement/defence.rtf.
[94] 'List of Geostationary Orbits in Ku-Band (From 100 Degrees East to 180 Degrees East', *Radio Use Website*, Ministry of Internal Affairs and Communications (Japan), 31 March 2004, at http://www.tele.soumu.go.jp/e/adm/freq/orbit/ku.htm.

121° E.[95] In 2014, however, two new DEF-R-SAT positions were added, designated as 5B, at 68° E, and 6B, at 95° E.[96]

The three DEF-R-SAT positions in July 2002 were presumably occupied by Orion-1, Orion-2 (or Magnum-1, and Magnum-2) and Orion-3 The fourth position, 4B at 121° E, was probably occasioned by the launch of Orion-5 in September 2003, although this does not necessarily mean that Orion-5 took this slot; it may have replaced one of the older satellites which could then have been re-positioned at 121° E. In any case, the four DEF-R-SAT positions were presumably occupied by Orion-1, Orion-2, Orion-3 and Orion-5 from 2003 to 2010, and by Orion-1, Orion-3, Orion-5 and Orion-7 in 2010-11. Since early 2012, Orion-5 and Orion-7 have occupied the new slots of 5B at 68° E, and 6B at 95° E.

These positions are only nominal as, in practice, the satellites move around up to a few degrees either side of the designated longitudes. In some cases, the slot has been registered before the occasioning satellite has been launched, but in other cases it is evidently registered after it has already been occupied. Moreover, one position, 127° E, which has been occupied by Orion-3 since at least 2010, does not seem to have ever been registered.

The four DEF-R-SAT positions claimed from 2002 to 2014 (1A at 82° E, 2A at 72° E, 3A at 93° E, and 4B at 121° E) have all been vacant since 2013.

Conclusion

Bill Perry, later to become Secretary of Defense, and who worked with Wheelon on the foundations of the US geosynchronous SIGINT satellite program, said of Wheelon's work:

> The national reconnaissance systems which the United States now has which are truly jewels in our crown, all stem, in my judgment, from the creative work that Bud Wheelon did in the 1960s.[97]

[95] 'Actual Situation in the Geostationary Orbit: Information Provided by the Delegation of the Czech Republic', Scientific and Technical Subcommittee, Committee on the Peaceful Uses of Outer Space, Office for Outer Space Affairs, United Nations, Forty-ninth session, Vienna, 6-17 February 2012, A/AC.105/C.1/2012/CRP.25, at http://www.unoosa.org/pdf/limited/c1/AC105_C1_2012_CRP25E.pdf; and ACMA material provided to Philip Dorling.

[96] 'Indexed List of File Titles, January to June 2014', p. 32, at http://www.defence.gov.au/Publications/Parliament/SenateOrder/docs/2014-01_Jan_Jul_2014.pdf; and International Telecommunications Union (ITU), 'ITU Radiocommunication Bureau (BR) Annual Space Report to the STS-15 on the Use of the Geostationary-Satellite Orbit (GSO) and Other Orbits', p. 4, at http://www.itu.int/en/ITU-R/space/snl/SNLReport/SNS-ref-list-2014_e.pdf.

That creativity of Wheelon and his colleagues produced a remarkable series of scientific and technical achievements – the wizardry of Langley in Jeffrey Richelson's phrase. The initial and still principal importance to the United States of one of those 'jewels in the crown', Pine Gap, lies in its role as a ground control and processing station for geosynchronous signals intelligence satellites. Pine Gap's importance in that role has grown as the satellites and their associated ground systems have developed in size, capacity and range of applications far beyond what was envisaged half a century ago – or understood by the host government which accepted the base at that time.

The leap in capabilities between Orion-5, launched in 2003, and Orion-7, launched seven years later, is likely to have been profound, but the actual nature of the changes remains unclear. What is clear is that Pine Gap's three SIGINT satellites now involve the facility in much more than strategic intelligence; they are no longer just a National Technical Means of Intelligence whose great value to the United States lay in its classic Cold War role of monitoring the development of Soviet nuclear missile capacities, with a subsidiary contribution to arms control verification.

Writing of Pine Gap almost half a century ago Robert Cooksey first described the base as 'a suitable piece of real estate' – a phrase that has entered Australian political culture with no little sense of irony and despair. Now more than ever, the significance of that piece of Australian real estate for US military operations is clear. The stations of the current three Orion SIGINT satellites controlled by Pine Gap make possible the collection of a wide range of signals across more than half the surface of the planet – every continent except the Americas (although Antarctica is only partly covered), and every significant region of contemporary US military concern. The satellites of Pine Gap make that base a party to US military planning and operations in Africa, the Middle East, Russia, Central Asia, and East Asia.

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[97] Jeffrey T. Richeison, 'From JAM SESSION to the PFIAB: Albert Wheelon and U.S. Intelligence', *Intelligencer: Journal of U.S. Intelligence Studies*,(Fall/Winter 2013), p.31, at http://roadrunnersinternationale.com/Bud%20Wheelon001.pdf.

Table 2.
Names of signals intelligence satellites operated from Pine Gap, 1970-2015

US government codenames	COSPAR designation	US government unclassified name	Non-official attributed codenames	NROL number
Rhyolite-1	1970-46A	OPS 5346		
Rhyolite-2	1973-13A	OPS 6063		
Aquacade-1 (Rhyolite-3)	1977-114A	OPS 4258		
Aquacade-2 (Rhyolite-4)	1978-38A	OPS 8790		
Orion-1 (Magnum-1)	1985-10B	USA 8		
Orion-2	1989-90B	USA 48	Magnum-2	
Orion-3	1995-22A	USA 110	Advanced Orion-1 Mentor-1	
Orion-5	2003-41A	USA 171	Advanced Orion-3 Mentor-3	NROL 19
Orion-7	2010-63A	USA 223	Advanced Orion-5 Mentor-5	NROL 32

Table 3.
Signals intelligence satellites operated from Pine Gap, 1970-2015

Codename	Launch date	Launch vehicle/flight	Estimated mass (kg)	Estimated diameter of main intercept antenna (m/ft)	Comments
Rhyolite-1	19 June 1970	Atlas Agena S/N 5201A	700	20/65	Called 'Bird 1' by Pine Gap personnel. Retired by late 1970s.
Rhyolite-2	6 March 1973	Atlas Agena S/N 5202A	700	20/65	'Bird 2'. Retired by late 1970s.
Aquacade-1	11 Dec. 1977	Atlas Agena S/N 5504A	700	40/130	Retired by mid-1980s.
Aquacade-2	7 April 1978	Atlas Agena S/N 5505A	700	40/130	Retired by late 1980s?
Orion-1	24 Jan. 1985	Shuttle mission STS-51C	2200-2700	100/350	Reported operational in 2009; still under control at beginning of 2013; retired by 2014.
Orion-2	23 Nov. 1989	Shuttle mission STS-33	2200-2700	100/350	Still under control at beginning of 2013; retired by 2014.
Orion-3	14 May 1995	Titan 401A/Centaur K-23/TC-17 (45E-8)	4500-5200	100/350	Limited data relay system.
Orion-5	9 Sept. 2003	Titan 401B/Centaur 4B-36/TC-20	4500-5200	100/350	Originally scheduled for launch 28 April 2002. Some data relay capacity.
Orion-7	21 Nov. 2010	Delta 351 (4H/RS68)	>5200	100/350	Some data relay capacity.

Main sources: 'Advanced Orion', *Encyclopedia Astronautica*, http://www.astronautix.com/craft/advorion.htm; V. Agapov, 'USA-171: новое «ухо» на орбите' ('USA-171: New "ear" in orbit'), *Novosti Kosmonavtiki*, September 2003 (in Russian), https://web.archive.org/web/20040819101012/http://www.novosti-kosmonavtiki.ru/content/numbers/250/17.shtml; Desmond Ball, *Pine Gap: Australia and the US Geostationary Signals Intelligence Satellite Program*, Allen & Unwin, Sydney, 1988; Michael Cassutt, 'Secret Space Shuttles', *Air & Space Magazine*, 1 August 2009; T. Flohrer, European Space Operations Centre, *Classification of Geosynchronous Objects*, Issue 17, 28 March 2015, and other editions; Gunter Krebs, 'Orion 3, 4, 5, 6, 7, 8', *Gunter's Space Page*, updated 31 July 2015, http://space.skyrocket.de/doc_sdat/Mentor.htm; Jonathan McDowell, *Jonathan's Space Report*, No. 661, 1 July 2012, http://www.planet4589.org/pipermail/jsr/2012-July/000033.html; and Jonathan McDowell, *NRO satellites*, 30 August 2013, http://planet4589.org/nro/nro.html.

Table 4.
Longitudinal positions of geosynchronous SIGINT satellites controlled from Pine Gap, 1991–2015

Year	Satellite				
	Orion-1	Orion-2	Orion-3	Orion-5	Orion-7
1991	91.9 E	80.7-82.7 E			
1992	91.8-92.0 E	82.1-87.0 E			
1993	91-92 E	83.4-86.8 E			
1994	91-92 E	87.6-89.0 E			
1995	91.8-91.9 E	82.5-89.3 E	Launched		
1996	91.3 E	82.4-89.0 E	89.9 E		
1997	88.7-91.7 E	81.8-87.8 E	89.9-119.7 E		
1998	88.3-88.7 E	81.0-87.1 E	120.5-121.9 E		
1999	69.8-70.7 E	81.6-85.3 E	120.6-121.3 E		
2000	-	-	-		
2001	-	-	-		
2002	-	-	-		
2003	69.2 E	88.1 E	-	Launched	
2004	-	-	-	-	
2005	71.2 E	-	-	-	
2006	72.1 E	90.4 E	130.5 E	95.6 E	
2007	72.1 E	89.5 E	129.7 E	95.5 E	
2008	72.1 E	87.1-89.5 E	129.7 E	95.5-95.8 E	
2009	71.3-72.1 E	90.5 E	127.1 E	95.7 E	
2010	73.1 E	90.7 E	127.1 E	95.6 E	Launched
2011	73.8 E	89.4 E	126.0 E	93.6 E	100.9 E
2012	80.9 E	90.3 E	126.1 E	68.7 E	95.9 E
2013	82.2 E	89.5 E	127.0 E	68.0 E	95.8 E
2014	Drifting	Drifting	126.9 E	68.0 E	95.6 E
2015	Drifting	Drifting	126.9 E	67.9 E	95.6 E

Sources:
For 1991–1999: Agapov, V., "USA-171: новое «ухо» на орбите" (USA-171: New "ear" in orbit), *Novosti Kosmonavtiki*, September 2003 (in Russian), at https://web.archive.org/web/20040819101012/http://www.novosti-kosmonavtiki.ru/content/numbers/250/17.shtml.
For 2003: "Magnum", *Encyclopedia Astronautica*, http://www.astronautix.com/craft/magnum.htm.
For 2005-2015: T. Flohrer, European Space Operations Centre, *Classification of Geosynchronous Objects*, Issues 8-17; A. V. Didenko, B. I. Demchenko, L. A. Usoltseva et al., Зональный каталог геостационарных спутников (*Zone Catalogue of Geostationary Satellites*), Issue 2, Almaty: Gylym, 2000, Section 4.1, at http://lfvn.astronomer.ru/report/0000030/cover.htm. Orion-1 is listed as '13. Unknown 4', Orion-2 is listed as '63. Unknown 9', and Orion-3 is listed as '94. Unknown 7'.

Appendix 1.
Principles of SIGINT satellite interception [98]

The ability of a geosynchronous satellite to intercept signals depends on several variables, of which the most important are the size of the intercept antenna, the sensitivity of the satellite receiver, and the strength, directionality, frequency, and nature of the signal (e.g. telemetry data, other digital data, voice communications, radar emissions).[99]

Since signal strength declines inversely with the square of the distance, a satellite in a geosynchronous orbit of about 36,000 km is at a significant disadvantage compared to either an ELINT satellite orbiting at only 1,100 km (the *Intruder* satellites) or a ground facility located near the signal source. Until the beginning of 1979, for example, the principal CIA OSO telemetry intercept facility was located at Kabkan (code-named Tacksman 2) in northeastern Iran, some 65 km east of Meshad, only a few kilometres from the Soviet border and about 1,000 km south-west of the Soviet ballistic missile test site at Tyuratam. Given a range of about a factor of more than 30 greater than Tacksman 2, the telemetry signals received at the geosynchronous altitude would be only 0.1 per cent the strength of those received at the Iran station. [100]

The ability of a SIGINT satellite at geosynchronous altitude to intercept signals can be estimated from the requirement that the power received by the satellite must be sufficient to ensure that reliable information is received in the presence of noise.[101] This is expressed by the formula

$$\frac{PR}{N} > SNR_{min}$$

where

P_R is the received power

[98] With minimal updating to avoid anachronisms, this technical appendix is based on Desmond Ball, *Pine Gap: Australia and the US Geostationary Signals Intelligence Satellite Program*, (Sydney: Allen & Unwin Australia, 1988), pp. 30-33.
[99] Frank J. Montcrief, 'Can Geostationary Satellites Eavesdrop on ICBMs?', *Microwaves*, September 1979, p. 18.
[100] Philip J. Klass, 'U.S. Monitoring Capability Impaired', *Aviation Week and Space Technology*, 14 May 1979, pp. 44-51.
[101] Frank J. Montcrief, 'Can Geostationary Satellites Eavesdrop on ICBMs?', p. 47.

N is the noise power in the receiver

SNR_{min} is the minimum signal to noise ratio for reliable reception.

The received power is the transmitted power, reduced by the effect of free-space attenuation and multiplied by the gain of the receiving antenna:

$$P_R = \frac{P_T}{4\pi R^2} \cdot \frac{\pi}{4} D_R^{\ 2}$$

where

P_T is the transmitted power

R is the distance from the transmitter to the receiver (some 36,000 km from signal source on or near the Earth's surface to a SIGINT satellite at geostationary altitude)

and the factor

$\frac{\pi}{4} D_R^{\ 2}$ is the area of the intercept antenna, with D_R as its diameter.

The noise power depends on the effective antenna temperature T and the bandwidth B as

$$N = kTB$$

where k is Boltzmann's constant, 1.38 x 10^{-23} *joule/°K*

and the bandwidth B is approximately the data rate in bits per second.

The minimum signal to noise ratio depends on the manner in which the information is encoded. Typically this is phase-shift keying, in which case, for a minimum bit error rate of one error per million bits, SNR_{min} is approximately 12. These formulae and numerical values yield the approximate result

$$\frac{P_T D_{R2}}{B} > .002$$

For example, if the transmitted signal power is 10 watts and the data rate is 160 kilobits per second (kbs), then the intercept antenna at geosynchronous altitude must have a diameter of at least six metres. Alternatively, for a data rate of 8,000 kbs and an antenna diameter of 40 metres, a minimum transmitted signal power of 10 watts is necessary for reliable reception.

Table A.1
Signal power (watts) receivable at geosynchronous altitude

Digital data rate (kbs)	Diameter of signal intercept antenna (metres)				
	5	10	20	40	100
	Signal power (watts)				
160[a]	12.8	3.2	0.8	0.2	0.032
614[b]	49	12.3	3.1	0.77	0.12
6,144[c]	492	123	31	7.7	1.2
8,000[d]	640	160	40	10	1.6
12,928[e]	1,034	259	65	16	2.6
100000[f]	8000	2000	500	125	20

a. Soviet ballistic missile telemetry transmissions
b. US Poseidon SLBM telemetry
c. RCA COMSAT transmissions
d. e. Typical microwave relay transmissions
f. DSCS II transmissions

Table A.1 shows some typical signal strengths readable at geosynchronous altitude for various satellite receiver antenna sizes and signal data rates. The rate of 160 kbs corresponds to that of 1980s Soviet ballistic missile telemetry transmissions; the data rate of 614 kbs to that of the US Poseidon SLBM telemetry signals[102]; the data rate of 6.144 Mbs to that of the RCA COMSAT communications satellite system; the data rates of 8 and 12.928 Mbs to that of typical microwave relay systems; and the data rate of 100 Mbs to that of the US Defense Satellite Communications System (DSCS) Phase II satellites.[103] The 20-metre antenna corresponds to that deployed on the first Rhyolite satellites (1970-46A and 1973-13A) launched in 1970 and the 40-metre antenna to that on the Aquacade satellites (1977-114A and 1978-38A); the 100-metre antenna is representative of the designs that have been available since the time the first Magnum satellite (Orion-1) was produced.

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102 Frank J. Moncrief, 'SALT Verification: How We Monitor the Soviet Arsenal', *Microwaves*, September 1979, pp. 41-51.
103 R.J. Raggett (ed.), *Jane's Military Commmunications 1986*, Jane's Publishing Company Limited, London, Seventh Edition, 1986, pp. 221-55; 369-51.

The area on (or near) the Earth's surface that can be monitored for signal emissions from geosynchronous altitude depends on the diameter of the intercept antenna on the SIGINT satellites and the frequency of the signals being monitored. As a rough approximation,

$$d = \frac{10^4}{D_R f_G} \text{ kilometres,}$$

where d is the diameter (in kilometres) of the 'spot' being monitored, D_R is the diameter (in metres) of the intercept antenna, and f_G is the frequency (GHz) of the signals being monitored.

Table A.2
Signal intercept area (km^2) covered by geosynchronous satellites

Signal frequency	Diameter of intercept antenna (metres)				
	5	10	20	40	100
	Signal intercept area (km^2)				
150MHz	130,000,000	33,000,000	8,300,000	2,100,000	330,000
300 MHz	33,000,000	8,300,000	2,100,000	540,000	83,000
1 GHz	3,000,000	750,000	190,000	47,000	7,500
2.2 GHz	620,000	160,000	39,000	9,700	1,500
3 GHz	330,000	83,000	21,000	5,200	820
6 GHz	83,000	21,000	5,200	1,300	220
10 GHz	30,000	7,500	1,900	470	75
24 GHz	5,200	1,300	330	83	13

Note: The areas of coverage of this table represent 'spots' on or near the Equator, where area = $\frac{\pi}{4}d^2$. At higher latitudes, the spots become more elliptical and the area proportionately larger. At around 65^o N, the area of coverage should be increased by a factor of about two and a half.

For example, a 10-metre-diameter intercept antenna monitoring signal frequencies of around 3 GHz would be able to monitor an area of about 83,000 square kilometres on the Earth's surface. If the same 10-metre antenna were to be used to monitor signals of around 6 GHz, then the monitored area would be only 21,000 square kilometres. Alternatively, the use of a larger intercept antenna, providing increased sensitivity of signal reception (needed to compensate for the greatly diminished signal strength at geosynchronous altitude), would decrease the monitored area proportionately – so that, for example, a 20-metre antenna monitoring signals at 6 GHz would be able to monitor an area of only about 5,200 square kilometres. Table A.2 shows the area in square kilometres monitored by geosynchronous SIGINT satellites with intercept antennas from 5 to 100 metres in diameter targeted against a range of relevant frequencies.

Two further points should be made in connection with these estimates of beamwidth coverage. First, clear priorities must be established with respect to the areas to be monitored by the geosynchronous SIGINT satellites. The area of Russia alone, for example, is 16,376,870 square kilometres. A geosynchronous satellite with a 40-metre intercept antenna monitoring signals at around 6 GHz could cover an area of about 1,300 square kilometres at any given time, and hence in a 24-hour period could be aimed at a given 'spot' for only about 6.5 seconds (assuming no time is taken to realign and stabilize the intercept antenna with each move from spot to spot.) This would be a clearly useless way to conduct operations, even with half a dozen or more SIGINT satellites operational. Rather, the satellites are allocated certain regions for frequent and extended coverage, and are reoriented from one spot to another for scheduled periods, with general surveillance being conducted only infrequently.

Secondly, even the smaller areas of coverage are likely to contain numerous signals sources within the relevant frequency bands. The smaller antennas (e.g. the 5-metre and 20-metre-diameter antennas) have a larger area of coverage, but this is achieved at the expense of reduced sensitivity and increased signal noise. The larger (40-metre and 100-metre) antennas have a more limited 'spot' coverage but much greater sensitivity, and hence invariably also collect a much broader range of signals than those of immediate intelligence interest.

The problem of 'signal extraction' – of identifying and separating out the signals of interest from the numerous other extraneous signal sources – is suggested by the original codename of the original Program B geosynchronous SIGINT satellites. Rhyolite is a volcanic rock containing colourful pieces of quartz and glassy feldspar (i.e.

data of intelligence interest) embedded in a mass of other igneous material (i.e. a heterogeneous mass of radio and other electronic 'noise').

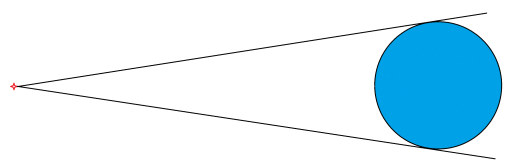
Appendix 2.
Geosynchronous and geostationary SIGINT satellite coverage of the Earth's surface

An object in geosynchronous orbit (GEO) travels in the same direction as the Earth's rotation and completes one orbit of the Earth in one sidereal day – a little under 24 hours.[104] A geostationary orbit is a particular case of geosynchronous orbit in which the orbit is circular, in the same plane as the Equator, and at an altitude of 35,786 kilometres. An object in geostationary orbit appears to an observer on the Earth's surface to be located at a fixed point in the sky.

Geosynchronous orbits that are not geostationary are at the same general altitude but are elliptical, inclined at an angle to the Equator, or both; when the orbit is inclined, the satellite will move north and south of the Equator, following a rough figure of eight pattern (not necessarily with equal halves) during the course of the day, extending its coverage of the Earth's surface north or south, though only for a limited period of each day.

A satellite in geosynchronous orbit can 'see' a little under half of the Earth's surface at any time. Theoretically, a satellite in GEO has a line of sight of 162.6 degrees of longitude along the Equator, or 81.3 degrees either side of the satellite's meridian. (See Figure A.1)

Figure A.1
Line of sight from a GEO satellite (to scale).



Since a single satellite doesn't quite see half of the Earth, two will not provide full global coverage, which explains why three satellites, suitably spaced around the Equator, are needed to provide coverage all the way around the globe. In practice, however, atmospheric attenuation on the circumference of the circle (or local horizon) limits the effective range for signal reception to somewhat less than this.

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[104] 23.9344699 hours or 0.99726958 mean solar days.

Similarly, a satellite ground station located on the Equator has a theoretical line of sight of satellites in geostationary orbit over 162.6 degrees of the sky, or 81.3 degrees east or west, north and south. Ground stations located north or south of the Equator have reduced views of the geostationary arc. Local terrain, such as mountains near a ground station, also attenuates the specific local line of site. In the case of Pine Gap, CIA engineers wanted a six degree clearance of local terrain, reducing coverage to as little as 74 degrees to the east and west.

Figure A.2
Pine Gap and local terrain, looking towards to the Western MacDonnell Ranges (1999)

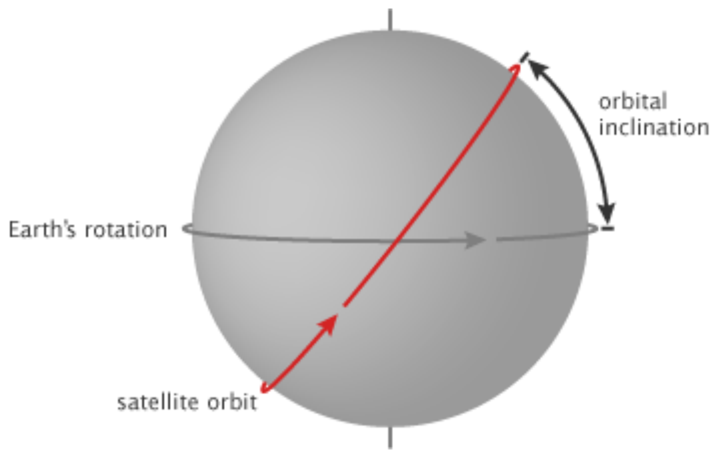
Source: Department of Defence

The extreme polar regions will not lie within a GEO satellite's line of sight, unless it is in an appropriately inclined geosynchronous orbit. For this reason, satellites in Highly Elliptical Orbit (HEO) are used to provide coverage of polar regions for signals intelligence (e.g. Trumpet), overhead infrared imagery, and communications.

Appendix 3.
The effects of orbital inclination

As explained in Appendix 2, geostationary satellites must maintain circular orbits that are in the same plane as the Equator, are in the same direction as the Earth's rotation, and have a period of one sidereal day. Orbits that are not in the same plane as the Equator are called inclined orbits.

Figure A.3
Orbital inclination



Source: 'Catalog of Earth Satellite Orbits', Earth Observatory, NASA, at http://earthobservatory.nasa.gov/Features/OrbitsCatalog/.

Geostationary orbits are difficult to maintain, because forces such as gravitational pull from the Sun and the Moon and anomalies in the Earth's own gravitational field act to drag the satellite out of position over time. In order to remain in a geostationary orbit, a satellite must conduct regular station-keeping manoeuvres to keep both its longitudinal position (east–west station-keeping) and the inclination of its orbit (north–south station-keeping) within tight limits. These manoeuvres eventually exhaust the fuel supply onboard the satellite, at which point the satellite can no longer be controlled and drifts out of its desired position.

When a strict geostationary orbit is not needed for the functioning of the satellite, its life can be extended significantly by permitting greater longitudinal drift before east–west station-keeping manoeuvres are performed and/or by permitting the inclination of the orbit to drift freely. North–south station-keeping is especially costly in terms of fuel consumption, so it is desirable to allow orbital inclination to drift unless there is a good reason to maintain a specific inclination.

Because they do not remain in the plane of the Equator, satellites in inclined geosynchronous orbits do not remain over a single point on the Earth's surface but travel to the north and south following a rough figure of eight pattern (not necessarily with equal halves) over the course of the day. This movement increases the amount of the Earth's surface that comes within view of the satellite, but coverage at the extremes of the satellite's 'footprint' is available only for part of the day (when the satellite is at the southern end of its track, it cannot see as far north as a geostationary satellite can see, but when it is at the northern end of its track, it can see further north than a geostationary satellite can).

Movement with respect to the Earth's surface may also be useful for other purposes. In the case of SIGINT satellites, such movement may enable the satellite to use directional or doppler measurements to determine the location of target transmitters. It has also been suggested that monitoring locations from a variety of angles may be useful for collecting signals from transmission sidelobes.[105]

There is evidence that the first two Rhyolite satellites may have attempted to maintain zero- or near-zero-inclination orbits throughout their operational lives. Pine Gap employees who worked with Rhyolite-1 and -2 told one of the authors (Desmond Ball) that the station-keeping section at the base worked hard to keep their orbits as close to zero degrees as possible, despite the difficulties that this entailed. Orbital calculations confirm that the two satellites began their operations in orbits at or near zero degrees in inclination.[106]

The reasons for this practice are not known. It is possible that the first-generation Rhyolites had only a limited ability to redirect the satellite's main intercept antenna. Since satellites in inclined orbits continuously change their position with respect to locations on Earth, an antenna with limited spot coverage would need to be continuously re-aimed in order to maintain coverage of a specific site (see Table A.2). Such rapid re-aiming may have been difficult or impossible for the early Rhyolites,

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105 Letter from Jeffrey Richelson to the authors, 27 September 2015.
106 *Ibid.*

forcing them to rely on north–south station-keeping despite its effect on the overall lifetime of the satellites.

The Program A SIGINT satellites, Canyon (operated from Bad Aibling) and Chalet, Vortex, and Mercury (operated from Menwith Hill), do not appear to have had this problem; all seem to have spent the majority of their operational lives operating in significantly inclined orbits, in most cases with little or no inclination control.[107]

Table A.3
Inclination of Orion-1, -2, -3, -5, and -7,
2010–2015 (in degrees)

Year	Satellite				
	Orion-1	Orion-2	Orion-3	Orion-5	Orion-7
2010	16.5	14.5	8.7	3.9	--
2011	16.9	15.2	9.6	4.5	6.9
2012	17.3	15.9	10.4	5.3	6.0
2013	17.6	16.6	11.2	6.1	5.2
2014	17.7	17.1	12.0	6.8	4.5
2015	17.8	17.5	12.6	7.7	3.8

Sources: T. Flohrer, *Classification of Geosynchronous Objects*, European Space Agency, Issues 12 (2010) – 17 (2015). Note that 'Year' in this table refers to the situation of the satellite at the end of the preceding year. According to the 2013 ESA report, Orion-1 and Orion-2 (called Magnum 1 and Magnum 2 in the report) were still under longitudinal control as at the beginning of that year. The 2014 and 2015 reports show that both satellites are no longer operating under control, indicating that they are no longer operational.

The later satellites operated from Pine Gap show a similar pattern. The Aquacade and Orion satellites appear to have begun their operations in 3.5- to 7.3-degree-inclination orbits, and appear to have been permitted to drift in inclination during most of their operational lives. (ESA data show that the upper-stage boosters that placed the Orion satellites in orbit are themselves in orbits that in most cases differ in inclination by less than one degree from the orbit of their payload satellite. Since the boosters have certainly been drifting freely in the years since they released their satellites, this strongly

[107] Ted Molczan, 'Identification of UI Objects in *Classification of Geosynchronous Objects*, Issue 11', Revision 2, 2 February 2010, at http://satobs.org/seesat_ref/IDCOGO11/Identification_of_UI_Objects_in_COGO_11.pdf.

suggests that most of the satellites have not been subject to significant inclination control.)[108]

One implication of this orbital history is that high-inclination orbits appear to have been neither necessary nor significantly detrimental to the operations of later-generation SIGINT satellites. Their ability to drift freely in inclination has undoubtedly been one of the factors that accounts for the extraordinarily long operational lives documented for both the Vortex/Mercury satellites and the Orion satellites.

[108] *Ibid*.; T. Flohrer, *Classification of Geosynchronous Objects*, European Space Agency, Issue 17, 28 March 2015. The same similarity in inclinations can also be seen between the Program A SIGINT satellites and their boosters.