Space Waste

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Introduction

The Space race has managed a significant achievement. In 50 years, humanity has sent tons of waste from Earth to space. "The ocean above" as Victor Hugo called it is a victim of industrial pollution of a new genre, striking, proliferating and long lasting it is of the same nature as the pollution of our worldly ocean riddled with plastic polystyrene and hydrocarbon waste however space waste is much harder to recuperate.

The life of a satellite is not much longer than that of a car, about twelve years. On earth, managing out-of-use cars and their accessories is a real headache. In space, managing Out of Use Satellites is a case of “each state for itself” and involves a certain amount of inconsideration. Waste management in all its forms is a science as well as a mirror of collective behavior. Space waste is no exception to the rule however no-one, especially operators, saw it coming. In the 1970s, traces of titanium and alumina were detected for the first time on Guinea pig satellites. This was blamed on solar flares or the chemical composition of asteroids but was actually from paint and combustion residues on the spacecraft. Space experts did not anticipate geometric expansion or the multiplication of waste from orbital collisions and explosions. In 50 years, human activities in space has created more waste in the Earth’s low and high orbits than meteorites injected by the solar system in billions of years.

Today, no manned space flight and satellite or interplanetary mission is safe from collision with destructive waste. On Earth, no one is immune to waste falling from the sky above or uncontrolled re-entry on the Blue Planet, not even a whale. Space waste contributes to light pollution in space and disturbs astronomers’ observations. Nuclear reactors on board the satellite mask the natural radioactive background noise in the cosmos, emitting gamma-rays even when the satellites are no longer in use.

All this for internet, GPS, satellite telephone and radio as well as many business activities, media and entertainment that make a lot of money and produce tons of waste without having to pay a space TGAP - General Tax on Polluting Activities. In the near future polluters should pay, in order to manage and recover space waste.
Space law is also broken. The steps that may put an international agreement on prevention and space waste management in orbit are far from the launch pad. The only glimmer of hope: space logistics managers now understand the urgent need to act to clean this spatial dump and prevent waste at the source.

Debris and Waste

The United Nations (UN) and the space community use the French and English word debris to describe abandoned objects in space. The debris comes from demolitions, disasters or calamities or geological or fossil remains or traces.

The UN defines debris "debris as all objects created by man, including fragments or parts of these objects, whether their owners can be identified or not, in the Earth's orbit or that return to the dense layers of the atmosphere, which are not functional and which cannot reasonably be expected to be used or reused for the purpose for which they were designed or any other function for which they were or may be authorized."

In European legislation, "any substance or object which the bearer discards or intends to or is required to discard" is considered debris." [1]

On this basis, the UN and EU definitions are the same. In essence, the word debris is much "lighter" if you will and does not require the origin to be known. For this report, which aims to provide public or private operators with more information, we have preferred to use the legal term, waste.

"Space waste" by Robin des Bois is the first report to cover this new subject fully as an environmental Non Governmental Organization. Space waste, the use of radioactive sources and the mechanical and environmental risks of re-entries in the Earth's atmosphere have been a major concern for Robin des Bois since 1987.

[1] Directive 2008/98/EC of the European Parliament and European Council, dated 19 November 2008 regarding waste.

I – The Space Environment

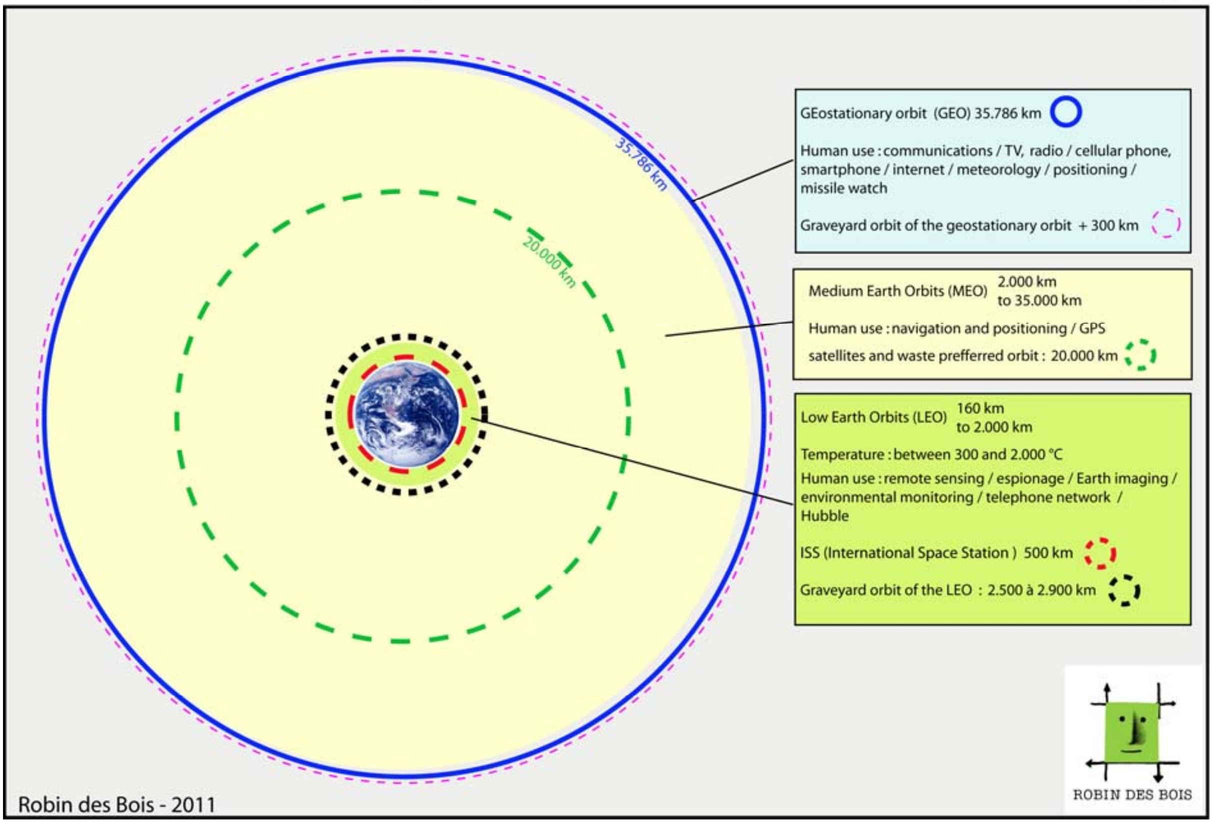
There is no precise boundary between the atmosphere and space. The shape and dimensions of the upper layers of the atmosphere are constantly changing depending on the gravitational pull of the Moon and the Sun, the gas density in the atmosphere, Earth's magnetic field and solar storms. The atmosphere/ionosphere interface is still measurable at 500 km altitude. Global warming and the increase of CO_2 in the atmosphere cause a cooling in low orbit where the majority of spacecraft operate.

The classification of the exploration and use of the space industry is divided into the three trajectories of satellites or waste debris. These trajectories are called orbits:

- Low orbits are between 160 and 2,000 km altitude. They provide the best possible resolution for optical and infrared detectors.
- Medium orbits are between 2,000 and 35,000 km altitude. They are mostly occupied by the constellations of navigation and positioning systems (the US GPS or Russian Glonass) at around 20,000 km altitude.
- The geostationary orbit is defined scientifically: it is at an altitude of 35,786 km. A device placed on the circular orbit moves at the exact rotation speed of the Earth, which makes it appear stationary from any Earth Observatory. This characteristic is essential for communication satellites and broadcast television. A spot here is very expensive!

Diagram of Earth orbits

map 1



II- Space waste

There are several types of space waste:

- Launchers.
- Combustion residue.
- Operational Waste.
- Out of Use Satellites.
- Fragmentation Waste.
- Space Erosion.

Space waste No.1: Launchers

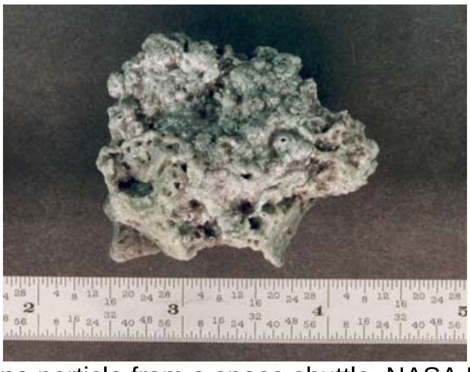
1,899

Launching satellite(s) in their orbits is carried out by the third stage of the launcher (Ariane, Titan, Delta ...) - or on the fourth stage for heavier satellites, such as the Russian Proton-K rockets. These large structures, which include an engine and gas tank, are left in orbit after separation, often at a high altitude, close to the satellite's orbit, which gives them an orbital life of tens or hundreds of years. The Ariane 5 rocket that launched the W3B and BSAT-3b satellites on October 28, 2010 added new waste, the Type A Top Cyrotechnical Floor (ESCA), at 645.9 km altitude. Each launch adds an upper launcher stage to space waste. 1,899 upper stage launchers were monitored by the U.S. Space Surveillance Network as of November 24, 2010.

Space waste No. 2: Combustion Residue

Several billion

The largest source of space waste comes from the combustion of powder engines used in the upper launcher stages, especially those used to send satellites into a transfer orbit. The instability of combustion, especially at the end of the thrust, causes clouds of residual particles of alumina (Al_2O_3), mainly in the form of dust - with a diameter of 0.1 µ to 100 µ - and slag of up to several centimeters to be ejected. These clouds pollute all orbits up to the geostationary orbit, but they are particularly numerous in low orbits. As particle size is too small to be detected and tracked, only spot sampling was carried out and quantitative estimates were made.



Alumina particle from a space shuttle. NASA Photo

In December 1996, returning from a 19-day mission, two windows of the shuttle Columbia were hit by particles and had to be replaced. Residue analysis showed that three impacts were caused by alumina particles. In 1997, a U.S. study estimated their proportion at 86% of a total of 1000 points of impact on the Long Duration Exposure Facility (LDEF), a scientific satellite from NASA (National Aeronautics and Space Administration) that was in orbit from April 1984 to January 1990 in order to perform experiments. It was later retrieved by the space shuttle *Columbia*. According to NASA, the alumina particles from the deliberate or accidental burning of solid motors can be estimated at several billion.[2] They can endanger the astronauts on extravehicular missions and puncture solar panels.

Space waste No. 3: Operational Waste

This category includes various fastening and protection elements for a satellite during its launch (cables, straps, caps, lens caps...) and separation devices (springs, explosive bolts ...) that are ejected into space at the time of deployment. Some satellites are accompanied by many accessories in their orbits. There are also tools, equipment and miscellaneous supplies deliberately or accidentally discarded by astronauts during spacewalks. This started with the first spacewalk in 1965 outside the Gemini 4 capsule, when astronaut Ed White lost a glove, which remained in orbit about a month before returning to the atmosphere.[3]

During its fifteen years of service in orbit from July 1986 to March 2001, the Soviet space station Mir tossed hundreds of bags of garbage from its back hatch. The space ship, which, starting in 1995, brought American astronauts to the station, had to repeatedly perform evasive maneuvers in Mir’s wake. These waste bags contained clothes (they are not washed onboard space stations), toilet paper, food packaging, scraps from meals, waste from scientific experiments...

Space waste No. 4: Out of Use Satellites

Approximately 2,500

The life of a satellite, that is to say its period of useful activity, varies from 1 to 10 years in low and medium orbits and from 4 to 15 years in geostationary orbit. It is the amount of propellant required on board to carry out orbit adjustment and instrument positioning that determines this life span, as well as the depletion of batteries and the wear of electronic equipment. Telecommunications satellites are designed to operate for as long as 15 years. Observation satellites which require more positioning sequences which consume energy have a shorter lifespan. Some reconnaissance satellites, or "spy satellites" – only have a life span of a few days or weeks to obtain optical information of about 10 cm or less. Their orbit must be very low and the atmospheric drag is such that the onboard propellant is exhausted quickly to correct course and altitude.

[2] “Orbital Debris: A Chronology,” David S.F. Portree, Joseph P. Loftus, Jr – NASA/TP – 1999-208856, January 1999.
[3] “Orbital debris: a growing threat to space operations,” Richard Crowther – Philosophical Transactions of the Royal Society – n°361, pp. 157-168, 2003.

At the end of their life, satellites are normally left in their orbit, becoming waste which will return to Earth's atmosphere or collide with other space waste in the future. Since 2000, some space agencies have begun to implement waste "mitigation" measures that call for controlled re-entry using the residual fuel to accelerate the return to Earth of satellites in low orbits or to move them to an upper "orbit graveyard."

Space waste No. 5: Fragmentation Waste

5a - Accidental Explosions

If fractions of residual propellants remain trapped in the tanks, there is a high risk of explosion due to leakage caused by thermal or ultraviolet radiation and ionizing radiation on aluminum structures. Each explosion expels hundreds or thousands of pieces of waste to the space environment, known as waste fragmentation. On November 13, 1986 the third stage of an Ariane rocket exploded into 489 pieces at about 800 km altitude.[4] The upper stage of an American rocket, Pegasus, which exploded on June 3, 1996 at 625 km altitude, generated more than 750 pieces of waste in excess of 10 cm distributed between 250 and 2,500 km altitude, despite its modest size (93 cm long and 97 cm in diameter).[5] The tank contained between 5 and 8 kg of hydrazine. It was made of carbon composite that, during the explosion, fragmented into many millions of shards ranging from 0.4 to 1 mm long.[6] One of the biggest explosions occurred on February 19, 2007 over Australia, when a Briz-M booster disintegrated with its 5 t propellant tanks nearly full. The upper element of a Russian Proton rocket, launched February 28, 2006, was abandoned with its load, the Arabsat-4A satellite, after suffering a failure that led to engine shutdown after four minutes of thrust. At least 1,100 pieces of waste more than 10 cm long were the result. 92 have already returned to the atmosphere, including 88 in 2010. A similar failure occurred on March 14, 2008 to another Briz-M booster carrying the satellite, Americom AMC-14. Also, carrying a large amount of fuel, the propellant may explode in the near future.

More than 200 explosions have already been detected.

5b- Accidental Collisions

42,120 km/h

Fragmentation waste is also produced by accidental collisions between active satellites and debris or between waste and waste or even between Out of Use Satellites and waste. All collision combinations are possible. Collisions may involve two objects moving in the same orbit, but in inversely.

Collisions cause clouds or patches of waste, which disperse around the Earth over time. Eight crashes have been recorded since 1991. The first to be detected was French: on July 24, 1996, the small military satellite Cerise (50 kg), controlled by the General Delegation for Armaments, was hit at 14.8 km/s by a piece of waste identified according to the United States as belonging to the third stage of rocket Ariane that had exploded a decade ago. The accident severed a 6-foot long antenna,

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[4] "History of On-orbit Satellite Fragmentations" 14th Edition, Orbital Debris Program Office - NASA/TM–2008–214779, June 2008.

[5] "History of On-orbit Satellite Fragmentations" 14th Edition, *op. cited.*

[6] "Characterization of the breakup of the Pegasus rocket body 1994-029B," M. Matney and T. Settecerri – Proceedings of the Second European Conference on Space Debris, Darmstadt, Germany, 17-19 March 1997, (ESA SP-393, May 1997).

creating additional waste and severely limiting Cerise's performance. On January 17, 2005, a collision was detected at 885 km altitude over Antarctica between one of the 300 pieces of waste from the explosion of the third stage of a CZ-4 Chinese rocket which occurred in March 2000 and the third stage of the abandoned American Thor launcher.[7] The latter had been in orbit for 31 years. The most serious collision was recent: on February 10, 2009 the U.S. satellite Iridium 33 (560 kg, active) and Russian satellite Kosmos 2251 (900 kg, out of use) collided at a speed of 42,120 km/h 790 km above Siberia. The clash resulted in 521 pieces from Iridium 33 and 1,267 pieces of Kosmos 2251 measuring over 10 cm[8] to be dispersed. As of December 31, 2010, 74 pieces of Kosmos 2251 waste and 37 of Iridium 33 waste had fallen into the atmosphere and thousands of detectable fragments from the explosion are still in orbit. There is no way to count the shards below 10 cm. In addition to the 72 communication satellites in the Iridium constellation, this region of space is traversed by 3,300 other unnecessary items that amount to waste.

5c – Deliberate Destruction

At least 56 satellites were deliberately destroyed in 1964. These are military satellites, whose destruction is triggered by a pyrotechnic charge to ensure that no identifiable parts can be recovered after re-entry. The most recent was the Russian satellite, Kosmos 2421, which self-destructed on March 14, 2008 and then fragmented again on April 28 and June 9 at about 400 km altitude, generating more than 500 detectable pieces of waste. Most have already fallen back to Earth. Some were thrown into higher orbits, up to 900 km altitude, and could remain there for hundreds of years.

China is a special case: the large amount of waste belonging to the country totaled 3,492 pieces as of December 31, 2010 - for only 103 satellites in operation or at their end-of-life – due to the deliberate destruction of the Feng Yun 1C weather satellite at 845 km altitude by a missile launched from southern China on January 11, 2007. The aim was to check an anti-satellite weapons system derived from a ballistic missile. The explosion of the 960 kg satellite into 3,037 pieces of waste, mostly larger than 10 cm, can be identified and tracked and more than 150,000 pieces of waste greater than 1 cm can be quantified. The cloud of waste extends from 200 km to over 4,000 km in altitude, frequently crossing the orbit of hundreds of satellites in operation and the International Space Station. In addition, the majority of this waste was thrown into orbits where their life will be long, measured in tens or even hundreds of years. More than half of the waste was expelled to over 850 km of altitude. Described as "the worst contamination of low Earth orbit of the last fifty years[9]," this test is a huge blow to the process of reducing space waste generation initiated by the Interagency Coordination Committee on Space Debris, of which the Chinese space agency (CNSA) is a member. On September 15, 2010, more than three and a half years after the explosion, 97% of waste was still in orbit, accounting for 22% of total waste in low orbit.[10] Pieces of Fengyun-1C regularly fall to Earth. From January 1 to December

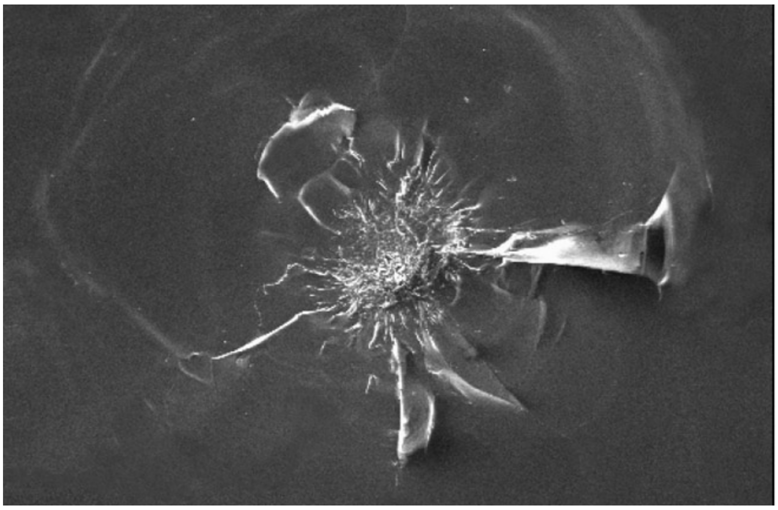
[7] "Accidental Collision of DMSP R/B and Chinese Debris on 17 January 2005," Orbital Debris Program Office – NASA Johnson Space Center, 7 February 2005
[8] "Orbital Debris Quarterly News" - Volume 14, Issue 3, July 2010.
[9] "Orbital Debris Quarterly News" - Volume 11, Issue 2, April 2007.
[10] "Orbital Debris Quarterly News" - Volume 14, Issue 4, October 2010.

31, 2010, Spacetrack counted 38.[11]

The U.S. Missile Defense Agency responded to this shows of arms a year later by shooting down one of its Out of Service Military Satellites. It was in very low orbit and would leave no detectable waste. All destruction waste would be pushed back into the atmosphere and most was incinerated during the atmospheric re-entry.

Space waste No. 6: Space Erosion

The orbital environment erodes the paint coatings and the external surfaces of spacecraft: extreme temperatures (permanent or in cycles), ultraviolet radiation (UVA, UVB, UVC) generated by the sun, radiation associated with solar wind and belts of radiation around the Earth, atomic oxygen[12] in low earth orbit, micrometeorites and space waste tear off the particles which themselves become waste with a high kinetic energy.
A characterization study on the impacts on space shuttle windows since the STS-50 mission (*Columbia* from June 25 to July 9, 1992) to the STS-114 mission (*Discovery*, July 26 to August 9, 2005) was conducted by the Johnson Space Center of NASA. During the 54 missions, 1634 impacts with glass were recorded, requiring 92 windows to be replaced.



Impact of a paint flake on the windshield of the space ship *Endeavour*. Photo from NASA

The detailed chemical analysis of the impacts identified 120 hits by aluminum particles, 111 by paint chips, 32 by steel, 6 by alumina, 2 by copper and 2 by plastic giving a total of 273 collisions. All of these metals and materials are space waste.
258 hits by natural micrometeorites have been documented.
1,097 craters could not be classified because of the lack of evidence to identify the origin of the hit.
The radiator of the shuttle *Endeavour* was hit by 317 particles, of which 53 perforated its façade. On the radiator, the craters attributed to waste were caused by collisions of which 35 were attributable to paint particles, 26 to steel, 6 to aluminum, 2 to

[11] http://www.space-track.org/perl/decay_query.pl
[12] Atomic oxygen (O) is produced by the dissociation of oxygen molecules (O_2) present in the atmosphere with solar ultraviolet rays.

sodium/potassium alloy, 1 to titanium and 1 to paint binder. A particle of urine, probably from the space shuttle's sanitary system, was also detected.

III- Space waste Inventory

1 – Catalogued waste

The United States, Russia and France, in cooperation with Germany, are the only countries that currently have the capacity to detect and track space waste.
In the LEO, up to about 1,000 km in altitude, trajectory tracking of particles from 10 cm in diameter is possible.
Medium earth orbit and geostationary monitoring is possible from a length of 1 m.
The following items are described as "Cataloguable."
Only the United States makes the data they collect through the Spacetrack partially public, which only lists objects whose origin is known. Spacetrack relies on the United States Strategic Command, USSTRATCOM. In addition, for various confidentiality reasons, foremost defense, about 25% of tracked objects are not made public.[13] Nevertheless, it is the only catalog available - and updated daily – of satellites, upper stages of rockets and space waste in orbit and objects that have fallen to Earth. On December 31, 2010[14], Spacetrack counted 16,109 objects in orbit, 3,506 of which had "payloads," 10,702 pieces of waste and 1,901 upper launcher stages, in all orbits.

The payload category does not distinguish between Out of Use Satellites and satellites in operation. Satellites in operation should not be counted so as to determine the amount of waste in orbit. For satellites in operation, the only available counts are provided by the American Association Union of Concerned Scientists (UCS), which counted 958 as of November 1, 2010.[15] The list of launches in November and December 2010 allows us to add 25 satellites.

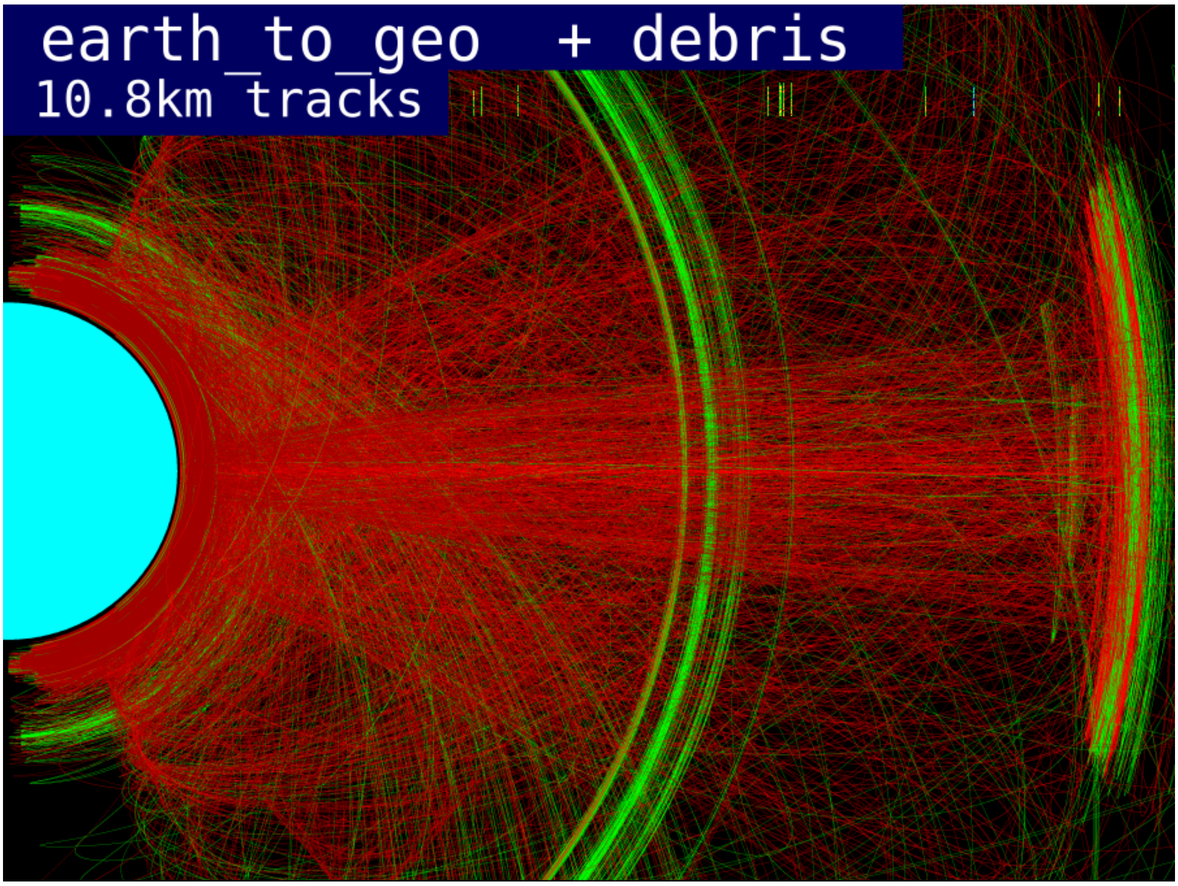
By comparing this data, we obtain 15,126 objects, including 2,523 Out of Use Satellites, 1,901 upper launcher stages and 10,702 pieces of waste.

As of December 31, 2010, the Russian Federation had the most waste, followed by the United States, China, France, Japan, and India...

NASA cites the figure of 19,000 pieces of waste measuring over 10 cm in orbit.[16] The Strategic Command of the United States asserts that "there are about 21,000 pieces of space waste in the Earth's various orbits, in other words about 6,000 metric tons of waste orbiting the Earth."[17]

[13] "Space Debris," Postnote no. 355 – UK Parliamentary Office of Science and Technology, March 2010.
[14] http://www.space-track.org/perl/boxscore.pl
[15] http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html
[16] http://orbitaldebris.jsc.nasa.gov/
[17] " 2010 Space Symposium – Keynote ", Frank A. Rose, Bureau of Arms Control, Verification and Compliance – United States Strategic Command, 3 November 2010.

The European Space Agency (ESA) estimates the amount of waste not listed by Spacetrack because of unknown origin at 4,000-6,000 pieces and U.S. military satellites whose orbital details are secret at around 100.



Representation of all active satellites (in green) and space waste measuring more than 10 cm (in red) on 26 August 2009 from Spacetrack, ranging from the LOE to the geostationary orbit. Illustration by Keith Lofstrom.

2 – Uncatalogued waste

600,000

There is estimated to be 600,000 pieces of waste between 1 and 10 cm in all orbits. They are too small to be tracked by radar, yet they are called the "lethal population" as their kinetic energy is sufficient to destroy or seriously damage a spacecraft or satellite yet their small size makes tracking their trajectory via radar surveillance impossible. However, USSTRATCOM has the means to detect objects between 5 and 10 cm. This catalog remains confidential.

135,000,000

There are estimated to be about 135 million[18] fragments from 0.1 to 1 cm. Other sources vary from between 35 million and 150 million. They are still able to puncture the hull of a craft and to cause damage which may shorten its life or its performance. However, the installation of shields on the most vulnerable panels can prevent or mitigate the damage. This waste is classified as "at risk population." For

[18] Report "European Security in Light of the Space debris Issue," Document A/2073, 17 June 2010. European Security and Defense Assembly.

spacewalkers, even dust and chips can prove fatal: no space suit can provide protection from these particles. During the last repair mission on the Hubble Space Telescope in May 2009, NASA estimated that the astronauts were running an 89% risk of being killed by waste when working outside the space shuttle.[19] It is perhaps this fear that led to an astronaut leave a solar panel in space, which, by now, will have undoubtedly fragmented into a myriad of waste.

Scientific publications on space waste do not lack striking analogies illustrating the substantial kinetic energy they carry. For example, "an aluminum sphere with a diameter of 1.3 mm, launched at 10 km/s, has the energy of a .22 rifle bullet or a *petanque* ball thrown at 100 km/h."[20] The English version: "A 2 mm piece of space debris colliding at 10 km/s is equivalent to being hit by a cricket ball at 100 km/h. A 10 mm piece of debris travelling at the same rate is equivalent to being hit by a large motorcycle traveling at 100 km/h."

The Center for Studies on Orbital Debris and Re-entries, funded by the U.S. Air Force, increases the size of the waste: "An aluminum sphere 1 cm in diameter is comparable to a 400 pound [181 kg] safe traveling at 60 mph [96 km/h]." In its 2009 report on space safety, the Association of Canadian scientists, Spacesecurity.org, stated that "the kinetic energy of a 1 g object hitting a satellite at a speed of 12 km/s (typical relative velocity between two objects in space near the Earth) would be equivalent to throwing a washing machine from the roof of a 100 m high building."

The association adds: "A piece of debris no larger than 10 cm in diameter carries the kinetic energy of a 35 t truck traveling at 190 km/h."[21]

Unidentified space waste. NASA Photo/Associated Press

[19] "Trackers of Orbiting Junk," William Matthews – Defense News, 10 June 2009.

[20] "La Pollution Spatiale sous Surveillance," p. 67. Fernand ALBY; Jacques AROULD; André DEBUS – Ellipses Editions, 2007.

[21] "Space Security 2009," SPACESECURITY.ORG, August 2009.

IV- Low Earth Orbit, LEO

1- Traffic

These are the most used: 470 satellites in operation in this orbit according to the UCS census (Union of Concerned Scientists) dated 1 November 2010.[22] The most congested altitudes are between 600 and 900 km, where there are 291 satellites. The orbits between 1,400 and 1,500 km altitude are also popular, with 61 satellites in operation. The International Space Station operates at between 300 and 500 km in altitude.

2 - Satellites in Operation, Functions, Nationalities

Fleets of commercial communications satellites (telephone, television, digital data) surround the Earth in low orbits:

- Iridium deploys 72 of them between 770 and 780 km in altitude, Globalstar has 20 at 800-900 km and 35 around 1,400 km. Orbcomm has 26 satellites at around 800 km. These three U.S. companies dominate the market.

- The Russian company Smolensk Satellite (SmolSat) controls 8 "Gonets" satellites relaying Internet and telephone.

- The Riyadh Space Research Institute of Saudi Arabia has deployed seven 12 kg telecommunications microsatellites for commercial applications (storage and data relay), built by students at the King Abdulaziz City for Science and Technology (KACST).

- The American company, Aprize Satellite, runs 2 satellites plus four others belonging to its subsidiary, Aprize Satellites Argentina. This fleet of microsatellites (12 kg each) specializes in the remote monitoring of oil wells, gas, pipelines and storage tanks as well as tracking containers, ships and trucks.

132 civilian satellites operated by government institutions or international organizations operate in low orbits. It is sometimes difficult to discern whether the missions officially announced for some of them are actually "civil": remote detection and reconnaissance can also be regarded as espionage.

- Japan, for example, has a fleet of five GPS reconnaissance satellites between 484 and 492 km in altitude in a sun-synchronous orbit that work directly for the "Satellite Intelligence Center" (CSIC), a government agency working for the services secrets (Intelligence and Research Office).

[22] http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html

- The United Kingdom has an "earth observation" satellite operated jointly by the British National Space Centre, a civil institution, and the Ministry of Defense.

- The only Iranian satellite - Sina-1 -, belonging to the Iranian Research Organization for Science and Technology (IROST), officially assumed the duties of "Telecommunications and Research" since its launch on 27 October 2005 by a Russian rocket from the Plesetsk cosmodrome in Siberia[23]. Iran declares it is used to "take pictures of Iran and monitor natural disasters in a nation prone to earthquakes." However, in November 2005, Ahmad Talebzadeh - Director of the Iranian Space Agency - told the Associated Press: "Technically speaking, yes. It can monitor Israel. But we do not need to. You can buy satellite photos of Israeli streets."[24] Sina-1 orbits the Earth 14 times daily at an altitude of about 700 km. The optical resolution of the cameras is estimated at 50 m, which would provide Iran with limited espionage abilities. But its observation area covers the entire Middle East.

- The Egyptian satellite, Egyptsat-1 (or Misrsat-1), launched in 2007, carries an infrared detection device and a high resolution multi-spectral imaging system. It has a definition of 4 m. Some Israeli experts believe the satellite collects information about Israel.[25] On July 19, 2010, the Egyptian National Authority for Remote Sensing and Space Sciences lost all communication with Egyptsat-1. It has since been identified by American and Swedish monitoring stations but the Egyptian authorities have no hope of regaining control of it.[26]

- India has six remote sensing and Earth observation satellites currently in low orbits, controlled by the Indian Space Research Organization (ISRO). Among the many tasks assigned to them (control of urbanization, forest coverage, crop yield assessment...) we note that Cartosat 2, which orbits at an altitude of 630 km, produces high-resolution images (80 cm) for "civil planning and other mapping needs."

- China has 33 satellites belonging to various scientific and government institutions, 11 of which are devoted to remote sensing or reconnaissance.

- Taiwan and the U.S. share control and operation of six remote sensing satellites within the Cosmic/Formosat series.

- The United States itself has 25 civil satellites in low orbits used mainly for weather, earth sciences and astrophysics.

- The European Space Agency has 7 satellites, plus the Hubble Space Telescope operated in cooperation with NASA, which has been in orbit since 1990 at 600 km altitude.

[23] "The Iranian Space Program and Russian Assistance," Alexandr V. Nemetz, Robert W. Kurz - Journal of Slavic Military Studies, 22:87–96, Taylor & Francis Group, 2009.
[24] http://www.haaretz.com/print-edition/news/iran-satellite-capable-of-spying-on-israel-1.174408
[25] "Egypt to launch first spy satellite," Yaakov Katz – 15 January 2007, The Jerusalem Post.
[26] "Egypt says 'visually' observing missing satellite" Safaa Abdoun /Daily News Egypt, 26/10/2010.

Other states or government agencies with one or more satellites operational in low orbits as of December 31, 2010: South Africa (1) Algeria (2), Germany (4) Saudi Arabia (3), Brazil (1), Canada (2), South Korea (1), Denmark (1), United Arab Emirates (1), Spain (3), France (3 + 1 together with NASA), Indonesia (1), Italy (1), Malaysia (1), Morocco (1 together with Germany), Nigeria (1), Norway (1), Russia (5), Sweden (2) and Thailand (1).

Three satellites dedicated to amateur radio wave transmission were operational in 2010: AMSAT-Echo, AMSAT Oscar-7 (USA), and Hope Oscar 68 (China). Launched by Delta on November 15, 1974, AMSAT-Oscar 7 is the oldest satellite still in operation, in all orbits. Declining performance betrays its age: it is no longer operational in sunlight and stops transmitting every time it passes through the Earth's shadow.

In the field of geospatial imagery and mapping, German company, RapidEye AG, has 5 satellites, the U.S. DigitalGlobe has 3, the French (including the Belgian and Swedish capitals) Spot Images has 2 and the Canadian Radarsat International has 2.

There are 30 operational civilian satellites belonging to universities or technology institutes. Seven are involved in observation and Earth Sciences. The other 23 are involved in various scientific experiments. Many are microsatellites with a total weight of 1-12 kg.

Thirteen countries control the 98 military "reconnaissance", "remote sensing", "Earth observation", communications, navigation, and ocean monitoring satellites identified by the Union of Concerned Scientists. 33 belong to the U.S., 30 to Russia, 12 to China, 6 to Israel, 5 to Germany, 3 to India, 3 to Italy and 1 each to Pakistan and Taiwan.
France has four, and shares three others with Belgium, Italy, Spain and Greece. They are controlled by the National Centre for Space Studies (Centre National d'Etudes Spatiales, CNES) and the information gathered is processed by the General Delegation for Armaments (DGA).
In this area, it's almost certain that the actual number of active satellites has been underestimated.

3- The International Space Station (ISS)

Interesting Facts: on August 27, 2008, residents had to seek refuge in the emergency escape module while the International Space Station maneuvered to avoid cataloged waste from the destruction of the Russian military satellite, Kosmos 2421. In March 2009, the ISS had to dodge again, avoiding a 13 cm projectile. Avoidance maneuvers consume several kilos of fuel and cannot be repeated infinitely. This may be enough to dampen the optimism of the CNES which in 2007 wrote that the probability of a collision between the ISS and space waste stood at one impact every three centuries.

The ISS is an orbiting residential and research complex. It is a modular structure placed in low orbit at an altitude ranging between 370 and 460 km. It can accommodate a permanent crew to carry out scientific experiments in space. The various modules are provided and maintained by the six agencies cooperating in the project: NASA, Roscosmos, Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA) and the Agência Espacial Brasileira (AEB).

The ISS seen from an approaching space craft. Photo STS-119 Shuttle Crew, NASA

The launch of the first element of the ISS, the Russian module Zarya, was completed in 1998. It is scheduled for completion in 2011. Its mass of 370 t and its dimensions - 108 m long, 74 m wide, 45 m high - make the ISS the largest and heaviest structure launched into space to date. Its living space is 360 m^3.

From November 2, 2000, the station has been continuously occupied by a joint US-Russian crew of two or three cosmonauts, joined occasionally by astronauts from other countries participating in the ISS. Since 2001, the Russian space agency, Roscosmos, has also opened the station to tourism in partnership with the American company, Space Adventures Ltd., established in 1998 and specializing in space tourism. 7 millionaires have spent 9-15 days on board.[27]
Since May 2009, six astronauts have occupied the ISS. They stay there an average of 6 months. Half of the crew changes every three months. Control of the station alternates between an American and a Russian. Crews are launched and returned to Earth via the Soyuz spacecraft. They only bring a few pounds of cargo with them.

Refueling is carried out by four different spacecraft, which are also used for waste disposal (see § 5: waste from the ISS):

- The space shuttle, which can carry the heaviest and largest loads - up to 16.4 t and 300 m3 - and bring them back to Earth, has made 34 flights to the ISS. The final launch of *Discovery* before the space shuttle was retired was scheduled for November 2010. However, following the discovery of a hydrogen leak due to cracks in the external tank, the launch was pushed back

[27] http://www.spaceadventures.com/index.cfm?fuseaction=orbital.Clients

to December, then "not before February 3, 2011," according to NASA.[28] It finally took place on February 25. Re-entry took place on March 9, 2011.

- The Russian cargo ships, Progress, undertake an average of 3-4 flights a year; 5 in 2010. To date, 35 freighters have refueled the ISS. Each Progress carries up to 3.2 tons of payload, including 1.7 tons of cargo for the crew (including 300 liters of water) and 1.5 tons of fuel for the ISS.

- The Automated Transfer Vehicle (ATV) is a European space freighter designed by EADS Astrium for ESA. It is controlled on the ground by the National Center for Space Studies (Centre National d'Etudes Spatiales) in Toulouse. With a length of 10 m, a diameter of 4.5 m and a takeoff weight of 20.7 t, the ATV can carry up to 7.5 t of payload, including 5.5 t dry cargo (food, spare parts, clothing ...) and 840 l of water. The launch of the first ATV, *Jules Verne*, occurred on March 9, 2008 from the Kourou base by an Ariane 5 rocket. The launch of the second ATV, *Johannes Kepler*, was undertaken on February 15, 2011. Three other missions are scheduled to follow. Re-entry is scheduled for June 21, 2011.

Automated Transfer Vehicle - ESA Photo - D.Ducros

- The H-II Transfer Vehicle (HTV) is an automated space cargo vehicle developed and controlled by the Japan Aerospace Exploration Agency (JAXA). Like the ATV and Progress, it was designed to supply dry and liquid cargo to the ISS. The HTV qualification flight took place from September 11 to November 1, 2009. The launch of the second HTV, called "Kounotori" ("White Stork"), was conducted on January 22, 2011. There are five other HTV scheduled to supply the ISS until 2016.

[28] http://www.nasa.gov/mission_pages/shuttle/launch/index.html

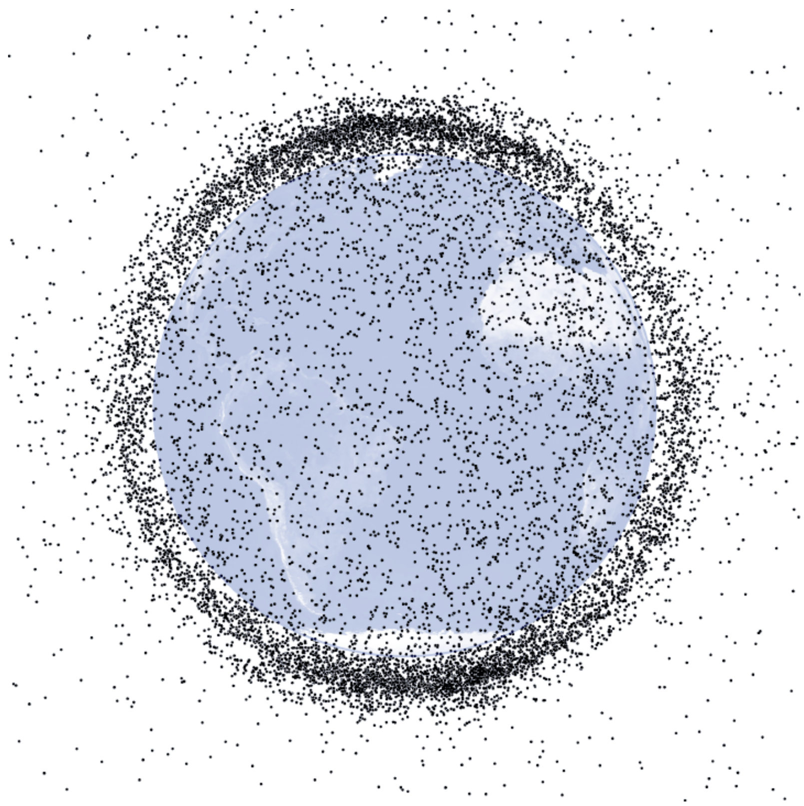
The HTV-1 as it hooks-up to the ISS – Photo JAXA

4- Low Orbit Waste

Studies on temperature changes in the atmosphere have shown the influence of global warming: a cooling trend has correlated with the increase in CO_2 levels for 35 years. The result of this cooling is a decrease in atmospheric density of about 10% in low orbits, causing less friction on objects in orbit and increasing their velocity. The orbital lifetime of Out of Use Satellites and space waste is thereby extended by up to 24% according to some calculations, increasing the risk of collisions. The space segment most affected by this phenomenon is the altitude of between 200 and 1,200 km, in other words, the low orbit saturated by satellites and waste.[29]

Space waste in low orbit is identified and tracked by the LEO Space Surveillance Network represents over 60% of total waste. This estimate is comprised of about 11,500 objects over 10 cm in size and 360,000 items measuring 1 to 10 cm.

[29] "Response of the Space Debris Environment to Greenhouse Cooling," H.G. Lewis *et al*, Proceedings of the Fourth European Conference on Space Debris, Darmstadt, Germany, 18-20 April 2005 – European Space Agency, August 2005.



Space waste larger than 10 cm in LEO, August 25, 2009. NASA Image.

Low orbits are traversed by convoys destined for medium and geostationary orbits or interplanetary travel. Some fail to reach these distant horizons. On October 29, 2010, following the detection of a leak in the oxidizer tank, the owner and manufacturer (Eutelsat Communications and Thales Alenia Space respectively), officially announced the loss of W3B. The compensation that will have to be paid out by the 28 insurance companies involved totals €245 million, making it the most expensive disaster to date in the field of space insurance. Launched on October 28 from the Space Centre in French Guiana by an Ariane 5 ECA, W3B was propelled to an altitude of 240 km on a transfer orbit enabling it to reach its final position in geostationary orbit itself. However, the fuel leak was too large for the satellite to reach its target or be placed in a graveyard orbit. Following these findings, teams from the Eutelsat control center in Rambouillet decided to de-orbit it and perform a re-entry. This option was also abandoned since the satellite no longer has the amount of fuel needed to maneuver. W3B was officially declared an "inanimate object" by Eutelsat. Its current elliptical orbit should cause it to fall to Earth in 20 to 30 years.[30] Previous liquid leaks in space have shown that every drop solidifies, becoming space waste. The number of drops of fuel released by W3B, their diameter and positions are not measured by Eutelsat. The origin of the leak is unknown. It is possible that space waste would be responsible.

The Graveyard Orbit

By application of a sort of common charter of good conduct and cleaning their work area, the main industrial and logistics figures in the space industry have advocated the transfer of Out of Use Satellites to a graveyard orbit. With reference to the busiest low orbit band, this involves placing wreckage a few hundred kilometers below the

[30] http://www.spacenews.com/satellite_telecom/101105-failed-w3b-satellite-orbit-decades.html

Medium orbit. These orbits, called graveyard orbits, are recommended for Out of Use Satellites whose rapid and uncontrolled return to Earth would likely create health or environmental issues. The best known example is that of satellites with nuclear reactors. Field implementation of this recommendation is far from systematic for both economic and technical reasons.

5 – ISS waste

The waste management plan on the ISS falls into two categories:[31]

- “trash,” which consists mainly of worn or defective equipment, expired consumables and useless objects.

- “waste,” which includes chemical and radioactive materials, batteries, needles, unused active biological and biomedical products and consumables.

For a three-person crew, the daily volume of waste generated on board the ISS is estimated at 0.07 m^3. It is mostly plastic packaging, meal scraps, textiles (clothes are not washed and only worn three times), hygiene products, and excrement.[32] The volume of waste generated by scientific experiments on board is not assessed.

The primary waste disposal method included in the ISS management plan involves loading the waste onto a Russian Progress cargo shuttle which reenters the Earth’s atmosphere. In rare cases, if Progress is unavailable, the U.S. space shuttle could be used to return certain waste to Earth, which is then processed on the ground. With the end of the shuttle program in 2011, only "consumables," according to the term used by NASA, from "re-entry vehicles," as they are called by ESA or “transfer vehicles,” as they are called by the JAXA agency, can transport waste from the ISS.

The exact nature and quantities of waste transported by the Progress, ATV and HTV vessels when they reenter the atmosphere and ocean are not disclosed by the various space agencies. Governed by confidentiality clauses, ESA has not been able to provide the manifests of the ATV *Jules Verne* and *Johannes Kepler* upon their return. However, it has declared that the ATV was not carrying radioactive waste.

- The Progress cargo ships can carry 1-1.7 t of waste (up to 5.8 m3). Once the drinking water and cargo are unloaded, the cargo tanks are filled with waste water produced by the ISS crew and solid waste is stored in the pressurized compartment. According to ISS waste management plan, "... there is no limit to the amount and type of waste that Progress can remove so long as the weight and center of gravity limitations are respected." The Progress cargo ship is then de-orbited to perform a controlled re-entry into the atmosphere above the South Pacific, where it breaks up and partly burns before striking the ocean.

[31] “Non-Recoverable Cargo (Trash/Debris) Management Plan”, International Space Station Program – NASA/Russian Space Agency, December 2000.
[32] “Weightless washcloths and floating showers,” ISS Business Newsletter – ESA, April 2006.

– The Automated Transfer Vehicle has a maximum payload of 6.4 tons of waste[33]. During the sole mission completed by the ATV to date, the *Jules Verne* was loaded with 2.5 tons of solid and liquid waste at the time of re-entry on September 29, 2008.[34] The *Jules Verne* disintegrated into hundreds of fragments that sank in the Pacific Ocean. The vast area where the wreckage of the ATV entered the water is uninhabited and used infrequently by air and sea traffic. It is known by specialists as the "South Pacific satellite graveyard." The 900 kg of solid waste and 264 l of used water from the ISS were largely "burned" during re-entry. The re-entry sequence of the *Jules Verne* is described in section IX: Re-entry to Earth.

– The Japanese HTV can carry up to 6 t of waste.[35] It was also designed to be de-orbited at the end of mission back into Earth's atmosphere loaded with waste from the space station. After the HTV qualification flight in 2009, waste from the space craft landed in the Pacific "between New Zealand and South America," according to JAXA.[36]

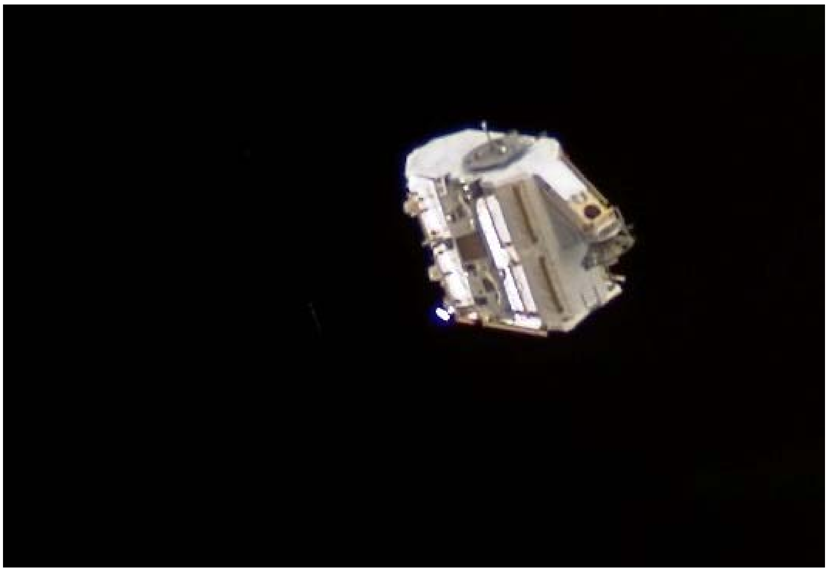
With regards to radioactive waste, the waste management plan prepared for ISS by NASA and Roscosmos provides certain flexibility within the differences in regulations: "NRC [Nuclear Regulatory Commission] Regulation does not allow for the treatment of radioactive debris by incineration, with the exception of special cases." NASA recognizes that the Russians may have different regulations and other thresholds to allow for the incineration of radioactive waste. Incineration is understood to be the process of self-combustion during the minutes on re-entry into the Earth's atmosphere where the waste from the area is subject to temperatures above 2000 °C.

The list of objects lost in low orbit also includes a set of tools and materials used in maintenance operations on the International Space Station (ISS):

– a putty knife that was dropped by British astronaut, Piers Sellers, in 2006.
– on November 22, 2006, cosmonaut Tyurin Mykhail was part of a publicity stunt that involved shooting a golf ball into space with a club made of scandium by a Canadian brand. Estimates for the orbital lifetime of the ball vary. NASA[37] said 3 days; Roscosmos said 3 years.
– a runaway camera in June 2007 while astronaut Suni Williams was busy unhooking a solar panel.
– a 635+ kg coolant tank full of ammonia, deliberately abandoned in space after its replacement in July 2007. It served as backup storage in case the cooling system leaked. According to NASA, the tank could not be brought back to Earth aboard the space shuttle for processing because the risks of carrying a tank filled with ammonia when reentering the atmosphere were too great. During re-entry into the atmosphere on March 9, 2008, NASA announced that

33 http://www.esa.int/SPECIALS/ATV/SEMOP432VBF_0.html
34 “Jules Verne Automated Transfer Vehicle (ATV) Re-entry” Information Kit – ESA, September 2008.
35 “HTV-1 Mission Press Kit,” Japan Aerospace Exploration Agency, 9 September 2009.
36 “ History-making Japanese Space Mission Ends in Flames “, Stephen Clark, SPACE.COM, 2 November 2009.
37 “Spacewalkers Tee Off on Science, Mechanics,” NASA, 23 November 2006. http://www.nasa.gov/mission_pages/station/expeditions/expedition14/exp14_eva_112206.html

because of its size "some small pieces may survive the descent and fall to the earth's surface." It was estimated that around 15 pieces varying in weight from 40 g to 17.5 kg could reach the ground. "If anyone finds a piece of something on the ground Monday morning, I hope they don't get too close," said the NASA ISS program manager at the time, Mike Suffredini.[38] After it fragmented at an altitude of about 80 km over Tasmania, the pieces of the tank fell into the ocean "between Australia and New Zealand" according to NASA.



635 kg tank full of ammonia from the ISS in 2007 which partially fell to Earth in 2009. NASA Photo.

- In June 2007, the US Government Accountability Office (GAO) released a harsh report on NASA's management of its equipment and materials inventory. Of the $94 million in equipment lost or stolen in 10 years, the GAO cited several examples, including a computer worth $4,265. To explain its disappearance, the engineer who should have received it said: "Even though it was assigned to me, this computer was used aboard the International Space Station. I was informed that it had been thrown overboard to burn in the atmosphere when it broke." [39]
- needle-nose pliers lost by the American Scott Parazynski in November 2007 while repairing a solar panel.
- a 15 kg tool bag, putty knife and grease guns lost in November 2008 by the American, Heidemarie Stefanyshyn-Piper. The tool bag reentered the atmosphere on 3 August 2009.

[38] "Space Station Trash Plunging to Earth," Tariq Malik – SPACE.COM, 31 October 2008.
[39] "Lack of Accountability and Weak Internal Controls Leave NASA Equipment Vulnerable to Loss, Theft, and Misuse," United States Government Accountability Office, GAO-07-432, June 2007.

Loading ISS waste onto the HTV-1 re-stocking module.
JAXA Photo.

The withdrawal of the ISS, originally scheduled for 2016, has been pushed back to 2020 by President Obama and included in NASA's budget.[40] When it reaches the end of its life span, it must be de-orbited to trigger a controlled re-entry. If its engines are not powerful enough to perform the maneuver, an ATC could be sent to push it towards Earth. However, Russia has not stated its intentions clearly: it has discussed the possibility of keeping the ISS Russian modules in orbit.

V - Medium Earth Orbit, MEO

1 - Traffic

Delimited by agreement between 2,000-36,000 km in altitude, these orbits are currently infrequently used, with the exception of a segment at around 20,000 km. At this altitude, radio waves sent by a satellite can be received over very large areas of the earth's surface. This is the preferred area of satellite constellations used for navigation and positioning, like the American GPS system. The average velocity of objects is 5 km/s.

2 - Satellites in Operation, Functions, Nationalities

This section of space has only been used since 1977. On November 1, 2010, 62 operational satellites were identified in the MOE by the UCS.

The 32 U.S. Navstar GPS satellites controlled by the American Ministry of Defense and the U.S. Air Force crossed the 23 Glonass controlled by the Russian Ministry of Defense. The Glonass constellation should have been complete at the end of 2010,

[40] "Fiscal Year 2011 Budget Estimates", NASA, 1 February 2011.

but the loss of three, which fell into the Pacific on December 5, 2010 following a Proton-M launcher breakdown, threw a spanner in the works with regards to the goal of global coverage of the Russian positioning system. To compensate for the satellites at the end of their life span, eight additional Glonass are scheduled to be launched in 2011, 2012 and 2013.

Only two Galileo navigation satellites belonging to the ESA (undergoing qualification tests for a future constellation of 30) and 1 Chinese military navigation system satellite are part of the device deployed by the two great powers.
A British ICO-F2 communications satellite operates at 10,000 km altitude.

3 - Medium Orbit Waste

Used for a shorter period of time than low orbits and geostationary orbits, the medium orbits are less polluted by waste. However, the same phenomenon of fragmentation by explosion or collision can be seen. Chinese and European satellite constellation projects for navigation and positioning, intended to break up the Russian and American monopolies, will increase the risk of collisions in the mid-term and the amount of future waste. In addition, medium Earth orbits are also traversed by space convoys bound for geostationary orbit and other planets. Approximately 5,200 objects larger than 10 cm have been recorded in the Spacetrack database and 60,000 objects between 1 and 10 cm. The "West Ford needles" (see below) are not included in this total.

Around 20,000 km, the life span of an object in space prior to falling back to Earth is several thousand years. Sending satellites at the end of operations to the graveyard orbit is the management approach adopted by operators to minimize the risk of collisions with operational satellites. But the instability of these orbits caused by resonance between the gravitational forces of the Sun, Moon and Earth was discovered in 2000.[41] Subsequent calculations have shown that the graveyard orbits selected for GPS satellites, GLONASS and Galileo were affected by these disturbances, leading waste to reenter the operational area.[42] The solution proposed in this study is to modify the orbit of satellites which are at the end of activity to bring them onto a highly eccentric trajectory, resulting in a re-entry within 200 years. The risk of graveyard orbits at these altitudes must be highlighted: there, collisions between objects can generate an exponential amount of waste, likely to cross operational orbits.

From February 1991 to September 2006, 23 explosions in upper stages of Russian Proton-K launchers were detected between 17,000 and 22,000 km altitude, and 5 between 11,000 and 14,000 km.[43]

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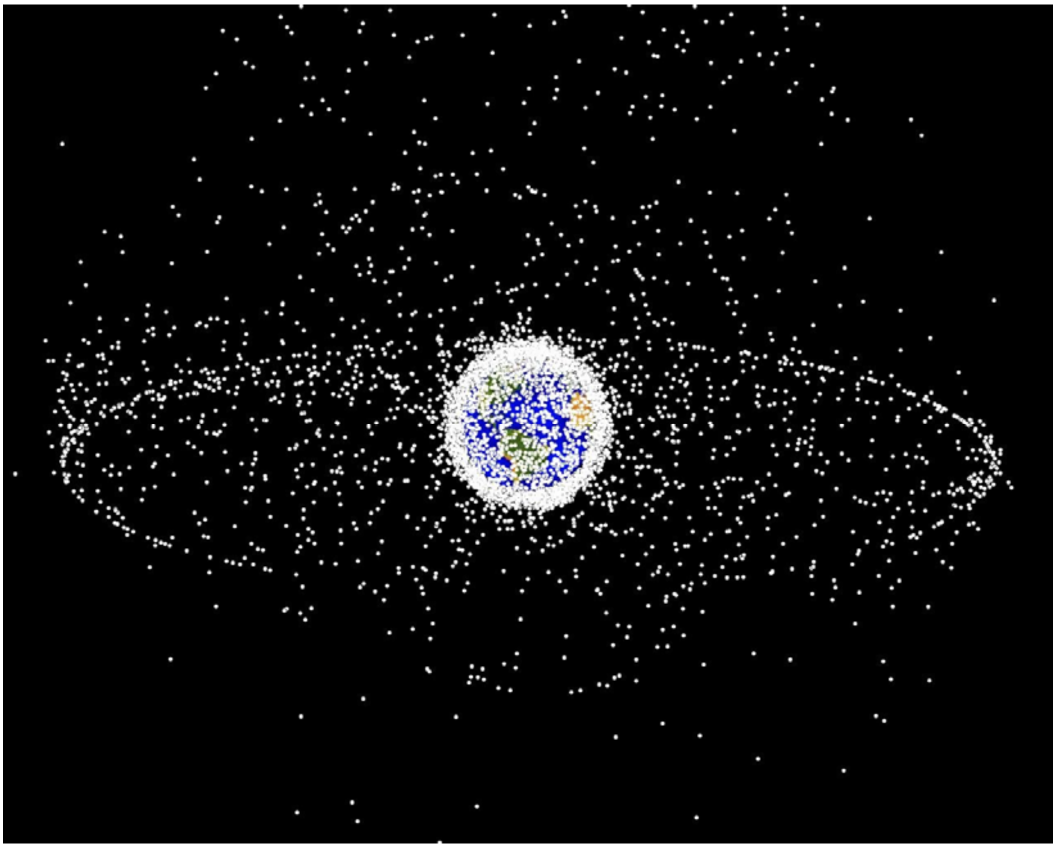
[41] "MEO Disposal Orbit Stability and Direct Reentry Strategy," C.C. Chao – Advances in the Astronautical Sciences, Vol. 105, pp. 817-838, January 2000.
[42] "Long-Term Evolution of Navigation Satellite Orbits: GPS/GLONASS/GALILEO," C.C. Chao, R.A. Gick – Advances in Space Research, Vol. 34, Issue 5, pp. 1221-1226, 2004.
[43] "History of On-Orbit Satellite Fragmentations » 14th Edition, Orbital Debris Program Office - NASA/TM–2008–214779, June 2008.

4 – The West Ford Needles

One of the largest concentrations of space waste is the result of an experiment conducted between October 1961 and May 1963 by the U.S. Air Force: launching 750 million 18 cm copper needles into space, the "West Ford needles," designed as dipoles to resonate with the Goldstone radar.
Two Midas satellites scattered them along their orbit, at an altitude of 3,200 km, to form a ring 8 km wide and 40 km thick around the Earth. This was used as a passive reflector radio for military communications.
Even before the first launch, astronomers complained about the use of optical telescopes as well as radio telescopes. Their fear was that the belt of needles around the Earth would interfere with their own observations. In June 1960, the National Academy of Sciences had to ensure that the dipoles "would not affect any branch of science". The U.S. military believed that the thickness of the needles and the inclination of the orbit chosen would lead them to fall back into the atmosphere within a maximum of 5 years.
The West Ford project was a failure: Midas 4 dropped 350 million needles and Midas 6.4 million but they do not form a ring. It formed clumps of at least 150, which were detectable by radar and which did not return to earth within 5 years. However, in 1966, the U.S. Air Force claimed that the experiment was a success and all needles had returned to the Earth's atmosphere.[44]
In fact, the shape of the clumps modified the response of the needles when under pressure from solar radiation, causing them to drift into a circular orbit. In 1994, the Goldstone radar performed a 38 hour detection experiment for the streams of waste between 2,400 and 3,100 km altitude. About 40,000 objects were detected and subsequently identified as groups of all sizes of West Ford needles. The explanation given by scientists is that large groups of dipoles continue to form smaller clumps and release individual needles.[45] Of the 102 most important swarms tracked by the Space Surveillance Network, 60 were still in orbit in 1987 and 42 had fallen into the atmosphere.

[44] "Orbital Debris: a Chronology," David S. F. Portree; Joseph P. Loftus, Jr. – NASA, January 1999.
[45] "The Importance of Non-Fragmentation Sources of Debris to the Environment," op. cited.

VI- Geostationary Earth Orbit, GEO



Payloads and waste in the geostationary terrestrial orbit tracked by the Space Surveillance Network. NASA Illustration.

1 - Traffic

This is the preferred orbit for meteorological, telecommunications and television broadcast satellites as it is geosynchronous – its revolution period is the same as the Earth's rotation. In addition, if it is positioned on the same plane as the Earth's equator, it appears stationary from any point on Earth. This feature allows data to be continuously sent and received through a fixed antenna on the ground.

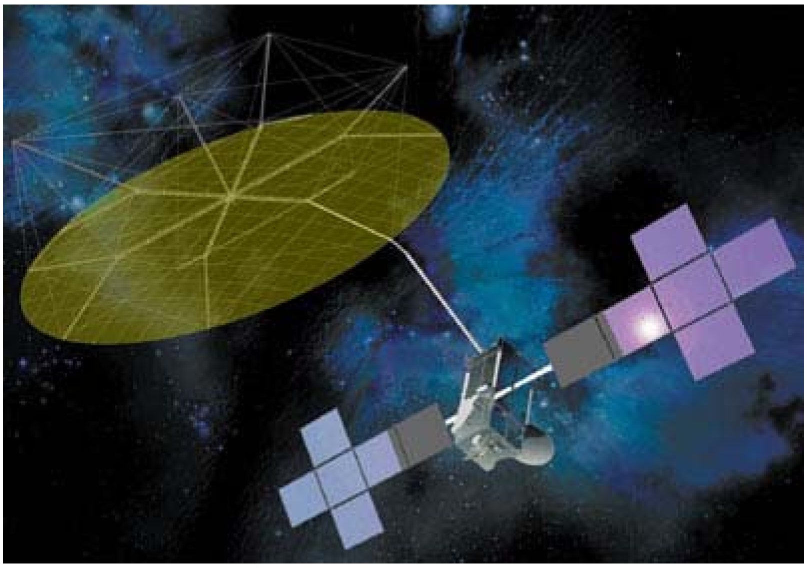
2 - Satellites in Operation, Functions, Nationalities

At this altitude, a satellite is influenced by the gravitational fields of the Sun, Earth and Moon, but is also subject to the pressure of solar radiation. Frequent orbit correction maneuvers are needed, requiring large fuel reserves. Satellites in geostationary satellites are the heaviest that are sent into space: the majority have a take-off weight of 2-8 t. They usually have a life span of 12-15 years but the U.S. Navy's UFO communications satellites only lasts four years.

On 1 November 2010, the Union of Concerned Scientists counted 389 active satellites in geostationary orbit, including 348 communications satellite (TV, radio, mobile telephony, Internet), 15 meteorological satellites, 8 navigation and positioning satellite, 7 electronic surveillance satellites, 4 early warning satellites (detecting

potential missile launches), 4 prototype satellites or technology validation test satellites and 3 devoted to space observation. 15 of them were launched between January 1 and November 30, 2010.
36 countries control one or more geostationary orbit satellites.

- The US has 154, including the Intelsat constellation (33 satellites), Americom (15), Galaxy (11), Echostar (10), Direct TV (9) which are used for television broadcasting and data. Four XM Radio Satellites have been noted, called Rock, Roll, Rhythm and Blues broadcasting hundreds of music channels for the U.S. market. Galaxy-26 and Galaxy-27, launched in 1999, have experiences difficulties that limit their operations and reduce their life expectancy to 13 years.
  With regards to TerreStar 1, launched in July 2009 by an Ariane 5 rocket from Kourou, its 6.9 t weight and 18 m diameter antenna make it the largest commercial satellite launched into space. It is used for voice transmissions to mobile phones and Smartphones. A second satellite of the same size is under construction but the owner, TerreStar Networks, has been in receivership since October 19, 2010. TerreStar 1 is for sale and ahumanright.org - an NGO established with the support of Deutsche Telekom and the Indian group Tata – is raising funds in order to buy it and transfer it into an orbit that would allow it to broadcast free internet channels to Papua New Guinea while continuing to offer commercial channels.[46]



TerreStar 1, the largest commercial satellite in orbit.
TerreStar Networks, Inc Illustration.

- Eight TDRS satellites monitor and relay communications with the space shuttle and other NASA missions. The GOES constellation (6 satellites) provides weather forecasts for NOAA (National Oceanographic and Atmospheric Administration).

[46] http://buythissatellite.org/about.php

The U.S. military has 41 communications, reconnaissance, electronic surveillance and early warning satellites controlled by the U.S. Air Force, the U.S. Navy, and the National Reconnaissance Office (NRO).

- Japan has 21 operational satellites including the JCSat constellations (8 communications satellites) and 2 Superbird satellites weighing 4 and 5 t.

- 24 Chinese satellites were active in GEO in 2010: 11 telecommunication satellites, 10 military - six of which are part of the “Beidou” navigation/positioning constellation, which should have 35 satellites by 2020 - and 3 Fengyun meteorological satellites.

- Russia has 19 satellites in GEO, including the Express constellation (8 telecommunications satellites), the 3 Yamal communications satellites belonging to the Gazprom conglomerate and 6 military satellites.

- The Grand Duchy of Luxembourg is one of the main operators in the geostationary orbit, with 15 Astra telecommunications satellites in operation launched between 1993 and 2010.

- The United Kingdom has two constellations in the GEO orbit: INMARSAT with 11 telecommunications satellites, including the huge INMARSAT 4 F1 and 4 F2 with masses of 4.5 t and 4.9 t respectively. They are the size of an English double-decker bus. Skynet (6 satellites) is a constellation for military communications.

- The Netherlands has developed a fleet of 10 satellites in the GEO between 1994 and 2009.

- Brazil has one military satellite and 6 telecommunications satellites, including Amazonas (4.5 t) launched in 2004, which had a fuel leak, thus shortening its anticipated 15 year life span.

- Canada has 10 telecommunications satellites, including Anik F1 (4.5 t) launched in 2000, which is owned by Telesat: its defective solar panels have reduced its lifespan, initially estimated at 15 years.

- Other States with active satellites in geostationary orbit: Germany (2 satellites), Argentina (1), Australia (4), South Korea (4), Egypt (2), United Arab Emirates (2), Spain (5) , France (2), Greece (1), India (10), Indonesia (5), Israel (3), Italy (2), Malaysia (4), Mexico (4), Norway (3), Pakistan (1) , Philippines (1), Singapore – owned jointly with Taiwan - (1), Sweden (2), Thailand (3), Turkey (3), Venezuela (1) and Vietnam (1).

38 satellites have been deployed by international organizations, including 23 by EUTELSAT (European Telecommunications Satellite Consortium), 6 by ASCO (Arab Satellite Communications Organization), and 4 by EUMETSAT (European Organization for the Exploitation of Meteorological Satellites).

3 - Geostationary Earth Orbit Waste

Unlike the low orbits, objects in geostationary orbit do not experience the effects of atmospheric drag as gas density is insignificant. Space waste, subject only to gravitational forces from the Sun, Earth and Moon and the flow of solar radiation, have an orbital life of hundreds of thousands of years. They therefore pose a continuing long-term risk for active satellites, for interplanetary probes crossing the GEO orbit and for future activities.

On December 31, 2009, 847 pieces of waste measuring more than 1 m were recorded in the DISCOS database of the European Space Agency[47], including 529 satellites having reached their end of life – including 21 during the year - 215 upper stages of launchers, 99 pieces of operational waste and 4 fragmentation waste. Operational waste is mostly securing cables ejected when satellites separate from their launchers, and protective covers from telescopes.

On December 31, 2009, the public Spacetrack catalog from the U.S. Space Surveillance Network identified 1,016 objects.

On December 31, 2009, 1,467 objects in geostationary orbit were tracked by the ISON (International Scientific Optical Network) telescope network comprised of 23 observatories in 11 countries, coordinated by the Keldysh Institute, Russian Academy of Sciences. This total included 892 satellites - including 391 operational and 501 Out of Use Satellites -, 250 upper stages of launchers and 325 fragments and unidentified objects. Hundreds of additional waste, over 30-40 cm and less than 1 m in size, were estimated but not observed. Discoveries of new waste continue at the rate of ten per month.[48]

The differences among the three specialized databases demonstrate spatial inaccuracy when it comes to counting objects: not only waste but satellites too.

Two U.S. Air Force communications satellites using nuclear energy have been in geostationary orbit since their launch on March 14, 1976. Named LES 8 and LES 9, they each carry two thermoelectric radioisotope generators powered by two charges of 36.69 kg of plutonium 238 (^{238}Pu). LES 8 was shut down on June 2, 2004.

For the space industry and geostationary orbit operators, the major problem is the size of the satellite track and the risk of collision. It could be compared to leaving highway crashes at the site of the accident, letting old vehicles continue to travel whilst over time shedding parts and accessories.

[47] "Classification Of Geosynchronous Objects" Issue 12, R. Choc, R. Jehn – European Space Operations Center, February 2010.
[48] "GEO protected region: ISON capabilities to provide informational flight safety support for tasks of spacecraft and space debris removal," Presentation for the 47th session of the COPUOS STSC, 8-19 February 2010, Vienna - Russian Academy of Sciences, Keldysh Institute of Applied Mathematics.

The Graveyard Orbit.

"We now know that the measures for transferring transfer satellites which are at the end of their life to a graveyard orbit are only partially implemented. In recent years, only a third of operators have performed these maneuvers correctly by following IADC (Inter Agency Debris Committee) recommendations. Another third of operators perform partial operations with an insufficient re-orbiting altitude. The remaining third of operators do nothing. They simply abandon their Out of Use Satellites in geostationary orbit."[49]

VII- Waste and Terrestrial Bacteria on the Moon

Humanity has left more than just footprints on the moon: the six crews of the Apollo missions from July 1969 to December 1972 left tons of electrical, electronic, nuclear and biological waste. Between 1959 and 2009, 49 automatic probes crashed, deliberately or otherwise, or were left on the surface at the end of the mission. Terrestrial bacteria have been inadvertently introduced, and survived several years. In total, nearly 180 t of waste are scattered over the moon.

Symbol of the rivalry between the U.S. and USSR, the Moon has been targeted by probes from these two great powers since 1958. The Soviets were the first to experience success with Luna 2, which deliberately crashed on 12 September 1959 at 10,000 km/h in the lunar region of Putredinis Palus after 33 hours and 30 minutes of flight. It was followed 30 minutes later by the third stage of its SS-6 rocket. The mission was a political success, proving the existence of solar wind and the absence of a radiation belt around the moon. In February 1966, the Soviet Union made the first soft landing with Luna 9, at 54 km/h in the region of Oceanus Procellarum. After eight hours of broadcasting the first images from the lunar surface, the probe ran out of batteries. The Luna series became massive. The probes weighed between 1.5 t and 2.7 t (Luna 15 in 1969), then increased to 5.6 t in 1970 with Luna 16, which collected soil samples to bring to Earth, abandoning its descent module. In 1976, Luna 24 was the last Soviet probe to land on the moon.

After a series of failures in the Pioneer 1-4 probes and the Ranger 1-2 Pioneer probes, which all fell to Earth, Ranger 3 was lost in space. The United States managed to hit the far side of the Moon with Ranger on 4 April 23, 1962. However, the probe broke down during the fall and did not send any data. Ranger 5 missed its target. The series of 9 Ranger probes continued until March 1965 with the same goal: transmitting images and video images during the descent before the crash. U.S. probes are smaller than Soviet probes, weighing between 300 and 400 kg. They aim to map the moon and collect data relevant to the Apollo program. From June 1966 to January 1968, 7 Surveyor probes were launched with the mission of landing and collecting data on the lunar environment. Two of them crashed.

Between 1966 and 1967, 5 Lunar Orbiter modules were responsible mapping the Moon whilst in orbit and taking detailed pictures of the moon landing areas planned for the Apollo missions. In the final mission, they were deliberately crashed.

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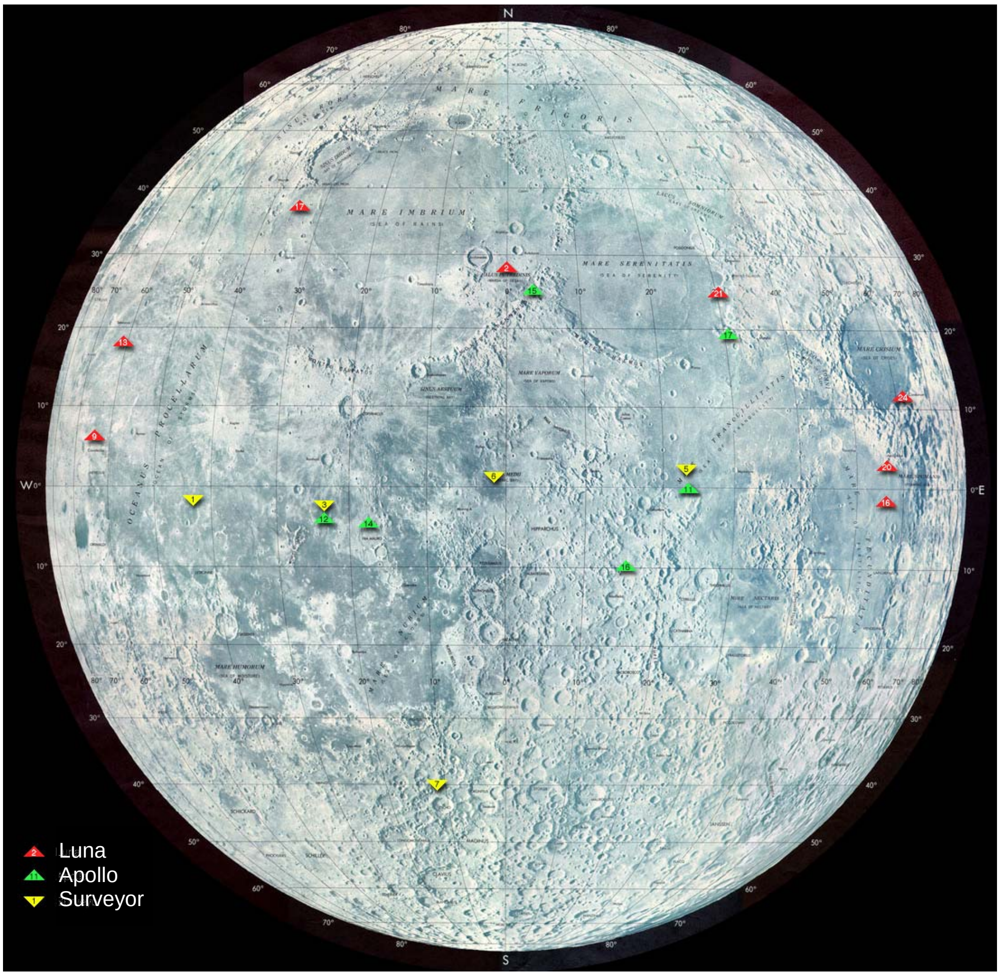
[49] "La Pollution Spatiale sous Surveillance," *op. cited*.

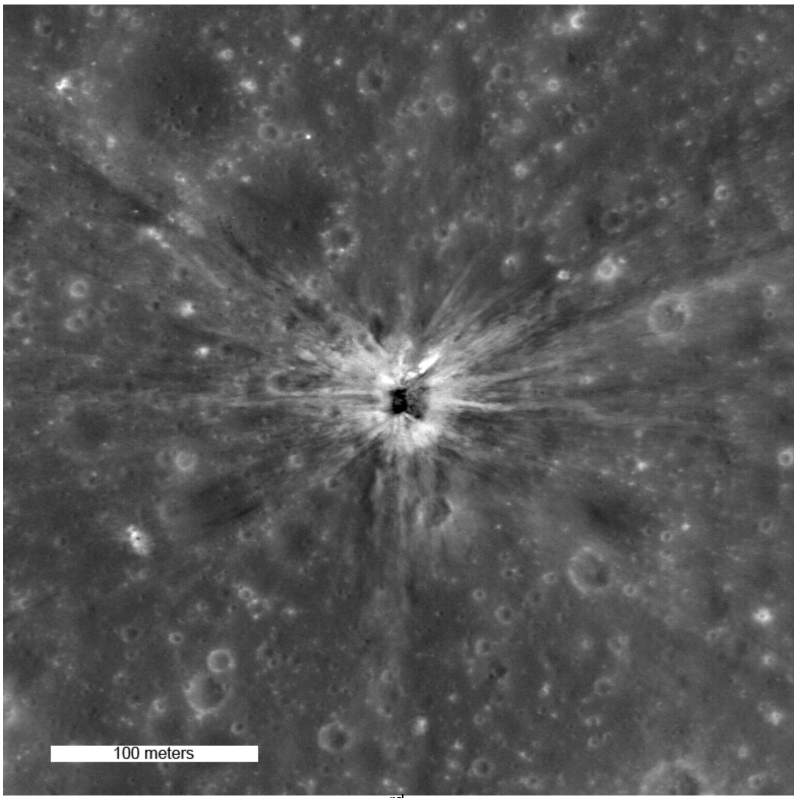


Lunar probe impact sites (in red), Surveyor (in yellow) and Apollo mission moon landing sites (in green). NASA Document.

1 – The Apollo Missions

There have been 6 Apollo missions which have landed on the Moon and 12 men have walked its surface. The main purpose of the program was to plant the Stars and Stripes on the moon's surface, which was carried out at six lunar landing sites. There were also secondary goals: the return of rocks and soil samples to Earth and the installation of scientific instruments to analyze the lunar environment for many years to come. The electrical energy required to operate this equipment was supplied by a thermoelectric generator fueled by ^{238}Pu radioactive isotopes. The last three missions used a two-seater electric ATV, the Lunar Roving Vehicle or Rover, powered by two zinc/silver batteries, 27 kg each.

Prior to the descent of the lunar module (Lunar Excursion Module - LEM), the third stage of the Saturn V rocket was launched towards the moon so that it would crash and eliminate the risk of collision with the command module remaining in orbit.



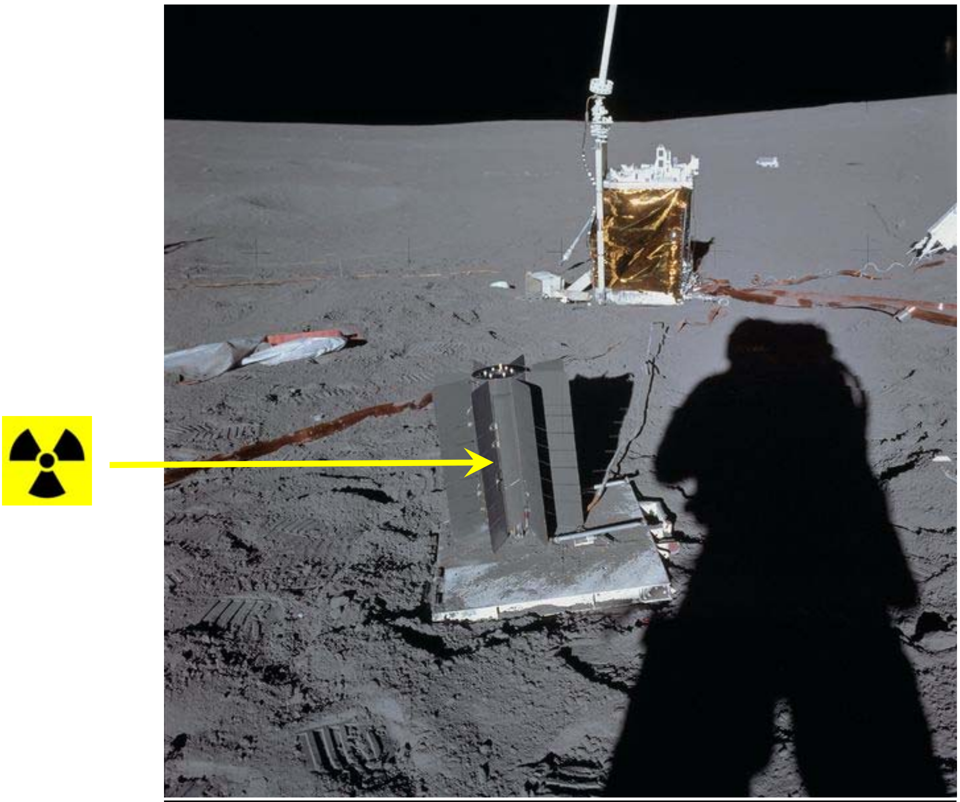
Mission Apollo 13: 3rd stage impact crater.
Credit: NASA/Goddard Space Flight Center/Arizona State University

During re-launch, the majority of equipment was left behind, as well as the rovers. Even the cameras were left; only the films were taken. The LEM left its descent stage on site, weighing 2,033 kg for Apollo 11, 12 and 14 and then 2,792 kg for missions 15, 16 and 17. After rejoining the command module which had remained in orbit, the astronauts would drop the ascent stage (4,889 kg up to Apollo 15, then 4967 kg) which crashed on the moon.

The inventory of material left by Apollo 11 on the Sea of Tranquility was conducted by a California-based association, The Lunar Legacy Project, by delving into NASA archives. The association members consider them as archaeological objects. Their goal is to classify the site of the first moon landing as a UN World Heritage Site. 106 items have been listed, equivalent to more than 2.2 t of waste. Many tools, boots, a camera and its lenses, cables, technical documentation, electrical appliances, bags of urine and feces, plastic packaging, an insulation blanket, sampling tubes, oxygen filters... are dotted over the site.

Scientific equipment deployed by the Apollo 11 crew was less sophisticated than during the following missions. Subsequently, a set of scientific instruments called ALSEP[50] (seismometers, magnetometer, spectrometer, gravimeter, dust detector, laser reflector ...) was installed on each landing site, controlled and powered by electricity from a central post. The thermoelectric radioisotope generator operated with a load of 3.8 kg ^{238}Pu oxide, or 44,500 Ci (curies).[51]

[50] Apollo Lunar Surface Experiments Package.
[51] "Space Nuclear Power: Opening the Final Frontier," G. L. Bennett, American Institute of Aeronautics and Astronautics, June 2006.

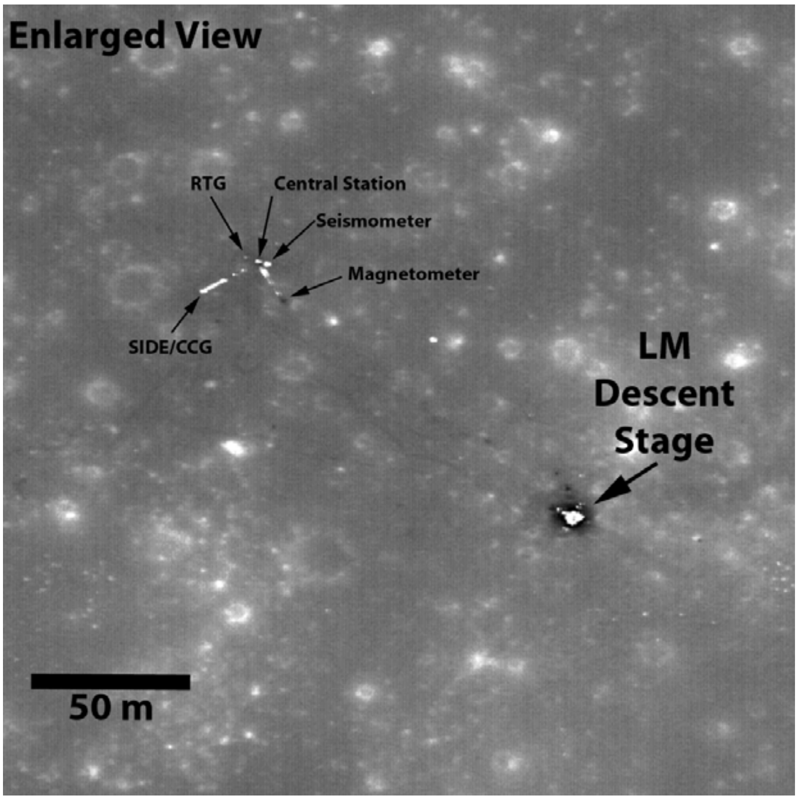


In the foreground, the radioisotope thermoelectric generator. In the background, the central post.
Apollo 14 Mission . NASA Photo.

The seismometers used pyrotechnic charges of 50 g to 4 kg, some of which have not been triggered.
The LEM was propelled by the reaction of fuel, Aerozine 50 (50/50 mixture of hydrazine and asymmetric dimethylhydrazine or UDMH) and an oxidizer, nitrogen peroxide. The tanks have not been bled; residual amounts of these fuels are still present in the descent stage left at each site or have been leaked onto the moon’s surface.

In November 1969, the Apollo 12 crew was commissioned to return the Surveyor 3 video camera to Earth under sterile conditions. Inside, the biologists discovered, to their amazement, one hundred bacteria from a species common to Earth, *Streptococcus mitis*, which had survived the launch, the spatial vacuum and then three years on the Moon with radiation at temperatures approaching absolute zero, without nutrients, water or an energy source.
"I’ve always thought that the most significant thing we've ever found on the Moon was that little bacteria that survived, returned, and that no one has ever discussed," says Commander Pete Conrad, Apollo 12.

Other observations and experiences have provided evidence that terrestrial microorganisms can survive space travel.



Site of the Apollo 12 moon landing. The SIDE/CCG measured the atmospheric pressure, the RTG is the radioisotope thermoelectric generator. On the right, the descent module (LM).
Credit: NASA/Goddard Space Flight Center/Arizona State University

2- Crash Tests on the Moon

With the success of the Apollo program, the United States stopped sending probes to the Moon. They started again in 1998 when they launched Lunar Prospector (126 kg) for a 19-month mission in lunar orbit. It ended with the probe plunging into a crater near the south pole with the aim of detecting the presence of water in the substrate ejected on impact. Nothing was found.
In October 2009, the LCROSS (Lunar Crater Observation and Sensing Satellite) mission discovered water in the form of ice mixed with regolith soil in the Cabeus crater, in the shade and near the south pole. To do this, the U.S. pulled out the big guns. The last stage of the Centaur rocket that had powered the mission deliberately crashed into the ground at 10,000 km/h. Weighing 2.3 t, the impact created a 20 m crater, 4 m deep, ejecting more than 350 tons of lunar material to an altitude of 10 km[52]. Having remained in orbit, a module called LCROSS Shepherding Spacecraft analyzed the plume and transmitted data back to Earth before crashing into the crater as well. On November 13, 2009, NASA confirmed the presence of water, and announced that "... the moon is chemically active and equipped with a water cycle." In October 2010, the publication of new analysis of the plume showed that many chemical elements are present, particularly mercury in quantities as large as the frozen water.[53] One member of the research team noted that, "The toxicity of mercury

[52] "Lunar Reconnaissance Orbiter (LRO): Leading NASA's Way Back to the Moon / Lunar Crater Observation and Sensing Satellite (LCROSS): NASA's Mission to Search for Water on the Moon," NASA, June 2009.
[53] "Detection of Water in the LCROSS Ejecta Plume," A. Colaprete *et al.*, Science, n°330, pp. 463-468, 22 October 2010.

in such large quantities could pose a problem for the human exploration of the Moon."[54]

From the 1990s, the race for political and technological prestige represented by sending space shuttles to the Moon began again, involving several countries who had developed their space industries. On January 24, 1990, Japan launched the Hiten satellite, which dropped the small Hagoromo probe (12 kg) into lunar orbit. It soon ceased to transmit. No one knows if it hit the moon or if it was lost in space. After three years in orbit around the Earth and Moon, Hiten was deliberately destroyed on April 10, 1993 and crashed between the Stevinus and Furnerius craters.[55]

In September 2003, the European Space Agency (ESA) launched SMART-1 on an Ariane 5 rocket from the Guiana Space Center. Designed and manufactured in Sweden, the satellite aimed to validate various technologies for use in space. This was the first European spacecraft to use a Hall Effect thruster, in which fuel -xenon- is accelerated by an electric field produced by solar panels. After testing, SMART-1 was directed towards the lunar orbit where it was positioned in November 2004. Several of its onboard instruments collected mineralogical, chemical and topographical data. On September 3, 2006, SMART-1 (287 kg) was deliberately de-orbited and crashed at 7,200 km/h in the middle of the geological formation called the Lake of Excellence.[56] To justify this impact, the European Space Agency put forward some unexpected arguments: "speed will be lower than a natural meteorite ... And the spacecraft will enter under a grazing angle - like a ski jumper." Concerning possible chemical pollution, the ESA puts the problem into perspective: "All chemical elements present on SMART-1 and in its instruments exist naturally on the Moon." The natural chemistry comes to the aid of artificial chemistry in the same way as natural radioactivity officially legitimizes artificial radioactivity. Comparing the device to "an artificial comet," the agency added, "In addition, the little hydrazine left in the SMART-1 thrusters will burn immediately on impact." Moreover," We should not think of it as debris." And, the ESA concluded:" ... the main part of SMART-1 could remain on the lunar surface as a monument to European space exploration."[57]

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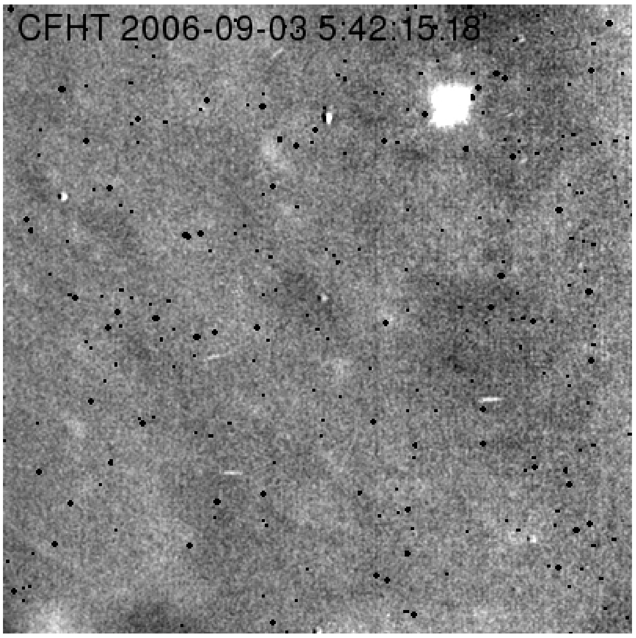
[54] " Le sol lunaire plus riche et complexe qu'on ne le soupçonnait," Jean-Louis Santini, AFP, 21 October 2010.
[55] http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=1990-007A
[56] "SMART-1, By Sun power to the Moon", N. Calder, ESA Publications Division, 2002.
[57] "SMART-1 Impact Frequently Asked Questions (FAQs)," ESA, 29 August 2006 http://www.esa.int/SPECIALS/SMART-1/SEMWSW5LARE_0.html



Impact of SMART-1 on the Moon, 3 September 2006.
Photo ESA.

In 2007, the launch of the Kaguya satellite (also called SELENE) with a mass of 2.9 tons carrying two 53 kg satellites relay - Okina and Ouna – was presented by Japan as "the largest lunar mission since the Apollo program ." As expected, the craft crashed on the moon at the end of the mission on February 12 (Okina) and June 11, 2009 (Kaguya). The date of the Ouna fall has not been specified.[58]

China launched its lunar exploration program in October 2007 with the launch of the Chang'e 1 satellite designed to map the planet in 3D and to address the abundance and distribution of 14 chemical elements. The 2.3 t satellite crashed on the moon in March 2009.[59]

In October 2008, India sent the satellite, Chandrayaan-1, on a two-year mission in lunar orbit, during which it released the Moon Impact Probe (MIP), which fell on 14 November 2008 near the Shackleton crater at the south pole. The goal, again, was to confirm the presence of water in the plume generated by the impact. In August 2009, contact with Chandrayaan-1 was suddenly cut off. According to Indian scientists, it should orbit for a further 1,000 days before crashing into an unidentified lunar site. It weighed 675 kg.[60]

All these crashes, impacts, destruction and abandonment of waste contravene the "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" (see Section X: International Regulations).

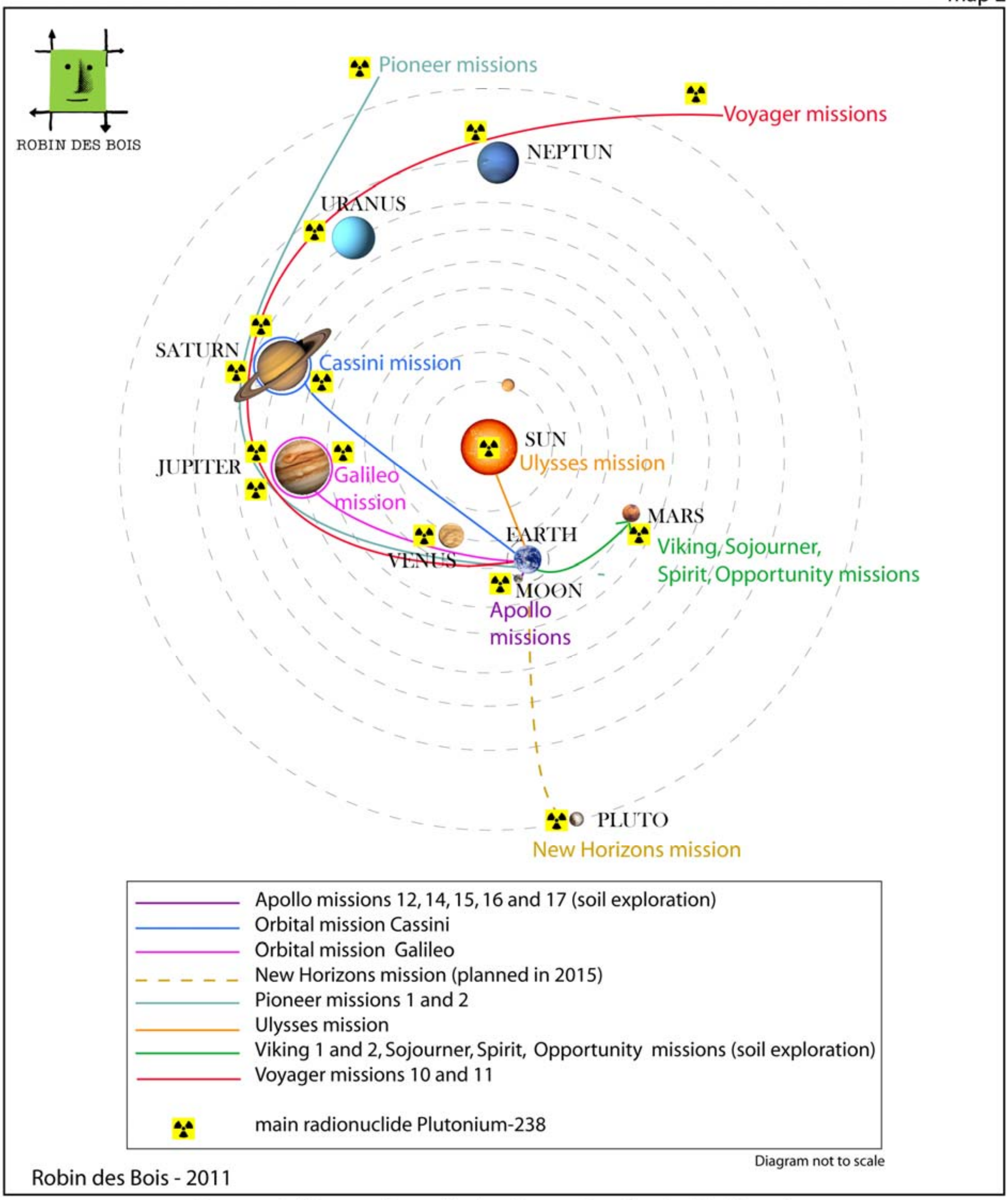
58 http://www.jaxa.jp/projects/sat/selene/index_e.html
59 "China's lunar probe Chang'e-1 impacts moon", Du Guodong, XINHUA, 1 March 2009.
60 http://www.isro.gov.in/chandrayaan/htmls/spacecraft_description.htm

VIII- Spatial and Nuclear Industry

Nuclear waste in the solar system and beyond

lunar and interplanetary missions

map 2



Sources : G. L.Bennett, Space Nuclear Power : Opening the Final Frontier

In space, the radionuclides mainly used have been polonium-210 followed by plutonium 238 and uranium 235. In very low doses, they expose human populations, biodiversity and the environment to multiple risks. Their respective half-lives are 138 days, 87.7 years and 704 million years. After 264 years, plutonium-238 still releases 12.5% of its initial radioactivity.

^{210}Po : polonium 210 ^{238}Pu : plutonium 238 ^{235}U : uranium 235	Ci : curie Bq : becquerel 1 Ci = 37 billion Bq

In 1959, U.S. President Eisenhower proudly and peacefully stated that the first atomic battery had been invented and would soon become part of the conquest of space. Two years later, an American satellite was actually equipped with a SNAP (Systems for Nuclear Auxiliary Power). During the 15 years of its life, the Transit 4A used atomic electricity generated from ^{238}Pu. Transit 5 will sink to the bottom of the Indian Ocean (see Section IX § 1: the Radioactive Boomerang).

In 2011, 52 years later, NASA reports that it no longer has a sufficient stock of 238Pu to ensure the autonomy of its interplanetary missions planned between 2014 and 2028. Only the experimental Idaho and Oak Ridge reactors would be capable of producing this from Neptunium 237, on the condition that a budget of 150 million dollars is unblocked as soon as possible.

In France, another atomic country, the National Center for Space Studies (CNES) approached the Atomic Energy Commission (CEA) in 1982 to design and test nuclear reactors fueled with ^{235}U and lithium. The multidisciplinary group, ERATO (Orbital Transfer Atomic Electro Tug), also developed reduced-model alternatives of the sub-generators Rapsodie, Phénix and Superphénix. The aim was to tow satellites from low orbit to geostationary orbit. The Central Nuclear Safety Inspectorate (SCSIN) examined minimum safety regulation guaranteeing shielding and delayed ignition of the reactors at a suitably high orbit. At this time, the USSR wanted to send men to Mars and was in the process of drawing up plans for a 400 t spacecraft powered by nuclear energy. A Franco-Russian space cooperation was then considered.

If nuclear energy still appears necessary for those involved in space exploration, for some experts space undoubtedly still remains the future outlet for radioactive waste on Earth. Thus, in April 2000, the UNESCO Working Group on the ethics of outer space, controlled by the Commission on the Ethics of Scientific Knowledge and Technology (COMEST), chaired by Mrs Vigdis Finnbogadóttir, President of Iceland from 1980-1996, unambiguously stated: **"In the mid-term, there are other means of intervention involving space technology that have shown great progress, particularly with regard to space transport from Earth to orbit. The most immediately accessible factor is the use of the space transportation system to rid the planet's most dangerous waste stemming from human activity from the surface of the Earth, notably waste from the nuclear industry. Circumsolar space, a long distance from the Earth, offers unlimited and indefinite storage capacity in this regard. "**

The UNESCO work group was composed of 6 international experts, including André Lebeau, former Assistant Director General of the European Space Agency, former president of the National Center for Space Studies and former director of Météo France.

An explosion during the launch, or shortly after, of a space convoy packed with radioactive materials is the main risk for human populations. The impact of contaminating the spatial environment, planets and their satellites with artificial radioactive isotopes has not been considered despite the 1967 Treaty Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, which, under Article IX, states that "States must undertake exploration so as to avoid the harmful effects of contamination."

Radioactive waste and the Graveyard Orbit

51 satellites or parts of Out of Use Satellites containing one or more radioactive isotope charges are currently circulating in low Earth orbits. 45 belong to Russia, but were launched by the USSR[61] and 6 belong to the United States.[62]
Two types of materials using nuclear energy to generate electricity have been used in space: nuclear reactors and radioisotope thermoelectric generators.
In a reactor, the energy source is the heat generated by the fission of ^{235}U.
In a thermoelectric generator, it comes from the natural decay of radioisotopes, which produces heat. The ^{238}Pu isotope is used in all American generators while the Soviets used ^{210}Po.
In reactors, as in thermoelectric generators, heat is transferred to a conversion system that converts it into electricity.

The first satellite powered by electricity from a nuclear power generator was launched on 29 June, 1961 by the United States. Called Transit 4A, it was the first in a 5 Transit series using a SNAP-9A radioisotope thermoelectric generator (0.91 kg of ^{238}Pu), derived from models installed on lighthouses and floating ocean monitoring stations deployed by the U.S. Navy. They were followed in 1968 and 1969 by two Nimbus meteorological satellites, each carrying two radioisotopes thermoelectric generators. Nimbus I fell into the water in 1968 (see Section IX, paragraph 1: The Radioactive Boomerang). After the accident, the U.S. stopped using nuclear energy on satellites in low orbits.

The USSR launched 44 satellites using a nuclear energy source from 1965 to 1988; 40 using a fission reactor and 4 using a radioisotope thermoelectric generator. 31 radar ocean reconnaissance satellites were launched by the Soviet Union between 1967 and 1988. The RORSATs (Radar Ocean Reconnaissance Satellite) orbited at 255 and 270 km in altitude. They monitored the activities of U.S. Navy fleet. Their active life was short, from one day to several months. Two fell back to Earth but others are still in orbit. At the end of its life, the satellite was, in theory, placed on a graveyard orbit at around 950 km to avoid the potentially catastrophic re-entry of

[61] "Spacecraft with a Nuclear Power System and Problems of Space Debris," A.I. Nazarenko *et al*, Proceedings of the Fourth European Conference on Space Debris, Darmstadt, Germany, 18-20 April 2005 – European Space Agency, August 2005.
[62] "Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration," National Research Council - National Academies Press, 2009.

radioactive materials (31.1 kg of uranium-molybdenum alloy with 90% enriched uranium - ^{235}U).[63] This graveyard orbit is supposed to guarantee that reactors would stay in orbit for 600 years; a period deemed sufficient by Soviet engineers to allow for radioactive decay before the inevitable return to Earth.

Starting with Kosmos-1176 (April 29, 1980), the last 16 satellites in the series were equipped with a device to eject the radioactive sources into the graveyard orbit. This was presented as a nuclear safety measure. It was based on the lessons learned from the 1978 Kosmos 954 crash (see Section IX paragraph 1: the Radioactive Boomerang). The joins of ^{235}U bars released into space are supposed to be consumed as they reenter the Earth's atmosphere. This source ejection has failed three times. Three others, where ejection seemed to have been successful, have not been detected and their position remains unknown. They may have fragmented into pieces which cannot be detected.

Swarms of drops and droplets of a sodium and potassium alloy (NaK) were identified between 850 and 1,000 km altitude. They come from leaks generated during the ejection of the uranium rods. Each satellite contained 9 kg of this liquid alloy to cool the nuclear reactor on board.

It appears that this core ejection is the source of the cooling circuit leaks. The number of drops and droplets was estimated at 110,000 and 115,000 for a total weight of 60 kg. The diameter of these metal spherules varies from 5-7 cm to 1 cm, for those detected by the Goldstone radar at the Massachusetts Institute of Technology. Droplets with smaller diameters, between 0.1 and 1 mm, are estimated to represent a stream of particles 12 times higher than the natural flow of micrometeorites present at this altitude.[64]

According to Don Kessler, the American space waste specialist who, with his team, discovered these swarms, this is the "most significant impact risk for a spacecraft operating at these altitudes."[65]

These drops are radioactive: the irradiation of NaK by ^{235}U during the operation of the reactor has led to the creation of two isotopes, sodium-24 and argon-39. If the period of the former is short - 15 hours – the period for argon is 39-269 years. The amount of radioactive isotopes present in the drops was not assessed.

This would leave more than 200 kg of NaK in the reactors abandoned in the graveyard orbit. Other leaks are foreseeable, whether caused by the collision of the reactors with other space waste or meteorites, or corrosion of the cooling circuits.

A RORSAT series satellite, Kosmos-1900, has not reached the graveyard orbit at around 950 km. It is in orbit between 700 and 740 km altitude and thus could be the first to land on Earth, within 500 years.

If the abandoned Russian and American satellites loaded with radioactive fuel hits space waste, the orbital life of the fragments produced will be considerably reduced. Dislocation expels waste in all directions, including low altitudes, resulting in atmospheric fallout. The probability that one of the uranium rods ejected from the RORSAT satellites will collide with a lethal 3.5 cm piece of space waste at an

[63] “Background on Space Nuclear Power,” Steven AFTERGOOD – Science and Global Security, Vol.1, pp. 93-107, 1989.

[64] “The Importance of Non-Fragmentation Sources of Debris to the Environment,” D. KESSLER *et al* – Advances in Space Research, Vol. 23, No.1, pp. 149-159, 1999.

[65] “Havoc in the Heavens: Soviet-Era Satellite’s Leaky Reactor’s Lethal Legacy,” Leonard DAVID – SPACE.COM, 29/03/2004. http://www.space.com/news/mystery_monday_040329.html

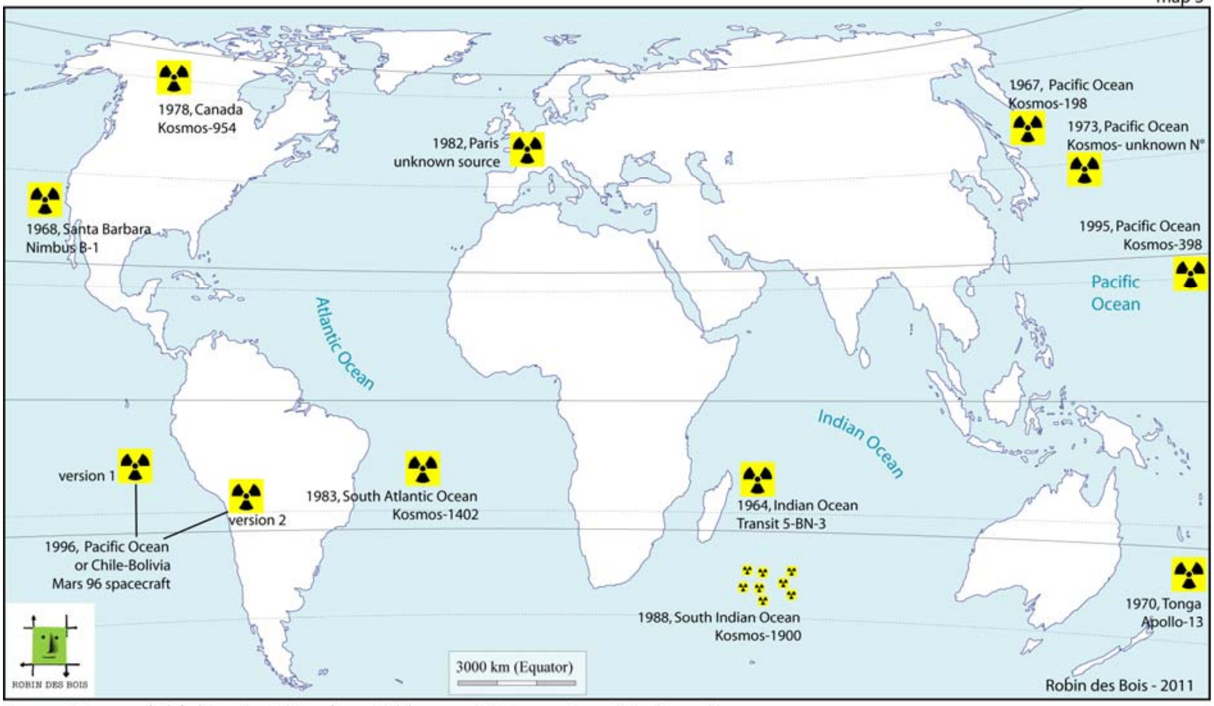
average speed of 12 km/s has been estimated in a Russian study at 10^{-6} (one risk per one million) risks per year for each of the 13 identified sources.[66]

IX- Re-entry to Earth

1- The Radioactive Boomerang

A significantly large fraction - around 15% - of all U.S. and Soviet space missions using nuclear power have ended in accidents, launch failure or other breakdowns."[67]
11 satellites equipped with nuclear reactors or radioisotope thermoelectric generators have fallen back into the atmosphere since the 1960s and have reached the land or sea. The onboard energy was produced by ^{238}Pu and ^{235}U.

Space missions : radioactive sources fallouts on Earth



Sources : Science and Global Security - 1989 volume 1 ; Flybynews ; AFP ; Agence Novosti ; Davistown Museum

1964: Transit 5-BN-3. Indian Ocean

Occurring on April 21, 1964 in the middle of the Cold War, and concerning a craft controlled by the U.S. Navy, little information is known. Having failed to reach its orbit, the military navigation satellite fell into the atmosphere on the day of its launch and disintegrated at an altitude of 50 km above the Indian Ocean, according to a prescribed procedure in the event of re-entry. The partial immersion of contaminated waste cannot be disputed.
Its radioisotope thermoelectric generator, the SNAP-9A, contained 1 kg of ^{238}Pu. In August 1964, ^{238}Pu was detected in the stratosphere at 32 km altitude over the southern hemisphere. In May 1965, radioactive dust was detected by aircraft. There is four times more ^{238}Pu recorded in the southern hemisphere than in the northern hemisphere. In November 1970, 95% of the plutonium dispersed in the atmosphere

[66] "Spacecraft with a Nuclear Power System and Problems of Space Debris," A.I. Nazarenko *et al*, op. cited.
[67] "Background on Space Nuclear Power", *op. cited.*

by the disintegration of Transit 5-BN-3 landed on Earth. It was detected on all continents and all latitudes, but 25% fell in the northern hemisphere and 75% in the southern hemisphere.[68]

The dispersion of the Transit 5-BN-3 energy source in the atmosphere as ^{238}Pu dust generated a total radioactivity of 6.3 x 10^{14} Bq or 17,000 Ci. In comparison, all atmospheric nuclear tests carried out between 1945 and 1974 released a total radioactivity of 3.3 x 10^{14} Bq (9,000 Ci) in ^{238}Pu.

1967: Kosmos 198. North Pacific Ocean

On December 27, the Kosmos 198 missed its orbit. It plunged into the Pacific Ocean north of Japan. The resulting radioactivity (^{235}U) was measured.

1968: Nimbus-1-B. Santa Barbara, California

Powered by a ^{238}Pu generator with 34,000 Ci, the first U.S. weather satellite was the victim of an accident caused by the launcher. It fell just off the coast of Santa Barbara. Several months later, the nuclear fuel was recovered at 100 m in depth in good condition according to official statements.

1970: Apollo. South Pacific

The Apollo lunar mission exploded after launch. 44,500 Ci should still be confined to the sub-marine pit in Tonga in the South Pacific.

1973: Kosmos. Pacific Ocean

A Rorsat Kosmos satellite, whose number is unknown, fell into the Pacific Ocean after a launcher failure.

1978: Kosmos-954. Canada

The fall of the 4 t satellite over Canada on January 24, 1978 would have been a disaster in urban areas: its nuclear reactor was powered by 31.1 kilograms of ^{235}U. Radioactive waste contaminated an area of over 124,000 km^2 in the Northwest Territories and the provinces of Alberta and Saskatchewan.[69] According to the Canadian Nuclear Safety Commission, only 0.1% of the total mass of uranium contained in the core of the reactor was found.[70]

It was estimated that about one quarter, or 7.7 kg of total mass, was deposited in the Northwest Territories in the form of particles smaller than 1 mm containing ^{235}U and fission products (strontium-90, iodine-131, zirconium-95, niobium-95, ruthenium-103, ruthenium-106, cesium-137, cerium-141 and cerium-144).[71] These microparticles were not collected. The remainder of the reactor is assumed to have been dispersed into the air before touching the ground.

Kosmos-954 was one of the most advanced Soviet spy satellites, designed to detect U.S. nuclear submarines, which explains the intensity or search operations for waste

[68] "Final Environmental Impact Statement for the Cassini Mission", Solar System Exploration Division – NASA, June 1995.

[69] "Why Canada Needs a Robust Arctic Air Rescue Capability," Ron Wallace – Canadian Defence & Foreign Affairs Institute, March 2009.

[70] The COSMOS 954 Accident", Santé Canada. http://www.hc-sc.gc.ca/hc-ps/ed-ud/fedplan/cosmos_954-eng.php

[71] "Health Impact of Radioactive Debris from the Satellite Cosmos 954," B. L. Tracy, F. A. Prantl, J. M. Quinn - Health Physics, vol. 47(2), pp. 225-233, August 1984.

and the increased participation of experts and U.S Military resources. Launched on September 18, 1977 at 150 km altitude in polar orbit, it was tracked by radars of the North American Air Defense Command (NORAD). A decline in the orbit of Kosmos-954 was detected from November, then the total loss of stability on January 6, 1978. NORAD estimated the re-entry date to be January 24, with a margin of error of two days[72]. The place of impact could not be predicted.
From December 19, the United States had created a work group led by the National Security Council (NSC). The re-entry of Kosmos-956 in the short-term was deemed inevitable. Composed of intelligence specialists (Defense Intelligence Agency), experts in radiation protection from the Departments of Energy and Defense and State Department diplomats, the group was named "Operation Morning Light." The decision was made not to make any public announcement and only inform U.S. allies of the re-entry of the satellite and the possibility of it crashing within their territory. Neither the Secretary-General of the United Nations nor the Committee on the Peaceful Uses of Outer Space (COPUOS) at the UN were warned. With regards to Russia, nothing was said to the UN or the international community. When asked discreetly by the United States about the presence of a nuclear reactor onboard, the Soviets responded that it was designed to be destroyed by incineration upon re-entry into the dense layers of the atmosphere, but that "Nevertheless, if there is an accident onboard the satellite (depressurization), it cannot be excluded that some parts of the reactor may reach the earth's surface. In this case, a little local contamination could occur at the site of impact on the Earth, which would require limited local cleanup."[73]
Starting on January 22, the U.S. put their atomic energy research and response unit on alert and loaded equipment onboard aircraft ready to fly to Andrews (Washington, DC) and Travis (California) military bases and Las Vegas (Nevada) international airport.
On January 24, 1978 at 11:53 Universal Time, Kosmos-954 entered Canadian airspace via the west coast, north of the Queen Charlotte Islands, after burning for about 3 minutes. The area of impact on the ground - the heaviest pieces crashing first - spread over a length of 800 km, west of Great Slave Lake, north of Baker Lake. The lighter pieces of waste (insulation materials, dust and fragments ...) were locally remobilized by the wind and transported beyond the area of the impact trajectory.

One of the eyewitnesses of the Kosmos-954 fall, a resident of Yellowknife on the shores of Great Slave Lake, said he saw "... something like a jet plane on fire. There were dozens of little pieces along with the main body, all burning and each with a small trail of fire like the big piece."[74]

President Jimmy Carter warned Canadian Prime Minister Pierre Trudeau by phone call 22 minutes after the impact of the satellite, offering him the American resources mobilized for "Operation Morning Light." The offer was accepted and the first C-130 transport aircraft loaded with personnel, detection equipment and radiation protection landed that night on the Edmonton air base in Alberta. U2 aircraft, already at high altitude, crisscrossed Canadian airspace to measure the concentrations of ^{235}U.
The announcement of the Kosmos-954 fall in Canada was made public. The Soviets

[72] "The Life and Death of Cosmos 954," Gus W. Weiss - Studies in Intelligence, 22, 1 (Printemps 1974), pp. 1-7.
[73] "The Life and Death of Cosmos 954", *op. cité*
[74] "Cosmos 954: An Ugly Death," TIME, 6 February 1978.

offered to send a group of specialists "... to mitigate the possible consequences and evacuate the remains of the satellite."[75] The offer was rejected by Canada diplomatically, who actually expected the technical specifications for the reactor and payload. However, the USSR provided no accurate data.

The day after the crash, the first low altitude reconnaissance flights carrying radioactivity detectors onboard began over the immense impact zone. On January 26, ground crew landed near Baker Lake. The first radioactive hot spots were detected by air on January 28 in McLeod Bay on Great Slave Lake. As the lakes are frozen at this time of year, waste had landed on the ice. They were therefore more easily detectable at ground level as the water column isolated them from the natural radioactivity of the substrate, at the bottom of the lake.

Royal Air Force of Canada Detection Team, Operation Morning Light.

In spite of the means deployed - 250 Canadian experts, 120 from the U.S., more than 600 aircraft and helicopter detection missions during the first two months - the first piece of waste on the ground was discovered by two hikers, on the ice of the Thelon River. They had not heard the news and carelessly examined the strange piece of metal. Back at their base camp, friends informed them that Kosmos-954 and its nuclear reactor had fallen from the sky and alerted authorities. They were taken to the Edmonton base for examination and found to be free of contamination or radiation.[76] A true miracle when we consider the unexpected result of the claim made by Canada to the UN: "Canadian authorities have determined that all fragments discovered were radioactive, except two. Some fragments were found to have a lethal level of radioactivity."[77]

[75] "Settlement of Claim between Canada and the Union of Soviet Socialist Republics for Damage Caused by Cosmos 954," 2 April 1981.
[76] "Operation Morning Light: Northwest Territories, Canada, 1979; a non-technical summary of United States participation," U.S. Dept. of Energy, 1978.
[77] "Settlement of Claim between Canada and the Union of Soviet Socialist Republics for Damage Caused by "Cosmos 954," 2 April 1981.

"Operation Morning Light" went on for nine months in extreme conditions. A main base camp for 100 people was set up near Baker Lake in arctic conditions. During the winter, temperatures dropped to -40 ° C; wind chill reached -100 ° C on stormy days.
C130 aircraft equipped with radiation detectors conducted reconnaissance 24 hours a day. The data collected was analyzed at the base camp and a ground crew was then sent to collect waste in lead containers. Polar temperatures sometimes only allowed a few minutes of outdoor work. The difficulties of travel in the snow and ice, the cold, the isolation, the deadly risks involved in handling of certain waste, weighed heavily on the team's morale.
Again, the odds were very low but there was still a risk. The Inuit village of Snowdrift was hit by the fallout of radioactive waste. A detection team collected many small pieces there. The commander of the Northern Region headquarters came in person to the people that say "little or no ecological effect is expected." The documents available on "Operation Morning Light," from official U.S. or Canadian sources, does not dwell on the radiological assessment of the populations and military personnel exposed to waste dispersed by Kosmos-954.

Collecting Radioactive Waste on Great Slave Lake.
Photo U.S. Department of Energy.

The cessation of operations in October 1978 was motivated by three main considerations:

- "It is highly likely that all the large, detectable radioactive pieces have been located and collected"
- "With the best technology currently available, it would be impossible to locate and collect more than a small percentage of the remaining debris, mostly comprised of small particles"

- "The additional collection of any remaining pieces is not practical on the ground and impossible on Great Slave Lake due to wide dispersal, the terrain, and the thawing of the lake."[78]

In 1979, the uranium isotopes corresponding to the signature of the Kosmos-954 reactor were detected in the stratosphere. The amount of ^{235}U released by the satellite was then estimated "to be able to increase the concentration of ^{235}U in the stratosphere by up to 100% (from 0.7% to 1.4%)."[79] As in the case of Transit 5-BN-3, the finest particles were mobilized by air currents, scattered over large areas and detected for several years in the air and rainwater. A study measuring the concentrations of uranium in rain water collected in Fayetteville, Arkansas, following the eruption of Mount St Helens (May 18, 1980), demonstrated the persistence in 1980 and 1981 of radioactive fallout from Kosmos-954.[80]
In Japan, a team of meteorologists sought uranium from June 1980 and June 1981 in air and rainwater in Tokyo and Tsukuba and compared the results with measurements obtained in 1979. After recording large increases in uranium levels during the months of March 1979 and March 1981, to be reconciled with the concentrations measured from April to May 1980 over the Pacific Ocean, scientists said there is "every reason to believe that the abnormally high activity rate and sharp increase in the ratio $^{234}U/^{238}U$ in surface air in the spring, in Japan and over the ocean, were caused by the disintegration of the Russian satellite Kosmos-954. This effect is believed to continue for several years."[81]

On April 2, 1981, Canada and the USSR signed a formal protocol in Moscow "regulating Canada's claim for damages caused by the disintegration of the Soviet satellite Kosmos 954 over Canada." This document was based on the UN Convention "on International Liability for Damage Caused by Space Objects." Canada accepted 3 million Canadian dollars in compensation even though it asked for 6.

1982: Unidentified Source. Paris
The Journal of Environmental Radioactivity reported in an article, written in 1988 by two scientists, that a major blast of ^{238}Pu was measured in rainwater in Paris in October 1982[82]. The authors did not formally identify the source. The very rare and expensive ^{238}Pu is used exclusively by the civil or military space industry. The satellite origin of this pollution is likely in the same way as a leak from a Research Center in Ile-de-France.

1983: Kosmos 1402. South Atlantic
The fall of Kosmos 954 and the dispersal of radioactive waste on the ground

[78] "Operation Morning Light: Northwest Territories, Canada, 1979; a non-technical summary of United States participation," *op. cited.*
[79] "Atmospheric burn up of the Cosmos-954 reactor," P.W. Krey *et al.* – Science 205, pp. 583-585, 1979.
[80] **"**Fallout of uranium isotopes from the 1980 eruption of Mount St. Helens," P. K. Kuroda, I. O. Essien, D-N Sandoval - Journal of Radioanalytical and Nuclear Chemistry, pp. 23-32, 1984.
[81] "Concentration of Uranium and the Activity Ratio of $^{234}U/^{238}U$ in Surface Air: Effect of Atmospheric Burn-up of Cosmos-954," K. Hirose, Y. Sugimura – Papers in Meteorology and Geophysics, Vol. 32, No 4, pp. 317-322, December 1981.
[82] Martin J.M. et Thomas A.J., Anomalous concentrations of atmospheric plutonium-238 over Paris. N°7

prompted Soviet engineers to design a nuclear radioactive space reactor whose core would be ejected at the end of the satellite's life at an altitude of 900 km where its orbital lifetime should allow radioactivity to decline before re-entry.[83] However, on Kosmos 1402, launched on August 30, 1982, the fuel system failed after it separated from the main body of the satellite. The latter fell on the 23 January, 1983 over the Indian Ocean, while the reactor core fell on 7 February 1983 over the South Atlantic, about 1,700 km east of Brazil. It consisted of 31 kg of ^{235}U, which partly dispersed in the atmosphere as dust. No radiological research or quantification could be carried out on the submerged section. Samples of rain and snow collected at Fayetteville by the Department of Chemistry at the University of Arkansas, from February 20, 1983 until June 3, detected strontium isotopes (^{89}Sr and ^{90}Sr) from the fission in the Kosmos 1402 core.
One year after the fall, aerosol samples collected using meteorological balloons showed the presence of ^{235}U concentrations from the Kosmos 1402 reactor 36 km above the northern hemisphere.[84]

The scientific findings are clear: "... a significant amount of radioactivity entered the atmosphere as a result of the burning of Kosmos-1402."[85]

1988: Kosmos 1900. Southern Indian Ocean

The Kosmos 1900, after several months of orbital life, fascinated international press in the spring of 1988 when it began its unscheduled decline. The French press was at the meeting. "The French authorities have taken security measures regarding the uncontrolled re-entry of a Soviet spy satellite, Kosmos 1900, with a nuclear engine in four months" (source Le Figaro). "Kosmos is due in October. There is no panic. The Secretary of State for major risks has provided reassurance. The Soviet satellite will fully disintegrate in 99 days but radioactive fallout is unlikely "(source Libération). A wave of anxiety and propaganda took over the world. A technical miracle or global manipulation: at the start of re-entry, thanks to a signal from the onboard heat sensor, the ^{235}U nuclear reactor would separate from the body of the satellite and the satellite would be ejected into a low graveyard orbit where it should remain for a few centuries, before falling back to Earth with partially decreased radioactivity levels. The satellite was fragmented and dispersed into a "trail of dust" 1,000 km in length over Africa before, according to official information, flowing towards the south of the Indian Ocean. If this version is correct, there is no doubt that the satellite was contaminated and irradiated during the few months it was joined to the nuclear reactor generator.

1995: Kosmos 398. Pacific Ocean

Quoted by Le Monde on 14 December 1995, Agence France Presse reported that waste from a Soviet satellite launched in 1971 fell back to earth, on December 9, into the Pacific Ocean, 2,000 km southeast of Hawaii. According to the report, the Kosmos 398 was not carrying a nuclear source, which, taking into account the launch date and the line of the Kosmos, is therefore not credible.

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[83] See chapter "Nuclear Debris and Graveyard Orbit"
[84] "Detection of Uranium from Cosmos-1402 in the Stratosphere," Robert Leifer *et al.*, Science, Vol. 238, n° 4826, pp. 512-514, 23 October 1987.
[85] "Radioactive strontium fallout from the nuclear-powered satellite Cosmos-1402," R.K. Guimon *et al.*, Geochemical Journal, Vol. 19, pp. 229-235, March 1985.

1996: Mars 96 probe. Pacific Ocean

"Earthlings prepare Mars invasion" read the double page headline of French newspaper, Libération (Saturday 16 and Sunday 17 November). Alas, the science fiction was short-lived. Despite cooperation between France and Germany, the Soviet probe Mars 1996 destined for great things crashed hours after its launch from the Baikonur base in the Pacific Ocean, between the coasts of Chile and Easter Island according to the U.S. military command. According to sources, it was carrying 200 to 299 grams of ^{238}Pu. "These are tiny capsules of nothing. I have held them in my hand. There is no danger," a CNRS expert told the same newspaper on 18 November. A second version appeared in the press, notably in the American newspaper, Christian Science Monitor, according to which the Russian probe had allegedly landed in the Atacama Desert near the border between Bolivia and Chile. Fruitless investigations were conducted by the U.S. military zone.

2 - The Metal Boomerang

According to the US Department of Defense, from the launch of Sputnik-1 on October 4, 1957 to July 2010, 21,800 human objects, greater than 10 cm in size, fell back into the Earth's atmosphere[86]. If NASA, using scientific calculations, was able to estimate the probability of a human being hit by a piece of waste at 10^{-4} - a 1 in 10,000 risk – for each re-entry[87], the accidents already recorded in fifty years of space exploration show that the space industry has been lucky. At times, it has come very close to disaster.

Re-entry of the MIR station near the Islands of Fiji on March 28, 2001. Photo Reuter's.
30 tons of waste in the South Pacific Ocean.

Every day, one or more pieces of waste, monitored by the Space Surveillance Network, fall into the atmosphere. Take the last months of 2010, for example: 46 objects fell back in September, 39 in October and 31 in November.
In 2000, a study undertaken by the Aerospace Corporation's Centre for Orbital and Re-entry Debris Studies (CORDS - El Segundo, California) estimated that over 193

[86] http://www.stratcom.mil/factsheets/jspoc/USSTRATCOM_Space_Control_and_Space_Surveillance/
[87] "Guidelines and Assessment Procedures for Limiting Orbital Debris, "NASA Safety Standard 1740.14, August 1995.

tons of material fell into the atmosphere in 1999.[88] "Of this total, we estimate that 84,000 pounds [about 38 t] survived re-entry" said William Ailor, director of CORDS.[89] While oceans cover 75% of the Earth's surface, CORDS estimates that 9.5 tons of waste has reached the ground.

When it begins to fall into the atmosphere, a piece of space waste has an average velocity of 7 km/s (25,200 km/h). It is then slowed by the friction of atmospheric particles to a velocity of several hundred meters per second. Most of the kinetic energy is converted to heat during a phase that lasts less than 6 minutes, when temperature rises to 2700°C. This intense heating process can melt the metal structures of a satellite and dismantle it, vaporize certain materials or disperse them into hundreds of fragments that burn separately. However, 10-40% of the initial mass of the object reaches the surface of the Earth.[90] Many internal components are protected by their position behind refractory materials or are large and thick enough to withstand several minutes of heat, such as stainless steel fuel tanks and pressurized gas titanium tanks.

Titanium tank that fell in 2003 near a farm in Nacogdoches, Texas.
Photo by Steve Liss-Corbis

[88] "1999 Re-entries of Rocket Bodies and Satellites," R.T. Holbrook - Aerospace Forum on Space Debris, Collision Avoidance, & Reentry Hazards, El Segundo, CA, 1-3 Nov. 2000.
[89] "After four decades of launching satellites into Earth orbit, space is a polluted junk yard", Leonard DAVID – SPACE.COM, 6 September 2000.
[90] "Analysis of Reentered Debris and Implications for Survivability Modeling," William Ailor *et al.* - Proceedings of the Fourth European Conference on Space Debris, Darmstadt, Germany, 18/20 April 2005 – European Space Agency, August 2005.

In general, "... elements from satellites made from materials with a high melting point, such as stainless steel, titanium or beryllium tend to survive re-entry and impact the surface of the Earth."[91] In 2001, 2004 and 2005, three titanium tanks from Delta rocket propulsion modules reached the ground in Saudi Arabia, Argentina and Thailand. Weighing about 50 kg and measuring 1.2 m in diameter, they represented a quarter of the total mass of the propulsion module.

Titanium tank weighing around 50 kg from the 3rd stage of the Delta 2 launcher, which fell on 21 January 2001 in Saudi Arabia after eight years in orbit.
Photo by NASA Orbital Debris Program Office.

[91] "The Realities of Reentry Disposal," Dr. Russell P. Patera and Dr. William H. Ailor, Center for Orbital and Reentry Debris Studies, The Aerospace Corporation.

Delta 2 launcher tank near Bangkok on 13 January 2005.
Photo by Orbital Debris Quarterly News.

Statistical risks are minimal, but the risk laughs in the face of probability. On June 5, 1969, a 3,000 t Japanese freighter passing between Sakhalin Island and the coast of Siberia, the *Dai Chi Chinei,* was damaged and five sailors were injured by waste falling from the sky - some of which weighed about 10 kg. After Japanese experts examination, the metal pieces were found to be from a Soviet spacecraft. The facts were reported by the Japanese delegation to the UN Legal Sub-Commission on Space.[92]

On December 19, 1996, a Chinese Boeing 757 in flight at an altitude of 9600 m between Beijing and Wuhan was hit by an unidentified waste that cracked the glass in the cockpit. The aircraft made an emergency landing in Beijing.

In July 2009 a resident of Hull in Great Britain saw the roof of his house pierced by a burning object about 2 kg in weight that landed in his living room. "It was a real shock. If it had landed in the street and hit someone, it would have killed them" said the man, aged 75, who called the police. They turned the object over to the Royal Air Force for examinations. After consultations with NASA and ESA, it turned out that the angular piece of waste came from an undetermined satellite and had spent ten years in space.

[92] Journal de la Marine Marchande et de la Navigation Aérienne, no. 2586, page 1621, 10 July 1969 and the Aerospace Corporation : http://reentrynews.aero.org/recovered.html

Some re-entries are controlled from the ground to minimize the risk of re-entry in inhabited areas by directing the craft to a specific area of the ocean. When it separates from the ISS after restocking, the European ATV is controlled by the CNES Control Centre in Toulouse to direct it towards an area of the South Pacific Ocean of around 2,700 km in length and 200 km wide, believed to be uninhabited and with no maritime routes (see Section IV-5: ISS Debris). Nearly 40% of the total mass of the *Jules Verne* ATV (13.5 t) is expected to reach the water's surface. Beforehand, the countries near the impact area are informed so they can pass on the warning to their sailors and pilots. The European Space Agency says that this procedure reduces the risk to 10^{-7} of waste hitting a human being. The re-entry sequence of the first ATV, *Jules Verne,* which took place on September 29, 2008, is described on the ESA website:[93]

12:01: first de-orbit maneuver.
The maneuver must take the ATV from its circular orbit at 330 km altitude to an elliptical orbit with an altitude of between 220 and 225 km.

12:10: operation successful!
The ATV is now in an elliptical orbit with a perigee altitude of between 220 and 225 km. Engine thrust lasted for 6 min 20 sec (the strongest of the mission with 30 m/sec). ATV-CC teams are now calculating the precise altitude of the orbit in order to determine the exact time for the second boost which should take place at around 15:00. The ATV will then have been around the Earth two times.

12:22: second maneuver at 14:58.
The ATV-CC teams have just determined the schedule for the second de-orbit maneuver. It will take place at precisely 14:58. The ATV will then reach its point of re-entry above the South Pacific.

14:02: the last lap!
The ATV starts its final orbit of the Earth before reaching the top of the South Pacific at an altitude of 120 km. Everything is going smoothly with a second de-orbit maneuver scheduled at 14:58 and atmospheric re-entry at 15:31.

14:58: second de-orbit maneuver
This maneuver should last 15 min and drop the *Jules Verne* down in order to bring it to the re-entry point over the South Pacific.

The operation went very smoothly. The *Jules Verne* is slowly losing altitude and is now at 230 km.

15:31: re-entry
The ATV plunges into the atmosphere.

15:33: loss and destruction of solar panels

15:37: separation of the mooring system, shields and destruction of the upper section of the pressurized module.

[93] http://www.cnes.fr/web/CNES-fr/6905-rentree-atmospherique-de-l-atv-29-septembre.php

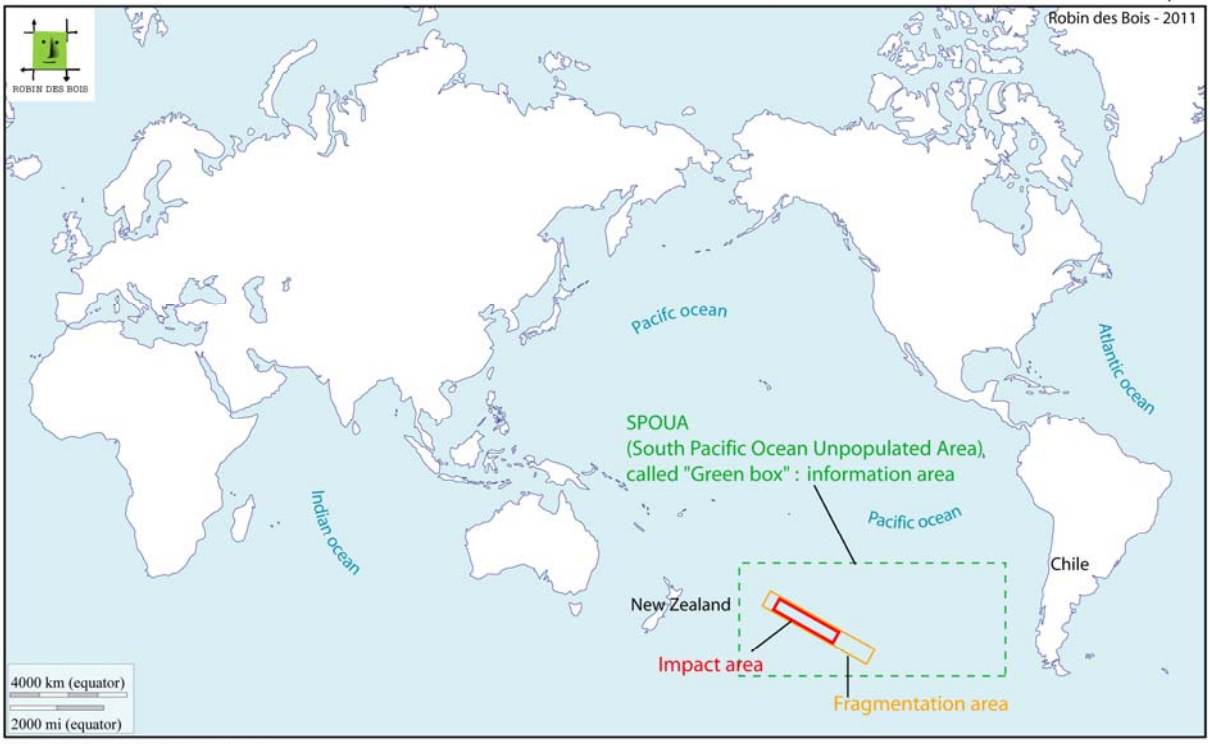
15:37 40 sec: separation of the upper wall of the pressurized module.
15:38 20 sec: fragmentation of nozzles and fuel tanks.
15:38 30 sec: fragmentation of tanks and cargo racks.
15:38 50 sec: destruction of the tanks.
15:39 30 sec: disintegration of the walls.

Waste fell into the sea within a targeted area, located in an uninhabited area of the South Pacific, 2,500 kilometers east of New Zealand, 1,000 km west of Chile and 1,500 km south of Easter Island.

The re-entry of the ATV *Johannes Kepler* in the SPOUA -South Pacific Ocean Unpopulated Area - is scheduled for June 21, 2011.

The re-entry of ATV Johannes Kepler

map 4



Sources : ESA European Space Agency

"There is a low probability that the stages, engines or parts of the body dropped from a launcher could hit a marine animal when they enter the ocean during nominal flight operations. The probability of a hit has been estimated (...) The results of this analysis indicate that there is an extremely small chance of a section of launcher hitting a marine animal. (...) There is less than a 0.5 chance of an animal being hit annually, even when all launch activities are added. Calculations are done for all species in the Atlantic and Pacific Oceans."[94]

[94] "Programmatic Environmental Impact Statement for Licensing Launches" - ICF Consulting, Inc./ U.S. Department of Transportation (DOT), 24 May 2001

X- International Regulation

1957: The Legal Vacuum

On October 4, 1957, Soviet space engineering gave birth to an 84 kg metal and electronic baby named Sputnik. The most beautiful offspring of communist pride was launched into the space from the 3rd stage of a Semiorka rocket with its cap weighing a total of 6,500 kg. A stage and a cap were destined to be the first manmade waste beyond the Earth and its atmosphere.

1963: The Beginnings of Space Law

The colonization of space has largely outpaced international law. 6 years after the launch of Sputnik and 2 years after Yuri Gagarin was the first astronaut to orbit the Earth, the United Nations unanimously adopted the "Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space." This recommendatory text is non-binding, even if it opens the way for a space doctrine based on peaceful cooperation, the pooling resources and profits, and the consideration of all humanity. It was a relatively calming vision in a bipolar world living under the threat of nuclear war between the USSR and the United States, who, at the same time, were the only two figures, rather than rivals, in the conquest of space. Among the principles that "should" serve as guidelines for expanding the domain of human activity, those from a non-governmental organization like Robin des Bois are particularly noteworthy:

- the principle of non-national appropriation by any means whatsoever of atmospheric space and its celestial bodies.

- the principle of responsibility with regard to the international community of each state involved in space, independently or on partnership with others.

- the traceability or polluter-pays principle: the two terms are not explicitly used however are fully implied when the UN Declaration states that "Any State which launches or handles the launch of an object into outer space is responsible, from an international point of view, for damages caused to a foreign state or individuals, companies or organizations by the said object or its components, on land, in the air or in space."

1967: Treaty Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other celestial bodies.

Two years before two American citizens walked on the moon and planted the Stars and Stripes there - a symbol of ownership that did not comply with the 1963 Declaration - the United Nations opened the "Treaty Governing the Activities States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies" for signing by member states. This Treaty came into force on 16 October 1967. It consolidates and expands the first stage of Space Law. Peace in the cosmos: "States Parties to the Treaty agree not to place in orbit around the Earth any objects carrying nuclear weapons or other types of weapons of mass destruction ...."

It also introduced a kind of biological and health precaution for organic life forms present on the Moon and Other Celestial Bodies: "States Parties to the Treaty shall pursue studies of outer space and will conduct their operations to avoid the harmful effects of contamination" (Article IX).

1972: Clarification of Responsibilities

In 1972, the Convention on International Liability for Damage Caused by Space Objects clarified and organized the concepts of damages and methods of recognizing and sharing responsibilities, i.e. arbitration and compensation.

The space object potentially liable for any damages refers to the payload which is the satellite and all elements of the launcher. The launching State shall pay compensation for damages to the Earth's surface and aircraft, i.e. aircraft in flight. In these cases, the liability of the launching State is absolute.

The 1972 Convention defines the launching State as the state that launches, the State which enables launching, the State whose installations are used for launching or the State from where launch takes place. Several countries may be declared as launching States and are therefore jointly liable in the event of an accident.

For damage caused elsewhere than Earth to a space object belonging to one launching State by an object belonging to another launching State, the latter is only liable if at fault has occurred in the guidance of its object. Disputes are settled through diplomatic channels. However, if it is found that a claim for compensation cannot be satisfied by these means, a Commission to settle claims may be installed at the request of an interested party. If no agreement is reached between the parties regarding the appointment of the President of the Commission, the Secretary General of the United Nations may, at the request of either party, make the appointment.

This attempt at clarification does not eliminate the risk of flags of complaisance, unique to maritime law. Indeed, the Sea Launch company, registered in the Cayman Islands and founded in 1995, used a floating platform, the Ocean Odyssey, registered in Liberia, with a Russian launcher and a shareholder held by Boeing, the Russian company RSC-Energia, an Anglo-Norwegian company and a Ukrainian company.

1973: We will explore the Moon and Other Celestial Bodies

Excited by "We have walked on the Moon" in 1954 and then by the first human footprints on the moon in 1969, the Organization of the United Nations opened the "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" for signing. It reflects the belief in imminent, substantial and enthusiastic human activity on the natural satellite of the Earth. "The construction of bases, military installations and fortifications, the testing of weapons of all types and execution of military maneuvers are prohibited on the Moon." "The activities of the States Parties shall not impede the activities of other States Parties." "A State establishing a station shall only use the area necessary to meet the needs of the station ...." "All vehicles, equipment, stations, facilities and space equipment found on the moon are accessible to other States Parties." "The installation on the surface or beneath the surface of the moon of personnel or vehicles, facilities or space equipment including structures connected to its surface or subsoil does not create property rights." "The States Parties to this Agreement agree to establish an international regime, including appropriate procedures governing the use of natural resources of the moon ...." The said international regime includes the main aims of "ensuring the orderly and safe development of the natural resources of the Moon, arranging equitable distribution among all States Parties of the benefits that will result from these resources, with special attention given to the interests and needs of developing countries." This set of provisions designed to prevent a stampede and unfair looting of the Moon's natural resources has, for the moment, turned out to be useless and naive. It was particularly inspired, in terms of the prevention of military activities, by the Antarctic Treaty, enacted in 1961. The Agreement on the Moon and other celestial bodies, however, opens the legal door to industrialization and the exploitation of extraterrestrial space for the sole benefit of humanity. Article IV of the Agreement specifically states that the exploitation of the Moon will take into account "the interests of the present generation and future generations and the need to promote higher standards of living."

In 1973, international politics had clearly found the solution to the foreseeable exhaustion of land resources. Growth was primarily focused on the Moon and then the planets close to the Earth.
Of course, the States Parties to the terms of Article VII should not disrupt the existing balance of the lunar environment with "harmful changes" but, on the whole, the Agreement is clear that the drafters and signatories were glad to colonize a inert celestial body where the protection of indigenous peoples and biodiversity, water and landscape would not be costly and cumbersome.

1992: Inclusion of Nuclear Power Sources in Space
On the proposal of the Committee on the Peaceful Uses of Outer Space (COPUOS), the General Assembly of the United Nations adopted the "Principles for the Use of Nuclear Power Sources in Space." It is not a question of prohibition but of restriction to "space missions that cannot be reasonably performed using non-nuclear energy sources." To protect the population from accidents, of which the probability is described as 'low', radiation exposure should only cover a limited geographic area. For each individual, exposure should be limited to 1 mSv/year in accordance with the objectives set by the International Commission on Radiological Protection. "However, it is acceptable to use a subsidiary limit of 5 mSv/year for several years provided that the average effective dose does not exceed the principal limit of 1 mSv/year over the life of individuals."

To date, the 1967 Treaty has been ratified by 100 countries including the major players in space industry. The Agreement on the Moon and Other Celestial Bodies of 1973 which emphasizes equitable access to potential resources has only been ratified by 13 countries, including just one European country: the Netherlands. France is at the signing stage. Neither China nor the U.S. nor Russia have begun the ratification procedure.

The London Convention on the Prevention of Marine Pollution by Dumping of Waste and other materials may, in the event of incoming vehicles from satellites or space, be concerned when these re-entries take place in the marine environment, a situation with a probability of 80%. However, the interpretation that the States Parties put forward to the London Convention has so far discounted waste from space. The London Convention takes into account waste from aircraft but does not extend its jurisdiction to waste from spacecraft. The debate may not be over just yet though.

Some states have adopted regulations for their space activities, including Russia, the United States, the United Kingdom and Belgium. France, an important launching State, adopted the Law on Space Operations on June 3, 2008. On a positive note: under liabilities, listed in Section IV, it includes harm to public health and the environment caused by a space object and refers in the control phase to "the passivation of activities", i.e. safely storing materials that may cause explosions or intensify their effects at the end of operations. Article VIII states that the administrative authority or authorized agents may at any time impose any measure considered necessary in the interest of the safety of persons and property and public and environmental safety.

XI- Mitigation Guidelines

The IADC (Inter Agency Debris Committee) brings together 11 space agencies: ASI (Agenzia Spaziale Italiana), BNSC (British National Space Centre), CNES (Centre National d'Etudes Spatailes), CNSA (China National Space Administration), DLR (German Aerospace Center), ESA (European Space Agency), ISRO (Indian Space Research Organization), JAXA (Japan Aerospace Exploration Agency), NASA (National Aeronautics and Space Administration), NSAU (National Space Agency of Ukraine) and Roscosmos (Russian Federal Space Agency).

The IADC is defined as an international forum of governmental structures whose aim is to coordinate activities to counter human waste and natural debris.

It provides ideas, acting as a platform for exchanging information and a "think tank" for the UN Committee on the Peaceful Uses of Outer Space (COPUOS).

It has written guidelines and practical recommendations to limit various categories of space waste generated by humans:

- operational waste should be limited as a precaution through the improved design of the satellite-launcher unit and avoiding the ejection of straps, covers, explosive bolts and other accessories into space.
- waste fragmentation. To reduce orbital explosions and the proliferation of deconstruction waste, we recommend ensuring, before the end of operations of the spacecraft, that the pressurization gas and fuel are fully consumed or protected so they may not explode in the event of a collision.

The good ideas put forward by the IADC come up against mistrust from satellite manufacturers and operators. As in any commercial competition, they claim to be ready to implement the recommendations if imposed and are reluctant to advance alone for fear of eliminating their competitive advantage.

What is worse, the enemy is also within, like the China National Space Administration (CNSA), which has been a member of the IADC since its creation in 2002. It could not prevent the Chinese military from taking an anti-satellite shot in 2007 that is sustainably and exponentially polluting all low orbits.

XII- The Work of Robin des Bois – ESA

The mission of the European Space Agency (ESA)[95] is to ensure and promote exclusively peaceful cooperation among European states in the areas of space research and technology and applying these developments for scientific and operational purposes. The 18 ESA Member States are Germany, Austria, Belgium, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Luxembourg, Norway, the Netherlands, Portugal, the United Kingdom, Sweden, the Czech Republic and Switzerland. In addition, Canada, Hungary, Poland and Romania are involved in some cooperation projects with ESA.

Following a request from Robin des Bois, an interview took place on January 14, 2011 at the ESA offices in Paris between the three members of the NGO and seven members of ESA. Three were physically present and four attended via videoconference from the Kourou launch center in French Guiana - including the ATv2 program director - and the European Space Research and Technology Centre (ESTEC) headquarters in Noordwijk, the Netherlands.

The ESA is a pioneer in earth observation mission programs including CryoSat – polar ice sheet study -, SMOS - Soil Moisture and Ocean Salinity dedicated to the studying soil moisture and ocean salinity -, and GOCE - Gravity Field and Steady-State Ocean Circulation Explorer on gravitational fields.

For ESA, the proliferation of waste in the Earth's orbit is a critical issue that threatens the safety of space missions. ESA is pleased that an environmental NGO is concerned with this issue.

ESA has been the principal architect of the "European Code of Conduct for Space Debris Mitigation" established in 2004 and signed by the Italian Space Agency (ASI), the English Space Center (BNSC), the German Space Center (DLR), CNES and ESA. This Code of Conduct states and improves the mitigation of the IADC (see previous chapter). It defines the way in which spacecraft can be designed and controlled to reduce waste. A space waste manager must be appointed for each project. That person must minimize environmental damage during re-entry to Earth.
For example, fuel may not be released in space if the particles are larger than 10 microns. The design of the craft, materials and accessories must not generate waste in excess of 10 microns during the orbital phase. The re-entry of a spacecraft to Earth must not produce adverse effects on the terrestrial area, notably in the radiological, biological and chemical domains. Compliance with this Code of Conduct has been mandatory since 1 April 2008 and the ATV program, which started before its enactment, applies these recommendations. If the project cannot comply with the objectives of the Code, non-compliance must be justified and recorded.
USSTRATCOM confirms in its confidential catalog that the ATV *Jules Verne* has left no waste more than 5 cm large in its orbit. The vital organs of the ATV are protected

[95] http://www.esa.int/esaCP/index.html

from meteorites and waste by a shield. The *Jules Verne* has made several evasive maneuvers. All waste generated by the ATC must be de-orbited and returned to the Earth's atmosphere within a year. It is confirmed that the ATV does not carry radioactive materials. The risk of an ATV causing an accident on the ground during its return is well below 10^{-4}, i.e. 10,000 to 1. Prior to ATV’s re-entry into the Earth’s atmosphere, and more specifically, into the South Pacific Ocean, the Chilean and New Zealand authorities are warned. Hopefully no illegal fishing vessel will be in the area when the *Johannes Kepler* hits the Ocean.
Without being able to release the manifest of waste transported by the ATV from the ISS to Earth, ESA has provided the following examples: sanitary waste, electrical waste, plastic packaging, medical equipment, dust filters, out-of-date foods, used measuring devices and batteries. It is expected that less than half of the total mass of the ATV will come into contact with the ocean - about 8 t for Johannes Kepler - and that all waste will sink.

ESA is working on a space cargo ship design capable of a totally controlled re-entry and a smooth return to Earth using parachutes, allowing equipment of scientific value and waste to be retrieved. In the mid-term, ESA’s goal is to develop and implement a vessel capable of capturing space waste.

Conclusion

Space is driven by military, scientific and business challenges. It is a branch of the Earth. Waste poses a multitude of problems. The safety of space activities is compromised by the proliferation and fragmentary knowledge of the amount and trajectory of existing waste. Initiatives are increasing with the aim of developing maps and inventory without the pooling of information.

The reduction of waste at the source in space is possible if all launching states and satellite operators are aware of the seriousness and risks. Accountability of all those involved should be accelerated by increased pressure from civil society and states, and by international agreement.

Laws on space must be cooperative, progressive and binding. The basic rules of prudence must be observed. It is significant that no formal diplomatic action was taken after China fired an anti-satellite missile in January 2007. It is urgent that the United States, Russia, China, Japan and other key launching states ratify the agreement on launchers to the Moon and other celestial bodies. The next goal would be an international convention on the prevention and management of waste in the Earth's orbit and the interplanetary system.

Research on how to capture or neutralize the biggest waste in space likely to fragment into millions of micro-projectiles, could be partly financed by a fund accrued by all space users, commercial satellite operators first and foremost.

With regard to the Earth's environment, satellite re-entries must be planned with a specified location, respectful to the marine environment and to populations at risk. More information about the impact of incinerating combustible parts of the spacecraft during re-entry into the atmosphere is needed to avoid the constant and systematic argument about the dilution of pollutants over our heads.

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