NASA Mars Science Laboratory Mission: Safety Review

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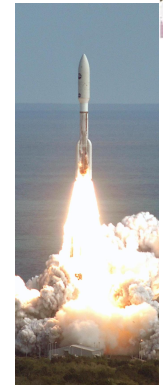
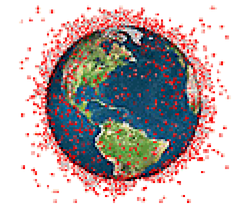
Outline



- **MSL Mission Overview**
- **Launch Vehicle**
- **Radioisotope Sources**
- **MSL Rover „Curiosity"**
- **INSRP Background**
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- **Research and Developments Supported by DoD INSRP AF SEC**
- **International Activities in Space Safety**
- **Academic Degree and Certificate Programs in Space Safety**
- **Conclusions**

Mars Science Laboratory (MSL)
Interagency Nuclear Safety Review Panel (INSRP)
Safety Evaluation Report (SER)

Atlas V

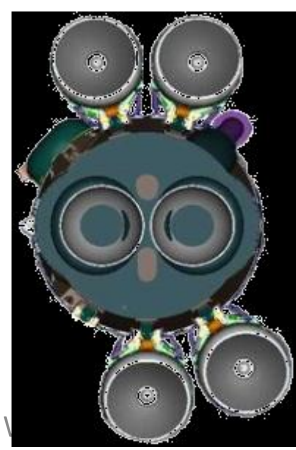
MSL Mission Overview

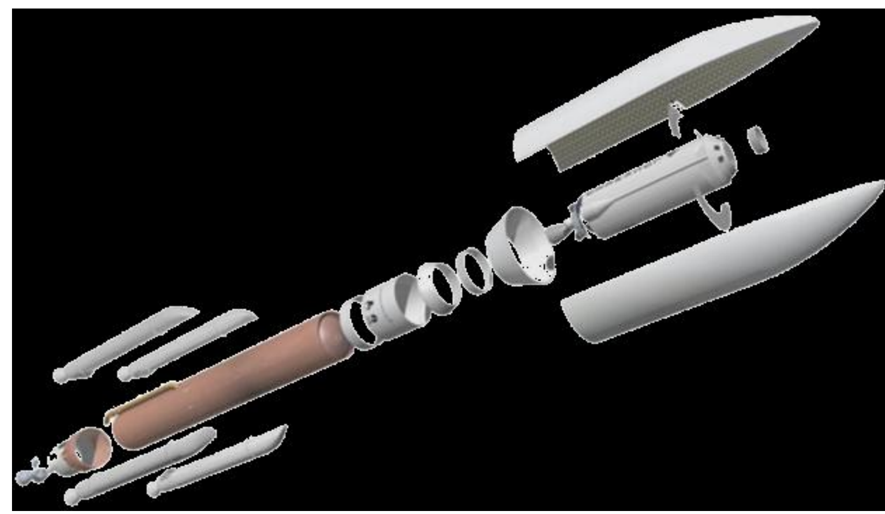
NASA's Mars Science Laboratory mission delivers the next generation rover to the red planet with goals including:

- **Characterization of Mars' climate**
- **Determination of whether life ever arose on Mars**
- **Characterization of Mars' geology**
- **Preparation for human exploration**

MSL Launch Vehicle

- United Launch Alliance (ULA) selected as MSL launch provider
- Atlas V –541 Configuration:
  - 5-meter Short Payload Fairing (68 ft) (PLF)
  - 4 Solid Rocket Motors (SRM)
  - Single RL 10 Engine

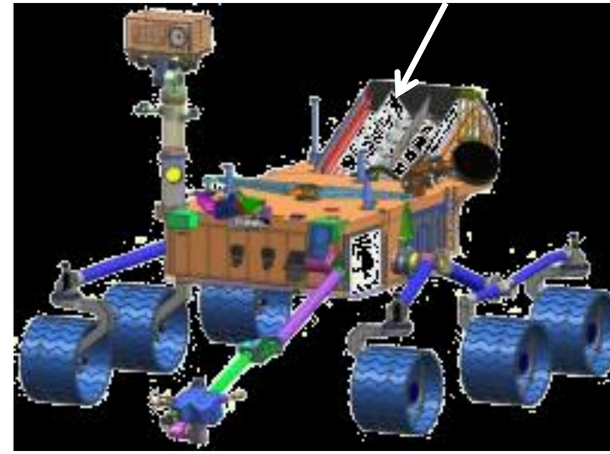


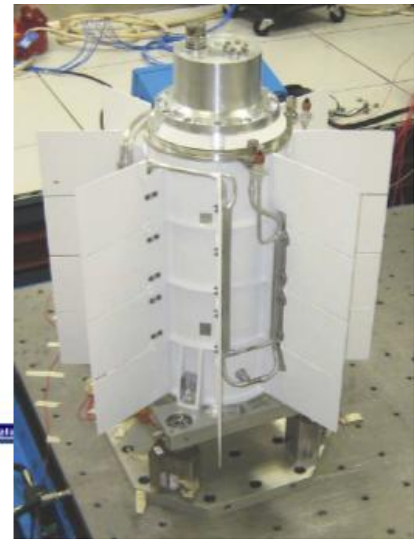


MSL Radioisotope Sources

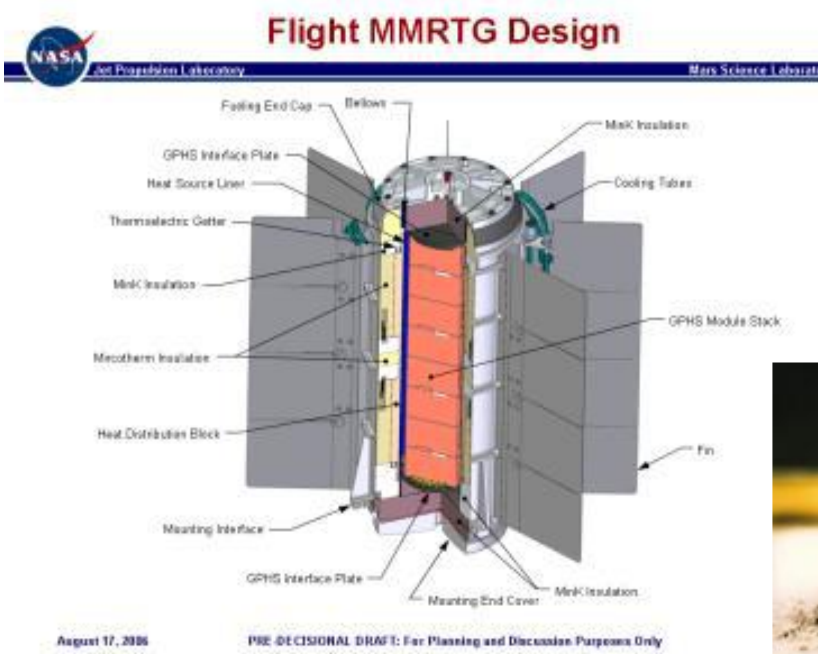
- Multi-Mission Radioisotope Thermoelectric Generator
- 8 GPHS Modules
- 32 Iridium clad PuO_2 pellets
- 60,340 Curies (Ci) activity
- 4.8 kg (10.6 lbs)
- Minor sources in science components

MMRTG

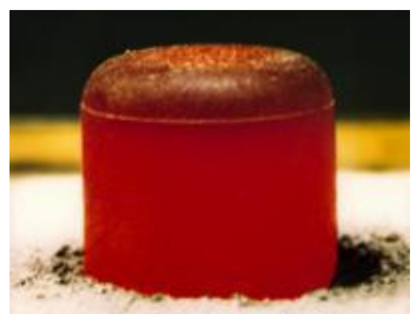


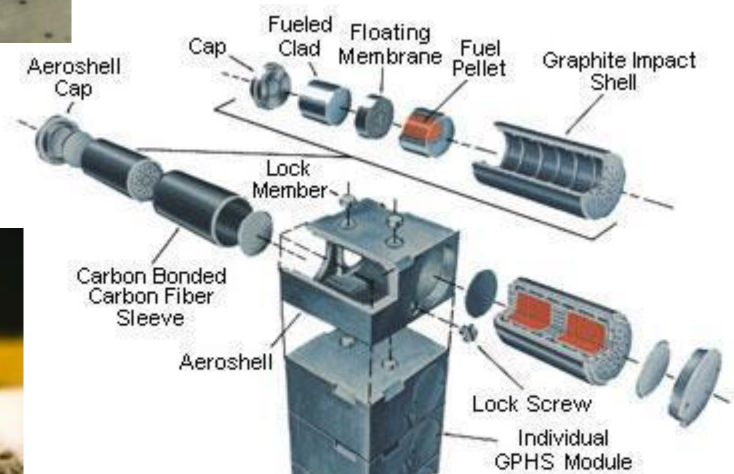


MSL MMRTG



^{238}Pu Ceramic
151 g; 1,499°F



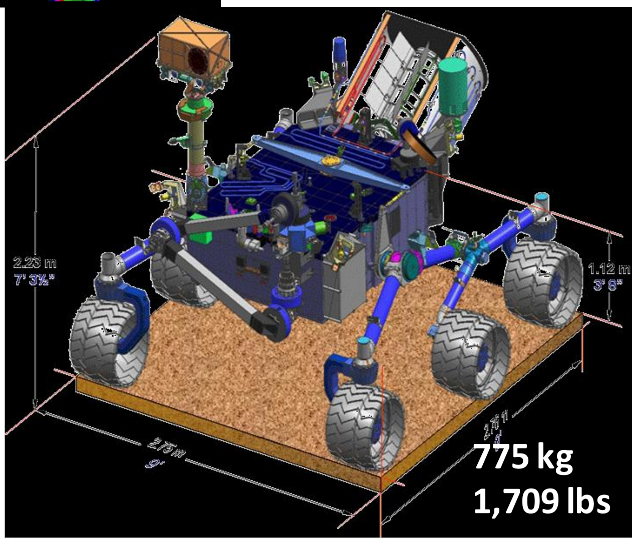


General Purpose Heat Source

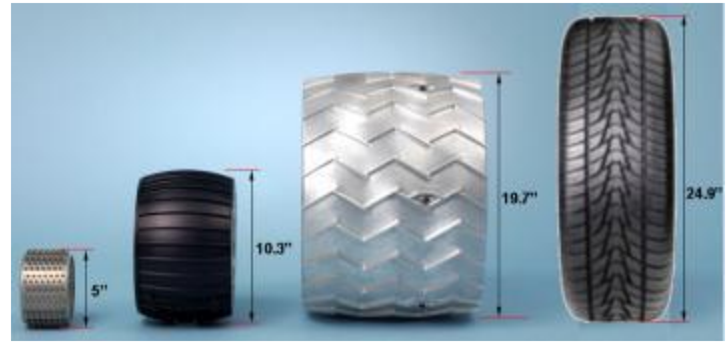
- **2 PuO_2 pellets per GIS**
- **2 GIS per GPHS Module = 4 pellets/GPHS**

MSL 'Curiosity' Rover

MSL's rover was named by Clara Ma, a sixth grader from Lenexa, Kansas



Rover1 Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) - 110 We10.6 lbs 238PuO_2
60,078 Ci



Curiosity Mars Science Laboratory Rover1

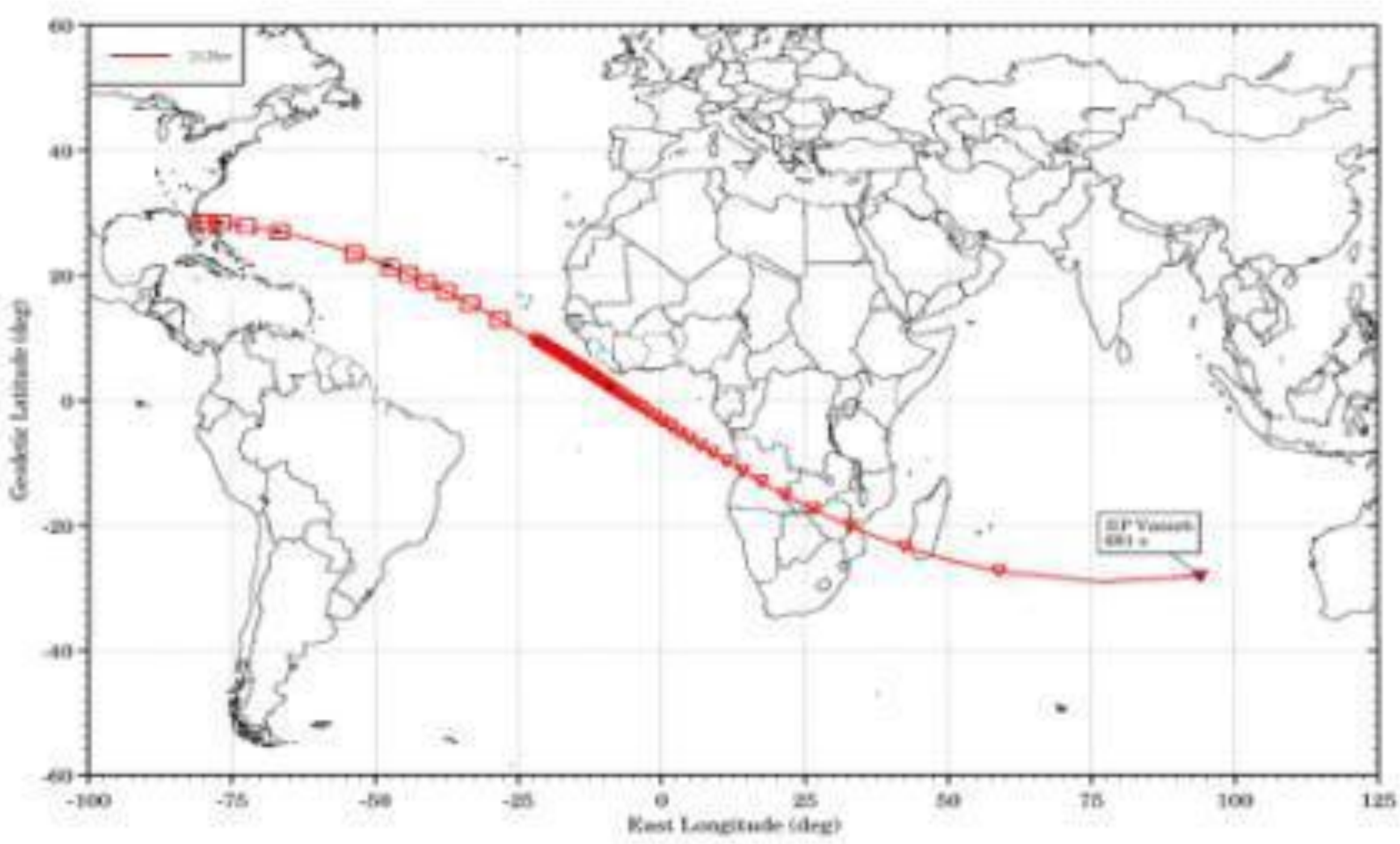
8 Light Weight Radioisotope Heater Units (LWRHUs)
0.8 oz 238PuO_2
265.8 Ci*MSL*

Pathfinder and MER Rovers used solar power for mission

3 Light Weight Radioisotope Heater Units (LWRHUs)
0.3 oz 238PuO_2
99.7 Ci

MSL Trajectory

Trip to Mars takes approximately 8½ months



MSL Interagency Nuclear Safety Review Panel (INSRP) Background

- In accordance with the Nuclear Safety Launch Approval Process Required by PD/NSC-25 (issued in1977 and amended in 1996)
- MSL INSRP empanelled in the Summer of 2006 by request from the NASA Administrator
- GOAL - Review, evaluate and document the radiological risk to the general public and Earth's environment from the MSL Mission for launch approval Decision Makers
- Members: DoD, DOE, EPA, and NASA with an NRC Technical Advisor supported by subject matter experts and consultants independent of the FSAR Program
- Provides a Safety Evaluation Report to member Agencies, the NASA Administrator, OSTP and the American Public upon approval
- Dissolved after mission cancelled or after launch when there is NO chance of mission return to earth (in writing from empanelling Agency Head)

Mars Science Laboratory (MSL) Interagency Nuclear Safety Review Panel (INSRP)

DoD:	**Sayavur I. Bakhtiyarov, Ph.D., D.Sc.**
DOE:	**James M. Heffner**
EPA:	**Samuel W. Poppell, Jr**
NASA:	**Peter G. Prassinos**
NRC:	**Gary M. DeMoss**

INSRP Subject Areas, Steps, and Activities

DoD NASA	LAUNCH ABORT and REENTRY	Accident Environment Definition	Accident Scenarios Accident Probabilities Accident Environments
DoD	POWER SYSTEMS	Source Term	Conditional Release Probabilities Source Term Amount & Location Particle Size Distribution Vaporization & Agglomeration
NASA	METEOROLOGY	Environmental Transport	Meteorology Data Sets Atmospheric Transport - Dispersion Environmental Contamination
NASA	BIOMEDICAL & ENVIRONMENTAL EFFECTS	Radiological Consequences	Radiological Doses Health Effects
NASA	RISK INTEGRATION	Risk Analysis	Risk Integration Uncertainty Analysis
Multi Agencies	INSRP COORDINATORS	Risk Quantification	Manage and Direct INSRP Process Mission Risk Evaluation SER

The MSL INSRP…

Provides an independent evaluation of the NASA/DOE analysis of radiological risk associated with the MSL Mission

Conducts in-depth reviews of:

- MSL Safety Analysis Report Databook (10/06)
- MSL Safety Analysis Report Databook Revision A (10/07)
- MSL Safety Analysis Report Databook Revision B (02/10)
- Preliminary Safety Analysis Report (PSAR) for MSL MMRTG Launch Approval (11/06)
- Draft SAR for the MSL MMRTG Launch Approval (11/07)
- Draft Uncertainty Analysis for the MSL MMRTG Launch Approval DSAR (12/08)
- Final SAR for the MSL MMRTG Launch Approval (07/08)
- FSAR for the MSL MMRTG Launch Approval, Addendum (04/10)
- FSAR for the MSL MMRTG Launch Approval, Addendum Update (09/10)

Supporting tests, simulations/analyses and documentation

Produced the Safety Evaluation Report for the 2011 Lunch of the MSL

MSL INSRP Results

Likelihood of an Accident

- Mean Likelihood of an accident ~ 1 in 32
- Mean Probability of Release given an Accident
  ~ 1 in 10
- Accidents in the first 50 seconds of flight have a relatively high likelihood of plutonium release

The Overall Mission Risk is Comparable between the INSRP and FSAR

Total Likelihood of Plutonium Release

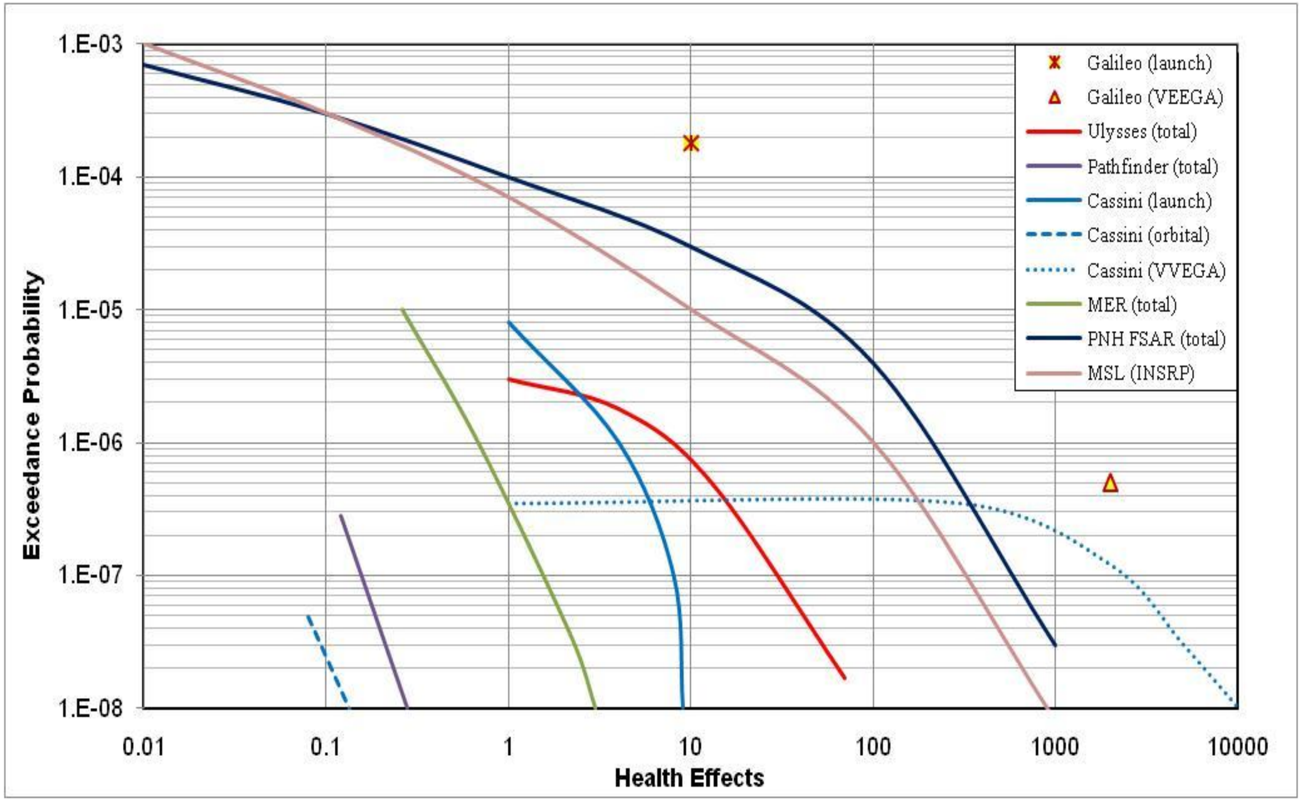
Mission Phases			Total Probability of Release
Phase Designation and Timing		No. of RASs*	
0	Pre-launch [-8 days to -2.7 sec]	1	1.8E-05
1	Early Launch [-2.7 to 50.1 sec]	9	2.8E-03
2	Late Launch [50.1 to 87.6 sec]	2	6.8E-06
3	Sub-Orbital [87.6 to 688.4 sec]	3	6.7E-05
4	Orbital [866.4 to 2607.1 sec]	1	3.4E-04
5	Long Term Return [after 2980.2 sec]	1	2.0E-07

RAS = Representative Accident Scenarios

Total Mission Mean Probability of Release of MMRTG Fuel ~ 1 in 312

Note: These are FSAR values. MSL INSRP estimate of the Total Probability of Release is 1 in 320

Comparison of the Risk Analysis Results for Past Nuclear Missions



Note: VEEGA=Venus, Earth, Earth Gravity Assist; VVEGA= Venus, Venus, Earth Gravity Assist

Risk estimates for missions differ because of:

- Varying quantities of radioactive material
- Varying mission configurations and trajectories
- Database differences
- Different time of year for launch
- Improvements in fidelity for analytical methods and models

DoD INSRP Working Groups

- The Launch Abort Working Group (LAWG) has been responsible for conducting an independent review and evaluation of the safety analyses prepared by the NASA's Jet Propulsion Laboratory (JPL) and the Department of Energy(DOE) for the plutonium dioxide based Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to be used for the MSL mission.

- The Power Systems Working Group (PSWG) independently evaluated the response of the space nuclear power source to the mechanical and thermal insult environments that might occur as a result of a Launch or reentry accident scenario and develops appropriate radiological release estimates and characterizations for use by other INSRP working groups. Under MSL project, Sandia National Laboratories (SNL) supported the DoD INSRP coordinator by performing the functions of the PSWG, including providing its leadership, arranging for its membership, and performing and documenting its assessments.

Launch Approval Process

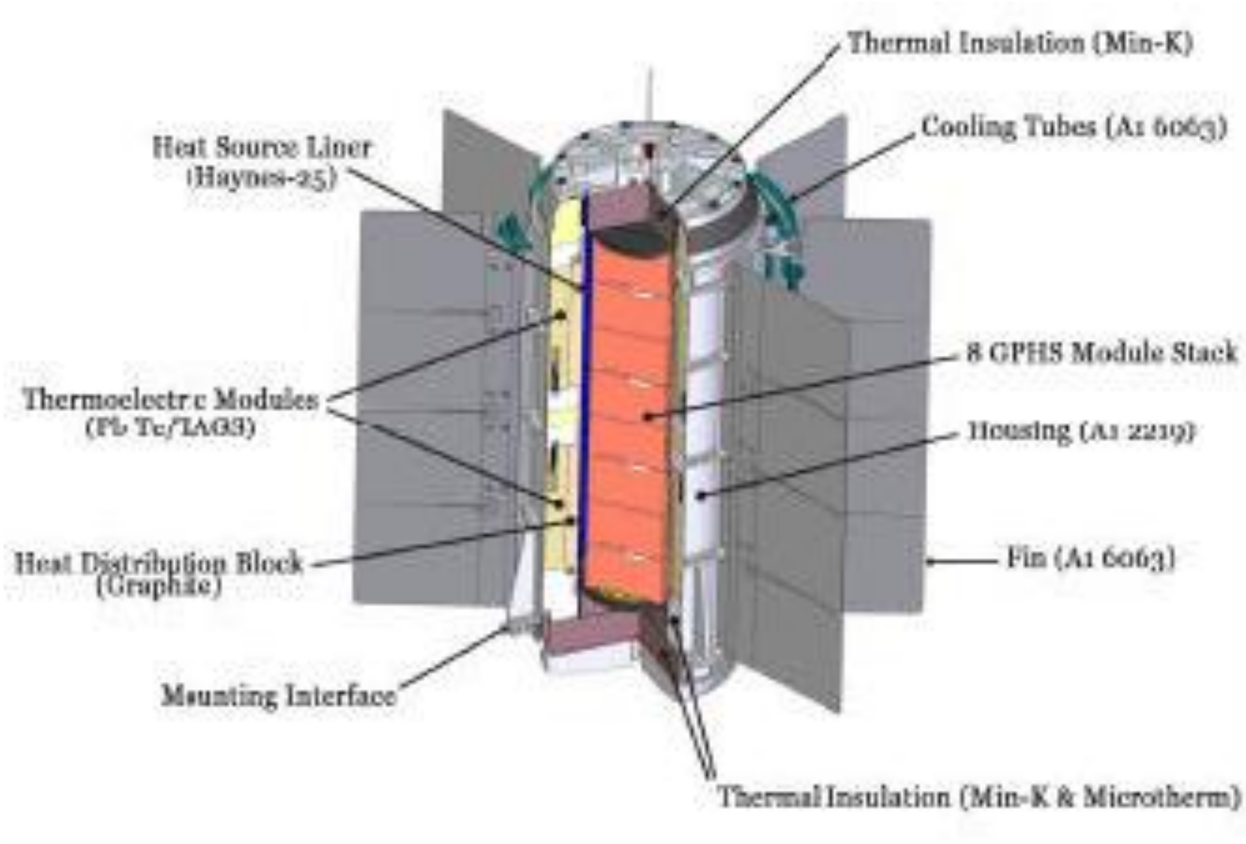
- INSRP has completed reviewing final version of Atlas V –541 MSL Databook and Final Safety Analysis Report (Addendum Update) from the Program
- INSRP completed Safety Evaluation Report and delivered to OSTP October 2010
- Supplementary Technical Information Volumes were prepared
- Provide each Working Group's detailed analysis and review
- Follow-on Agency, State briefings in work
- OSTP review and consideration for launch approval Summer 2011
- Range Safety processed any waivers and brought forward for consideration/acceptance
- Radiological Contingency Exercises Spring 2011
- Launch window opens 26 November 2011

Atlas V Launch History

Launch Date	Type	Tail Number	Site	Payload	Outcome
August 21, 2002	401	AV-001	LC-41	Hot Bird 6	Success
May 13, 2003	401	AV-002	LC-41	HellasSat 2	Success
July 17, 2003	521	AV-003	LC-41	Rainbow 1	Success
December 17, 2004	521	AV-005	LC-41	AMC 16	Success
March 11, 2005	431	AV-004	LC-41	Inmarsat 4-F1	Success
August 12, 2005	401	AV-007	LC-41	Mars Reconnaissance Orbiter	Success
January 19, 2006	551	AV-010	LC-41	Pluto New Horizons	Success
April 20, 2006	411	AV-008	LC-41	ASTRA 1KR	Success
March 8, 2007	401	AV-013	LC-41	Space Test Program-1	Success
June 15, 2007	401	AV-009	LC-41	NRO L-30R	Partial Failure [1]
October 11, 2007	421	AV-011	LC-41	WGS SV-1	Success
December 10, 2007	401	AV-015	LC-41	NRO L-24	Success
March 13, 2008	411	AV-006	SLC-3E	NROL-28 (1st Atlas V @ VAFB)	Success
April 14, 2008	421	AV-014	LC-41	ICO G1	Success
April 4, 2009	421	AV-016	LC-41	WGS SV2	Success
June 18, 2009	401	AV-020	LC-41	LRO/LCROSS	Success
September 8, 2009	401	AV-018	LC-41	PAN	Success
October 18, 2009	401	AV-017	SLC-3E	DMSP 5D3-F18	Success
November 23, 2009	431	AV-024	LC-41	Intelsat 14	Success
February 11, 2010	401	AV-021	LC-41	SDO	Success
April 22, 2010	501	AV-012	LC-41	X-37B OTV-1	Success
August 14, 2010	531	AV-019	LC-41	AEHF-1	Success
September 20, 2010	501	AV-025	SLC-3E	NROL-41	Success

[1] LOx valve failure during coast prior to Centaur second stage burn considered failure that led to mission not reaching desired orbit

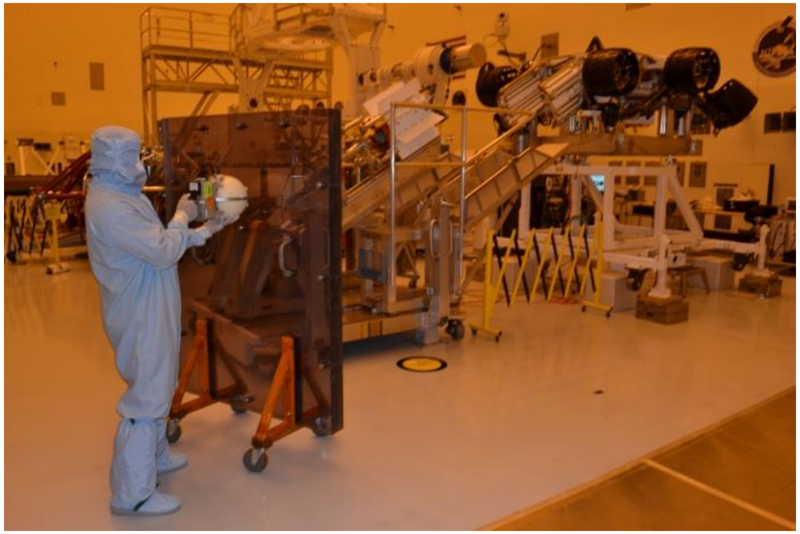
Multi-Mission RTG (MMRTG)*



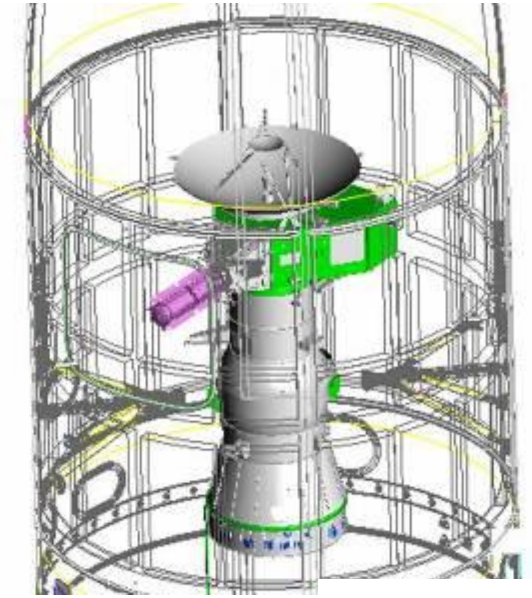
- Electrical Output - ≥110 watts
- Fuel Loading – 4.8 kg PuO_2 (~59,000 Ci)
- Weight – 45 kg
- Dimensions – 69 cm (length) x 65 cm (diameter)

* As described in Final Programmatic Environmental Impact Statement for the Development of Advanced Radioisotope Power Systems, NASA, September 2006

Light Weight Radioisotope Heater Units (LWRHUs)



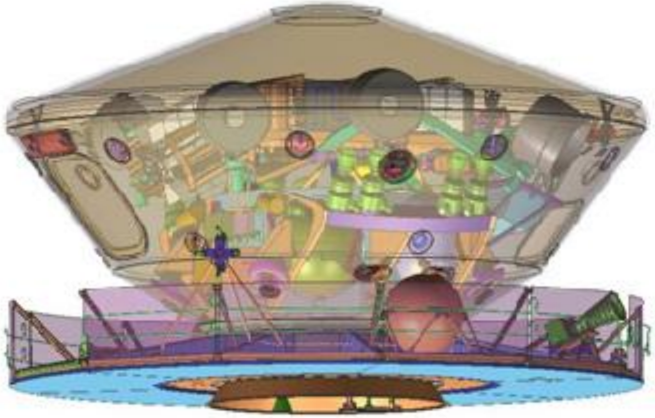
RTG Locations



Pluto New Horizons RTG

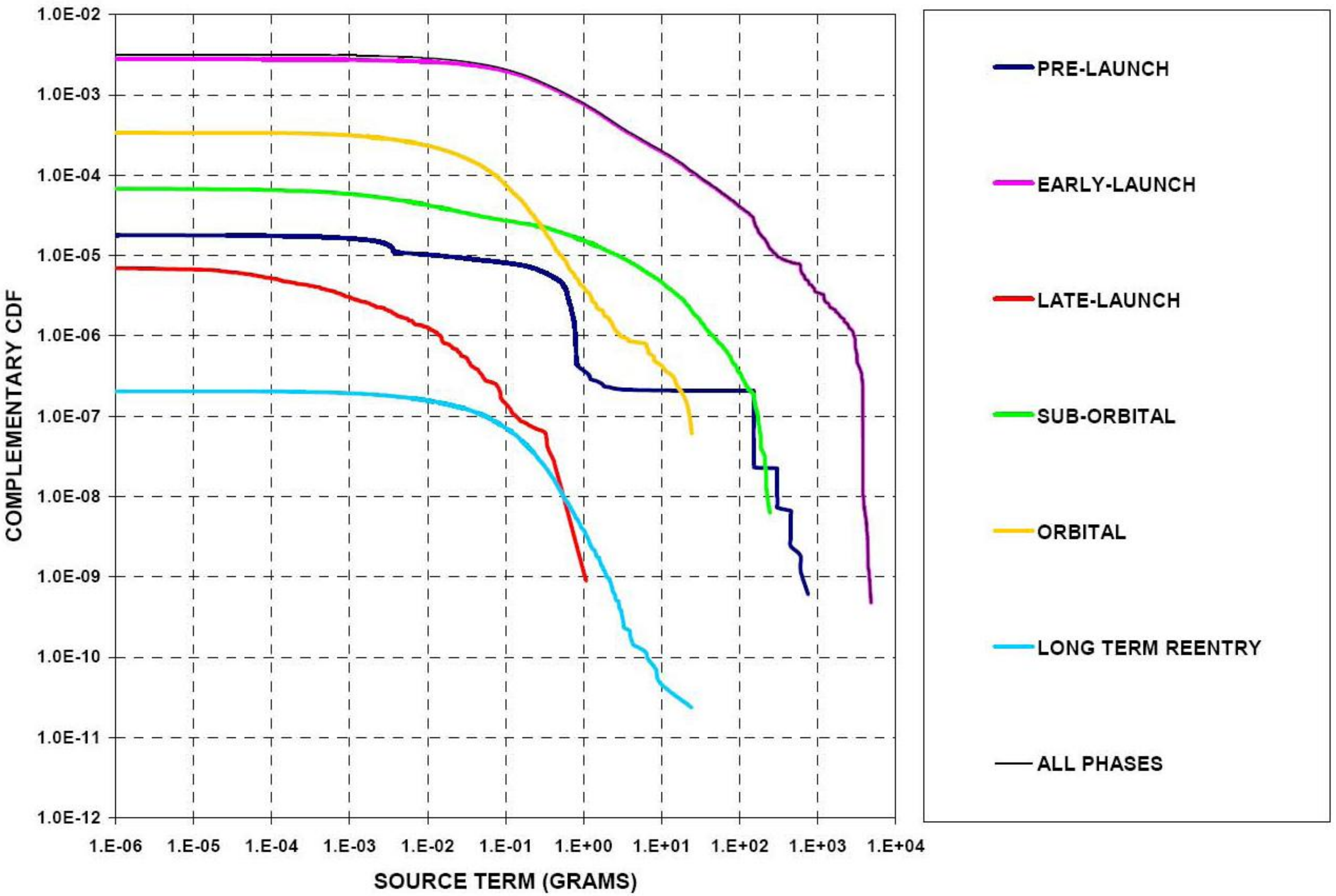
Cassini RTG (1 of 3)

MSL MMRTG

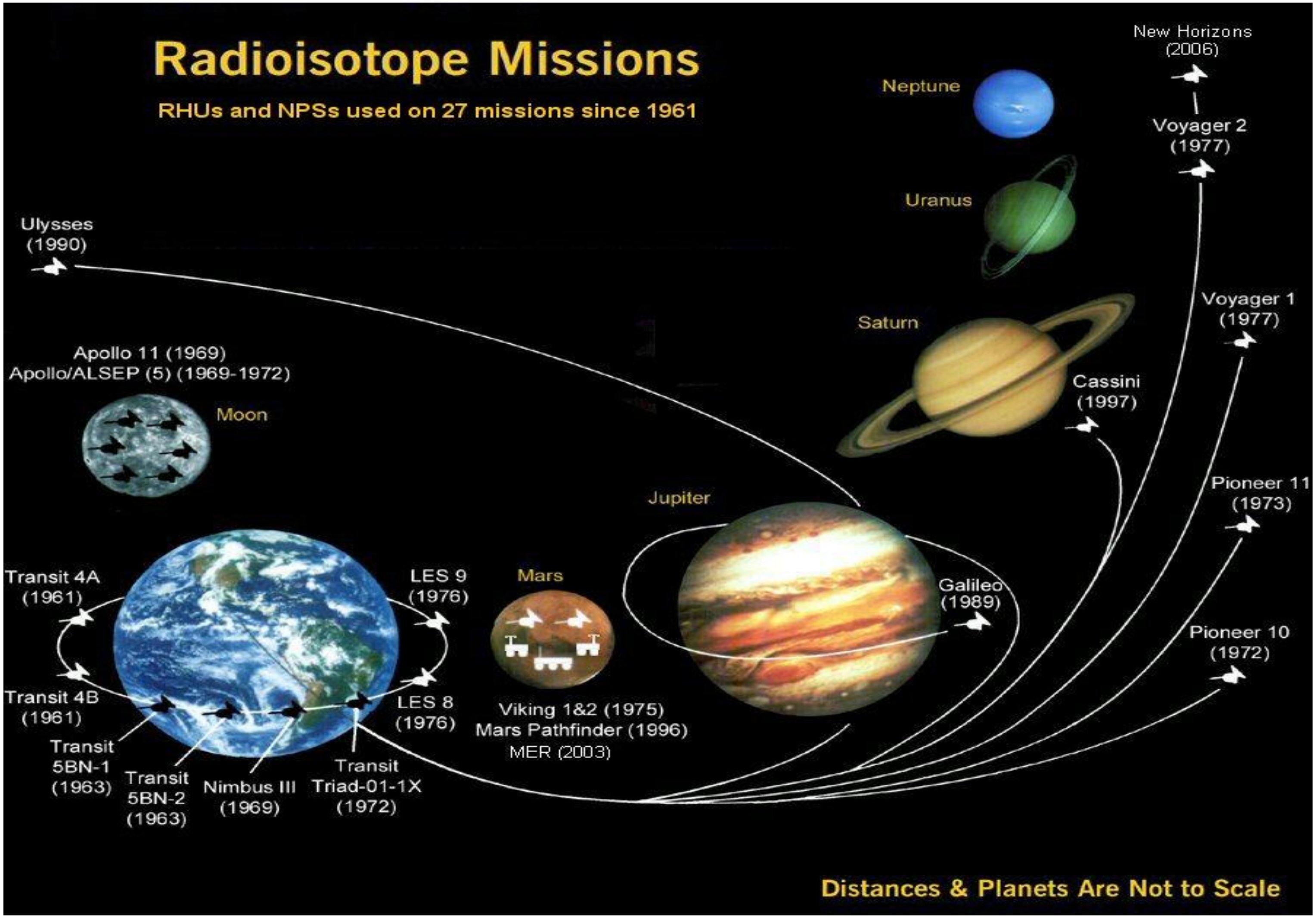


Source Terms

Complementary Cumulative Distribution Function (CCDF)



Past/Current U.S. Applications of Space NPS



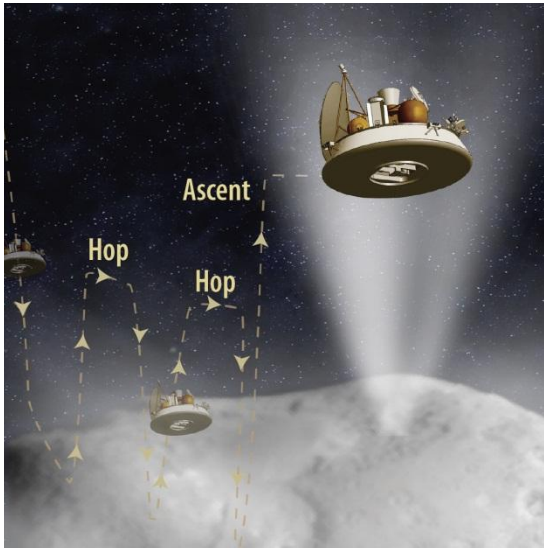
Gale Crater Vista

Future Space Nuclear Applications

The planetary missions selected to pursue preliminary design studies

- Geophysical Monitoring Station (GeMS) would study the structure and composition of the interior of Mars and advance understanding of the formation and evolution of terrestrial planets. Bruce Banerdt of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif., is principal investigator. JPL would manage the project.
- Titan Mare Explorer (TiME) would provide the first direct exploration of an ocean environment beyond Earth by landing in, and floating on, a large methane-ethane sea on Saturn's moon Titan. Ellen Stofan of Proxemy Research Inc. in Gaithersburg, Md., is principal investigator. Johns Hopkins University's Applied Physics Laboratory in Laurel, Md., would manage the project.
- Comet Hopper would study cometary evolution by landing on a comet multiple times and observing its changes as it interacts with the sun. Jessica Sunshine of the University of Maryland in College Park is principal investigator. NASA's Goddard Space Flight Center in Greenbelt, Md., would manage the project.

Comet Hopper (CHopper) will orbit and land multiple times on the Comet Wirtanen as it approaches the Sun.



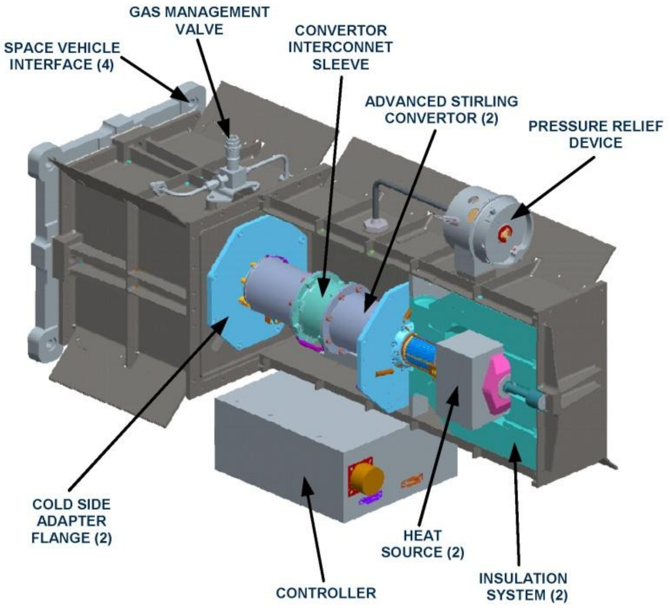
The CHopper mission goals are rendezvous with Comet Wirtanen (at 4.5 AU) and map the spatial heterogeneity of gas and dust emissions from the coma as well as surface solids.

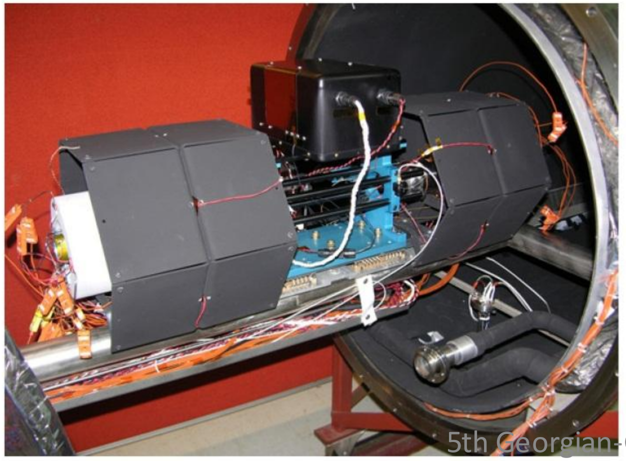
TiME is an outer-planet mission that would directly measure the organic constituents on Titan (a Saturn moon) and perform the first nautical exploration of an extraterrestrial sea, analyze its nature and, if possible, a shoreline.

Advanced Stirling Radioisotope Generator (ASRG) is meant to provide availability of long-lived power supplies for landed networks and other planetary missions.

Specifications

- ≥14 year lifetime
- Nominal power : 140 W
- Mass ~ 28 kg
- System efficiency: ~ 30 %
- Two GPHS 238 Pu modules
- Uses 0.8 kg plutonium-238 (Pu^{238})





The proposals selected for technology development

- Primitive Material Explorer (PriME) would develop a mass spectrometer that would provide highly precise measurements of the chemical composition of a comet and explore the objects' role in delivering volatiles to Earth. Anita Cochran of the University of Texas in Austin is principal investigator.

- Whipple: Reaching into the Outer Solar System would develop and validate a technique called blind occultation that could lead to the discovery of various celestial objects in the outer solar system and revolutionize our understanding of the area's structure. Charles Alcock of the Smithsonian Astrophysical Observatory in Cambridge, Mass., is principal investigator.

- NEOCam would develop a telescope to study the origin and evolution of NEOs and study the present risk of Earth-impact. It would generate a catalog of objects and accurate infrared measurements to provide a better understanding of small bodies that cross our planet's orbit. Amy Mainzer of JPL is principal investigator.

ExoMars*

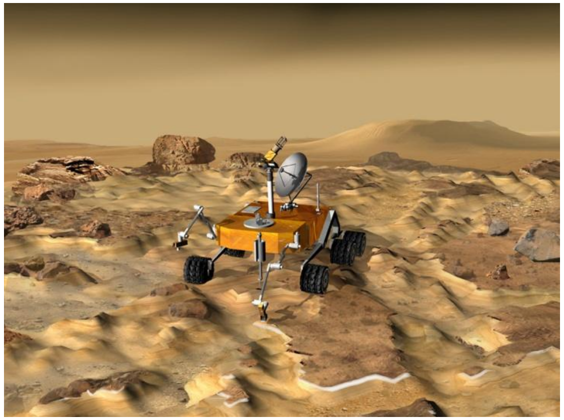
- Launch Date: TBD
- Objective: To further characterize the biological environment on Mars in preparation for robotic missions and then human exploration
- Type of NPS: Russian RHUs

Conceptual illustration

* http://www.esa.int/esaHS/SEM1NVZKQAD_exploration_0.html

Astrobiology Field Laboratory (AFL)*

- Launch Date: TBD
- Objective: AFL would conduct a robotic search for life. It would be the first mission since Viking in the 1970s to look specifically for evidence of past or present life. The robotic lab would carry instruments for identifying and measuring the chemical building blocks for life (as we know it), including thousands of carbon-carrying compounds, elements such as sulfur and nitrogen, and oxidation states of trace metals associated with life. It would conduct detailed analysis of geologic environments identified by the 2009 Mars Science Laboratory as being conducive to life.
- Type of NPS: MMRTG

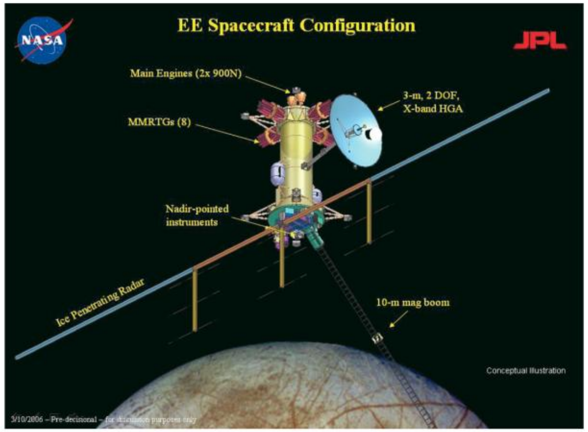


Conceptual illustration

* http://mars.jpl.nasa.gov/missions/future/future Missions.html and http://solarsystem.nasa.gov/missions/profilecfm?MCode=MAFL

Europa Explorer*

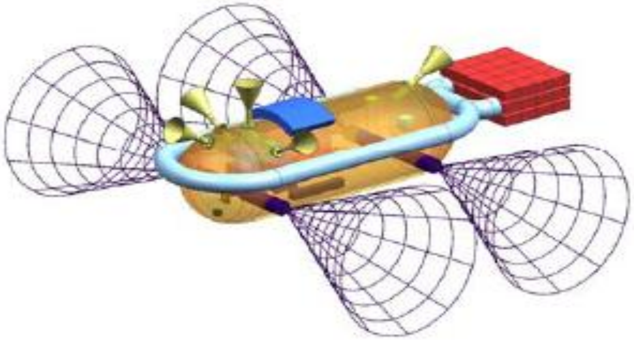
- Launch: TBD
- Objective: The Europa Geophysical Explorer Mission is a Design Reference Mission that would examime Europa's subsurface oceans and would search for possible landing sites for future missions. Researches would study the 3D distribution of subsurface liquid water and the overlying ice layer. EGE would also examine past and current surface activities, and the formation of surface features.
- Type of NPS: MMRTG



* http://solarsystem.nasa.gov/missions/profile.cfm?MCode=EGE

Venus Surface Explorer*

- Launch: TBD
- Objective: The Venus Surface Explorer (VSE) is a Design Reference Mission that would study the composition and isotopic measurements of Venus's surface and atmosphere. Plans call for the spacecraft to operate in the surface environment of Venus for at least 90 days. The Venus Surface Explorer would test key technologies for other Venus Missions, such as the Venus Surface Sample Return Mission (VSSR).
- Type of NPS: RPS

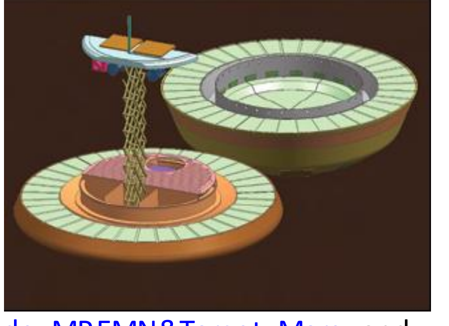


Conceptual illustration

* http://solarsystem.nasa.gov/missions/profile.cfm?MCode=VenusSE

Mars Planetary Evolution and Meteorology (Multi-Lander) Network *

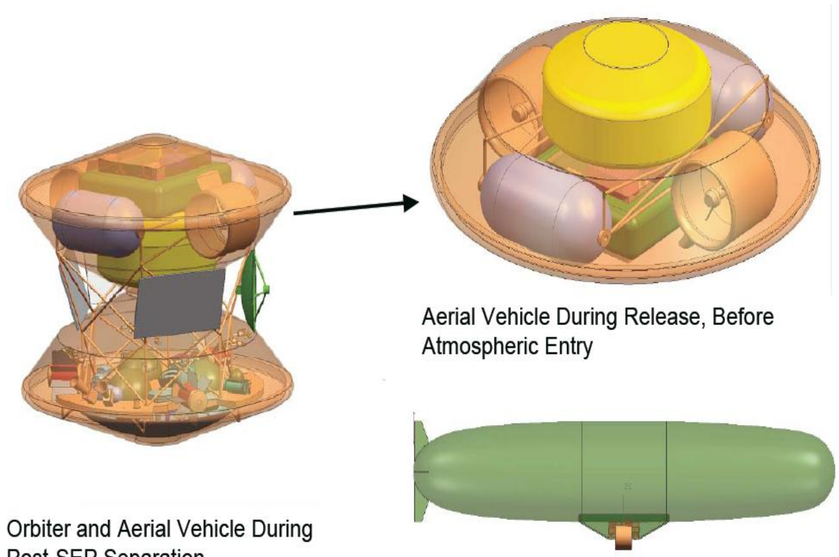
- Launch: TBD
- Objective: The Mars Planetary Evolution and Meterology (multi-lander) network would carry the instruments capable of performing essential measurements with a network of at least four static landers. The network would include seismic, heat flow, and planetary rotation measurements at a large number of sites to return fundamental information on the structure and processes of the interior. This network would also include many of the required capabilities for global meteorology.
- Type of NPS: RHUs and possible RPS



* http://sse.jpl.nasa.gov/missions/profile.cfm?Sort=Chron&StartYear=2010&EndYear=2040&MCode=MPEMN&Target=Mars and http://mepag.jpl.nasa.gov/reports/3715_Mars_Expl_Strat_GPO.pdf

Titan Explorer*

- Launch: Earliest Possible is 2025
- Objective: The Titan Explorer with Orbiter Mission is a Design Reference Mission that would map Titan with high-resolution radar, and would study pre-biotic chemistry and potential for life.
- Type of NPS: RPS



Orbiter and Aerial Vehicle During Post-SEP Separation

Aerial Vehicle During Release, Before Atmospheric Entry

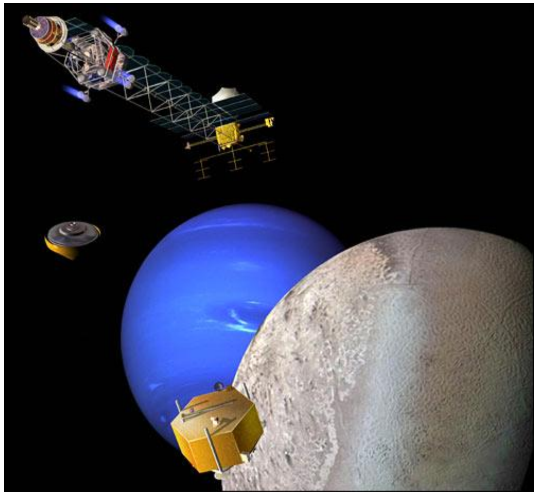
Aerial Vehicle During Deployment

Conceptual illustration

* http://solarsystem.nasa.gov/missions/profile.cfm?MCode=TE

Neptune Orbiter*

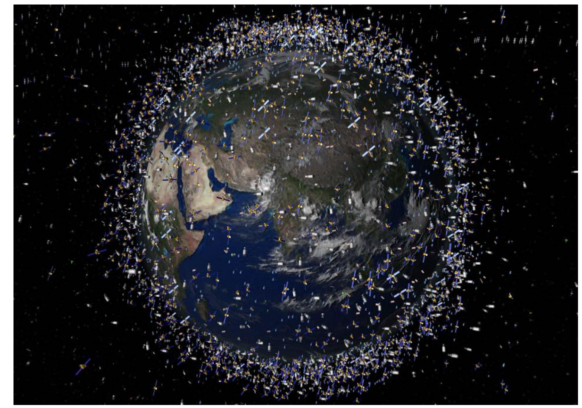
- Launch: Earliest Possible is 2035
- Objective: Neptune Orbiter is envisioned to answer many questions that still surround the planet. Its main mission would be to study Neptune's atmosphere and weather, its ring system, and its moons, particularly Triton.
- Type of NPS: RPS possible use of nuclear fission reactor propulsion system.

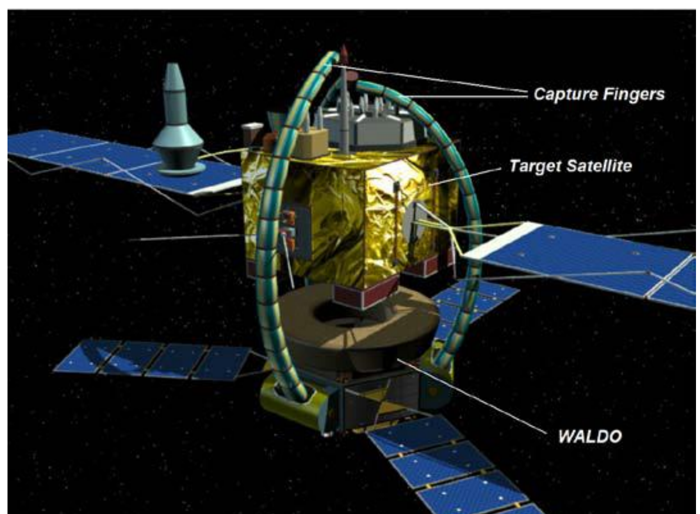


Conceptual illustration

* http://solarsystem.nasa.gov/missions/profile.cfm?MCode=TE

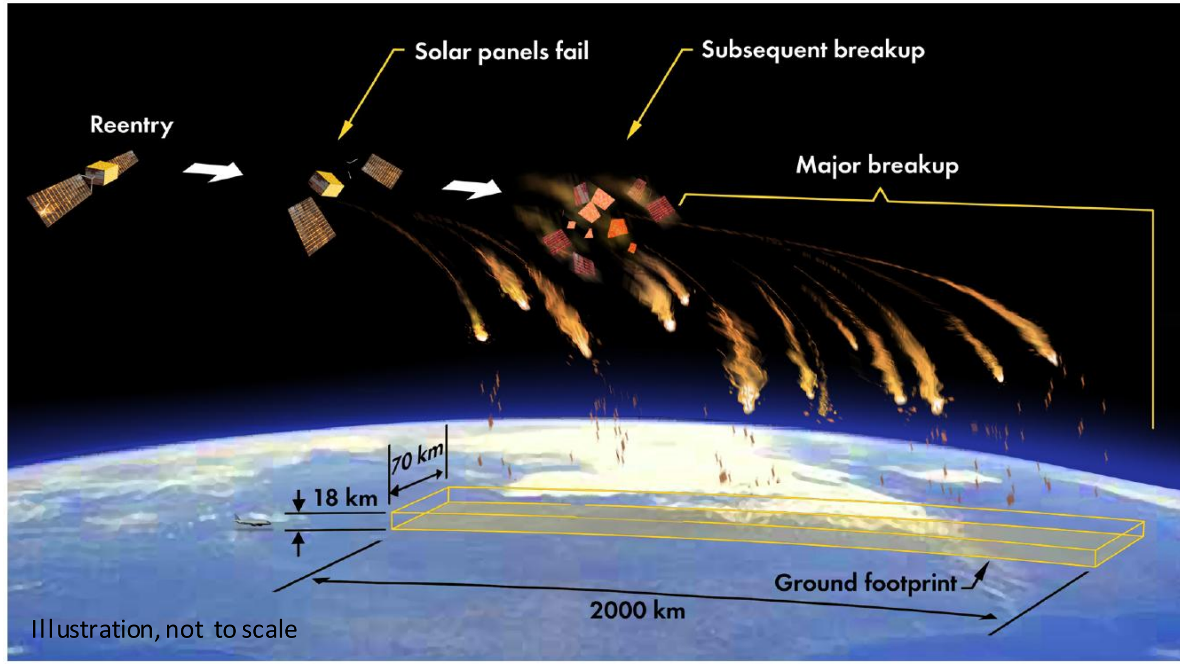
Research and Developments Supported by DoD INSRP AF SEC





Reentry Breakup Basics

- Space hardware reenters at very shallow angle (<1 degree)
- ~40 objects weighing more than 1 ton reenter randomly per year
- Major breakup at ~42 nmi (78 km)
- 10 to 40% of dry mass on orbit survives and impacts the Earth's surface; poses hazard to people and property
- Debris spread over long, thin ground footprint



Some Examples of Recovered Debris

Texas, 1997

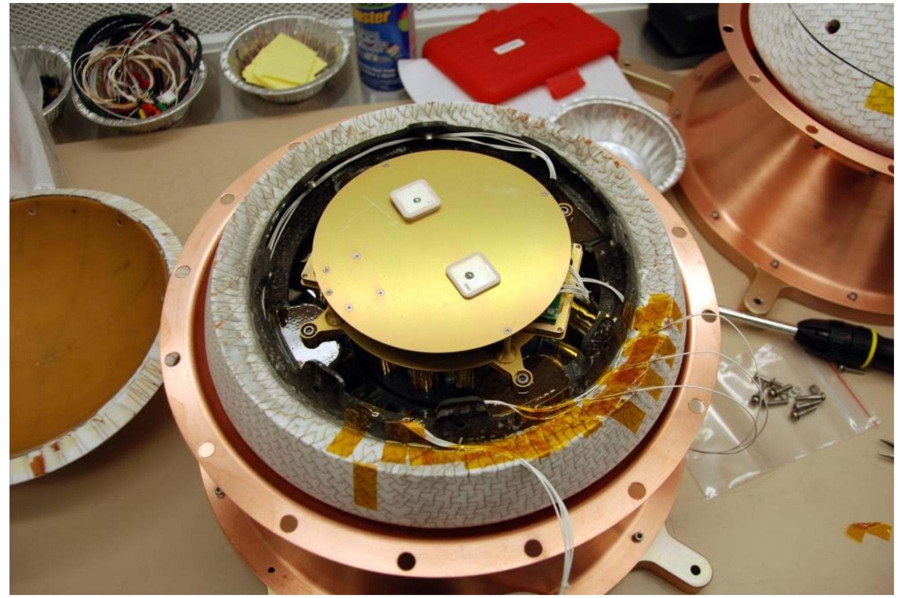
Oklahoma, 1997

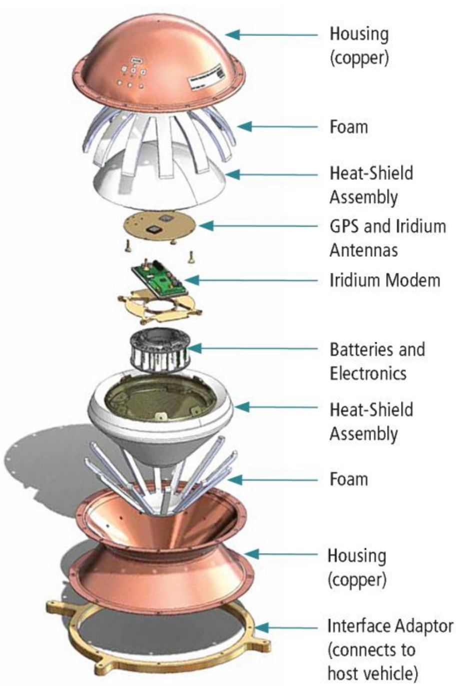
South Africa, 2000

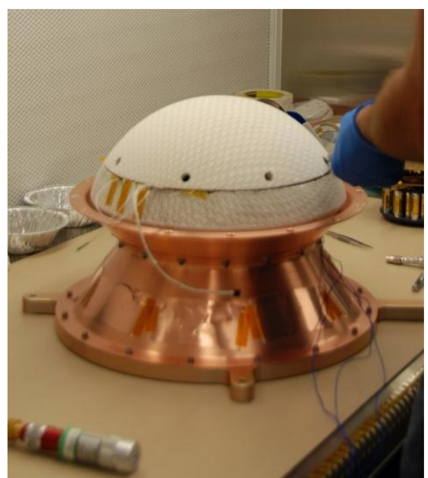
Saudi Arabia, 2001

Mongolia, 2010

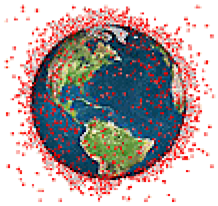
Reentry Breakup Recorder Hardware



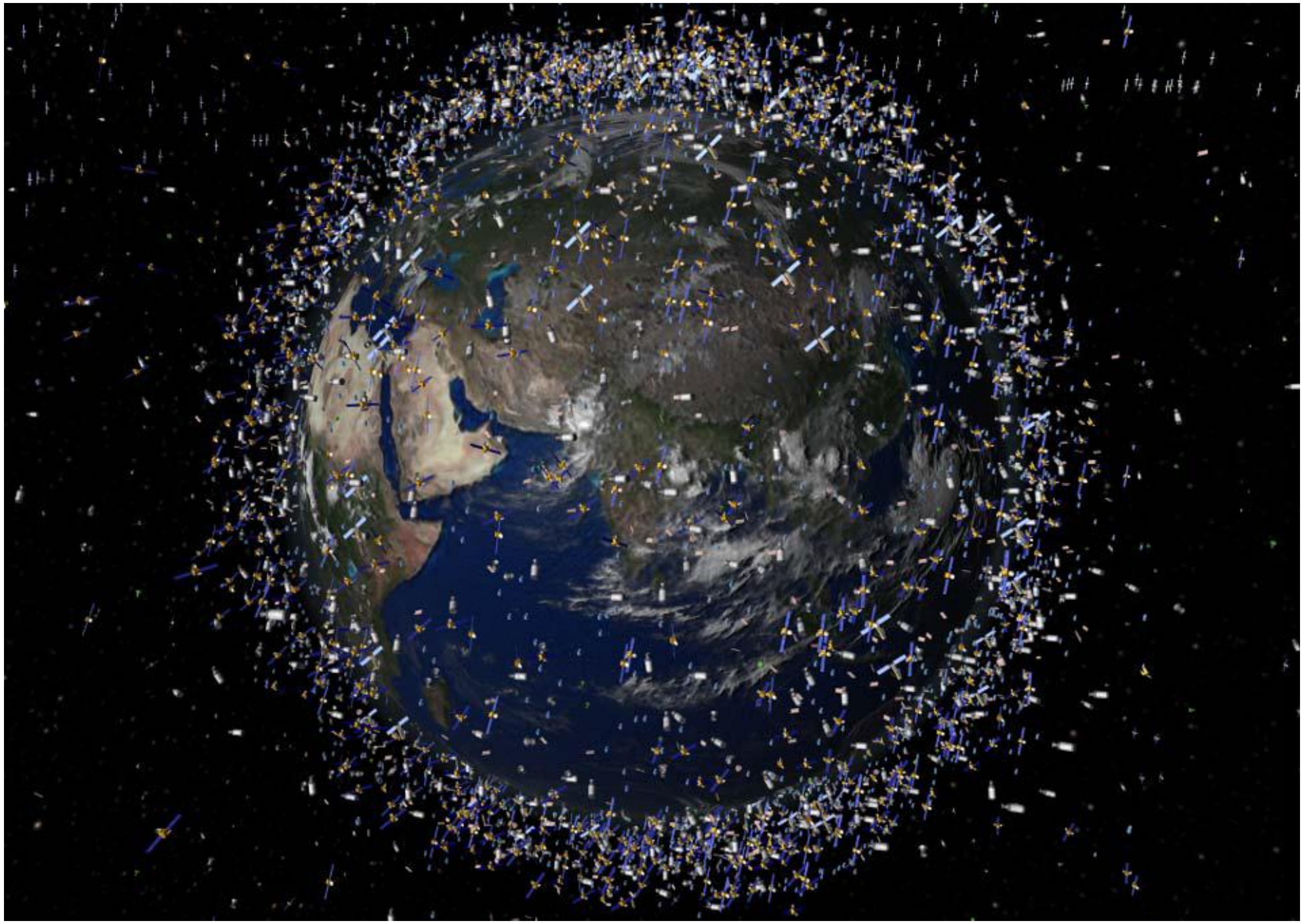




MITIGATING/REDUCING SPACE DEBRIS HAZARDS TO AIR FORCE SPACE SYSTEMS



- **The growth and evolution of the space debris environment**
- **The threat to manned and unmanned space systems is obvious especially to those that may carry nuclear materials**



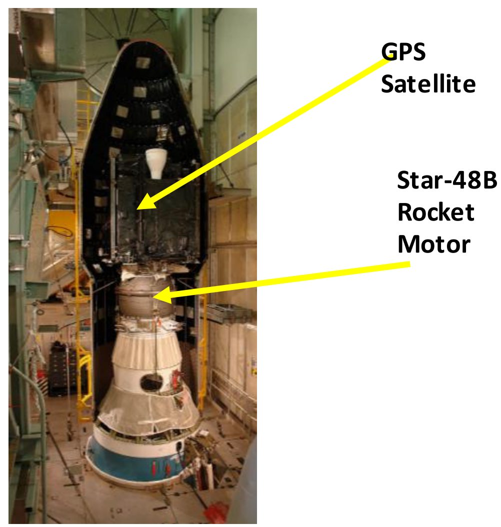
Homecomings…

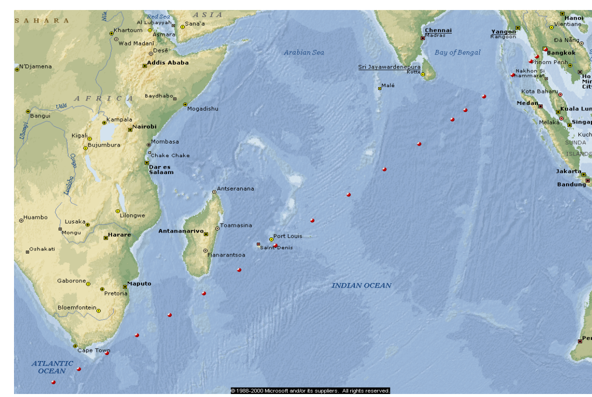
Shenzhou-8 Reentry Capsule Returns Home

Brazil. 1997 016C, an Ariane 43rd-stage rocket body reentered just off the coast of South America into the Pacific Ocean

Debris recovered after 1997 reentry of Delta II 2nd Stage used to launch AF MSX spacecraft

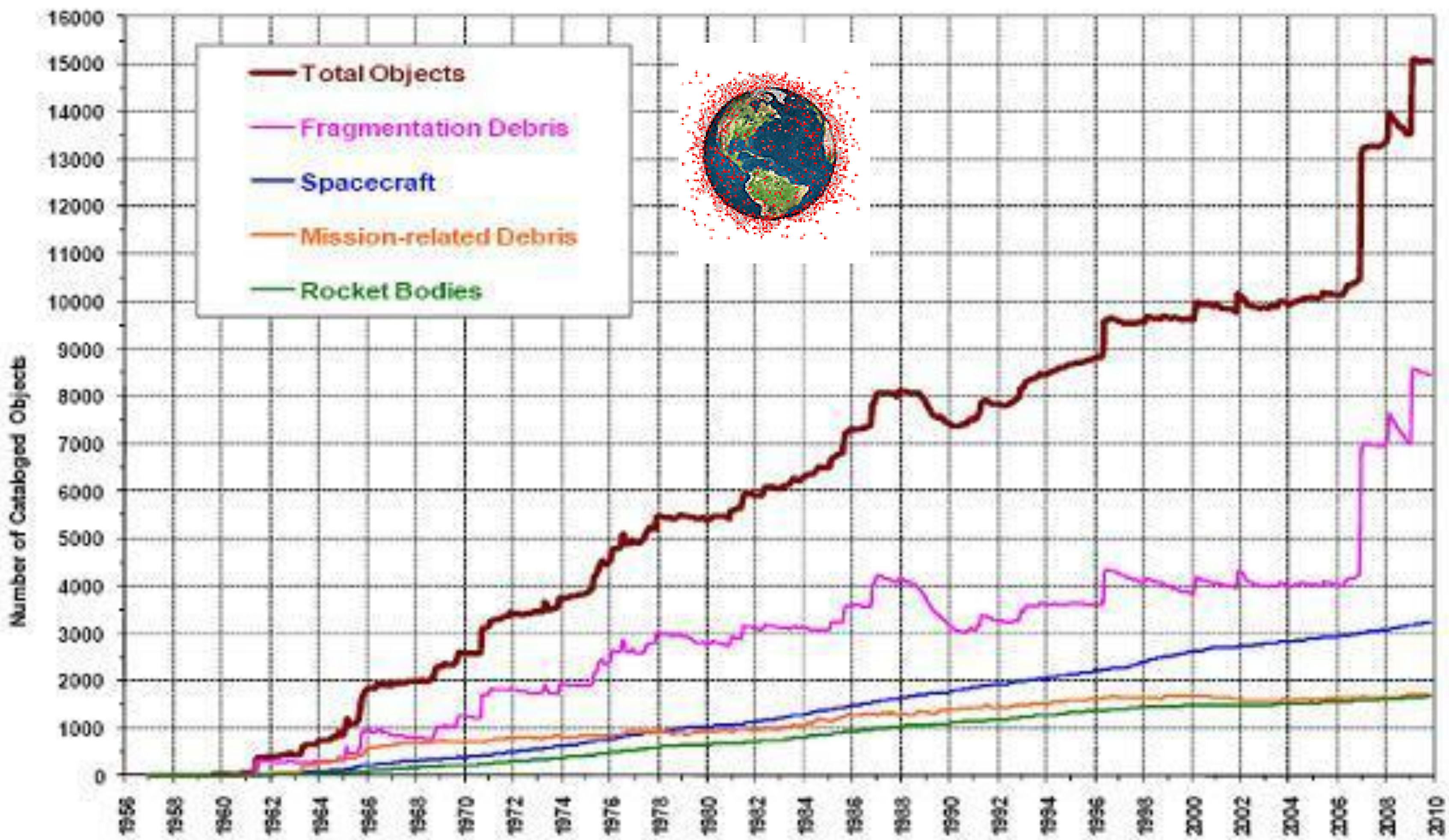
- Mission: GPS IIR-6
- Launched: 10 November 2000
- Debris recovered in Bangkok, Thailand





Reentry Trajectory

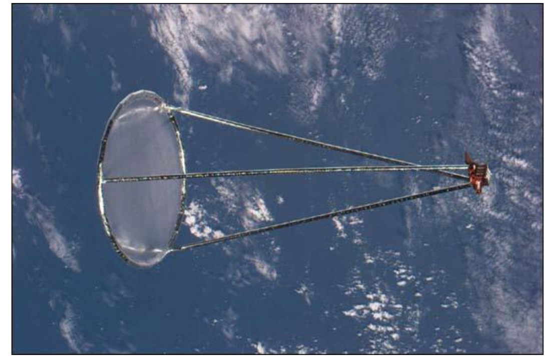
Number of catalogued objects in space over the last 54 years



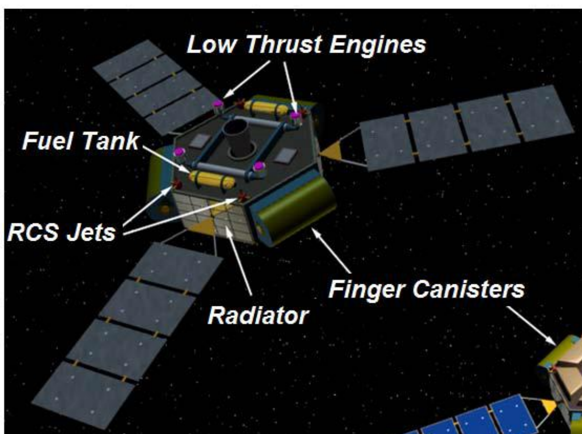
"WALDO" SYSTEM FOR REMOVAL OF LARGE ORBITAL DEBRIS

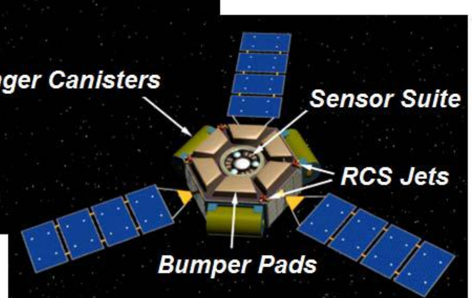
(Aerospace Corporation, USA)

Recovered propellant tank (left) and the gas pressurization tank from a spent Delta 2 second stage after surviving atmospheric entry. Courtesy of NASA

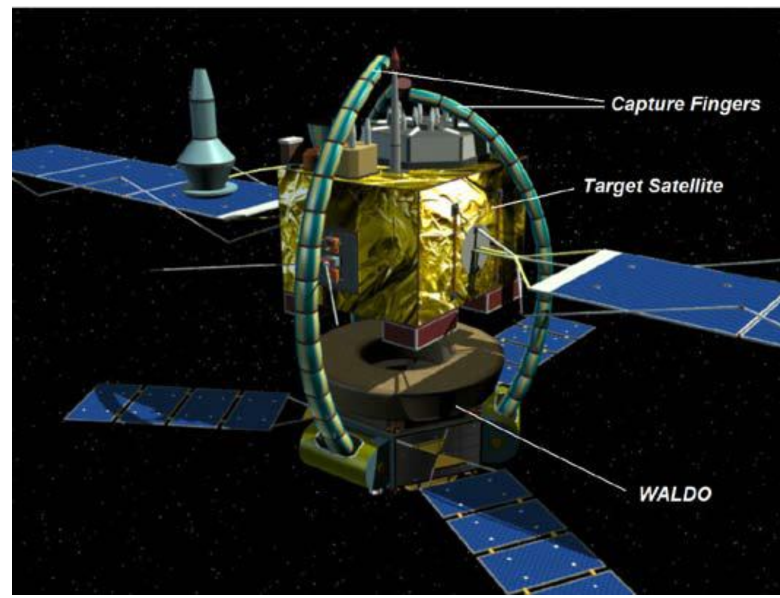


Inflatable antenna shown in the deployed condition in space





Main components of WALDO (Aerospace Corporation)



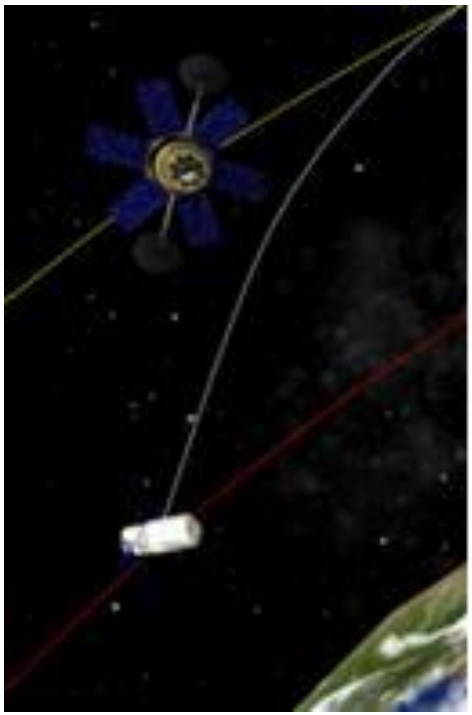
WALDO fingers deployed for soft embrace and capture of a target satellite

Waldo Animation.mov

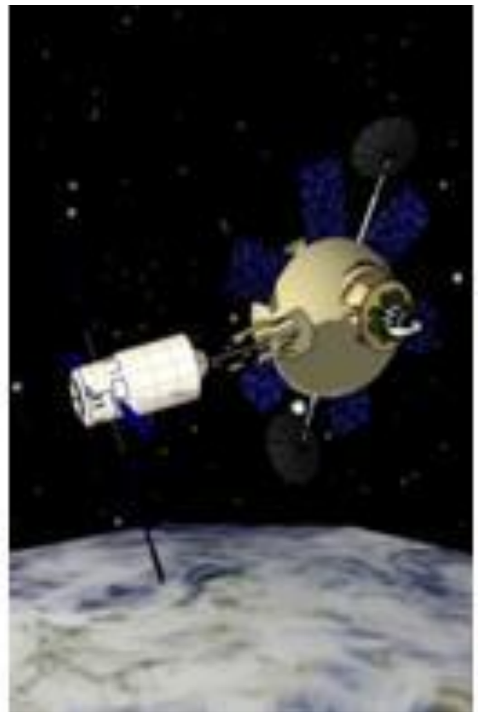
FOAM-BASED METHOD FOR ACTIVE SPACE DEBRIS REMOVAL

(University of Pisa, Italy)

Representation of the foam-based method



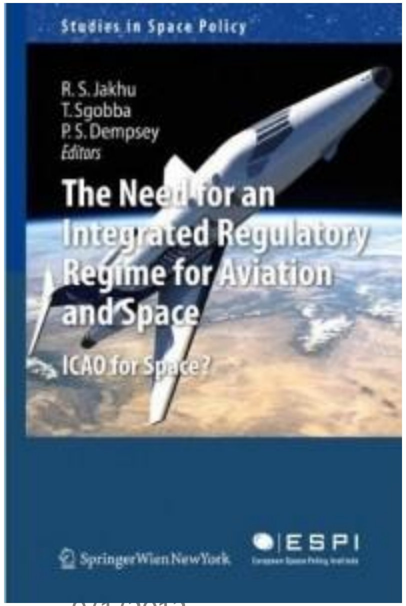
target debris interception

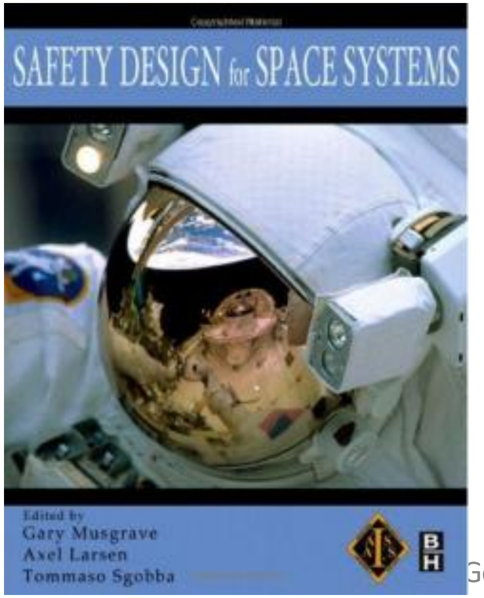


foaming process

debris deorbiting

International Activities in Space Safety





International Association for the Advancement of Space Safety (IAASS)

The International Association for the Advancement of Space Safety, legally established 16 April 2004 in the Netherlands, is a non-profit organization dedicated to furthering international cooperation and scientific advancement in the field of space systems safety.

Goals

1) advance the science and application of Space Safety

2) improve the communication, dissemination of knowledge and cooperation between interested groups and individuals in this field and related fields

3) improve understanding and awareness of the Space Safety discipline

4) promote and improve the development of Space Safety professionals and standards

5) advocate the establishment of safety laws, rules, and regulatory bodies at national and international levels for the civil use of space

Academic Degree and Certificate Programs in Space Safety

Educational Needs

- This decade will see:
  - Commercial human space transportation, and commercial space stations
  - Hybrid vehicles operating as aircraft and spacecraft for suborbital flights and later possibly for point-to-point transportation
  - The increasing space launch and re-entry traffic through the shared airspace due to commercial space activities
  - The emergence of space-based systems that are essential for aviation safety (navigation, communication)
  - The dissemination to aviation of data of common interest such as space weather forecast (for airlines on polar routes), and alerts on falling space debris

The safety of launch, on-orbit and re-entry operations, the safety of the aviation operations in the national and international airspace, space debris and the sustainability of the space environment, the integration of space and aviation situational awareness, will require space and aviation professionals with a solid background in system safety engineering, and knowledge of applicable regulations and standards.

Questions?

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