



Assessing Risks For The Launch Of Radioactive Materials

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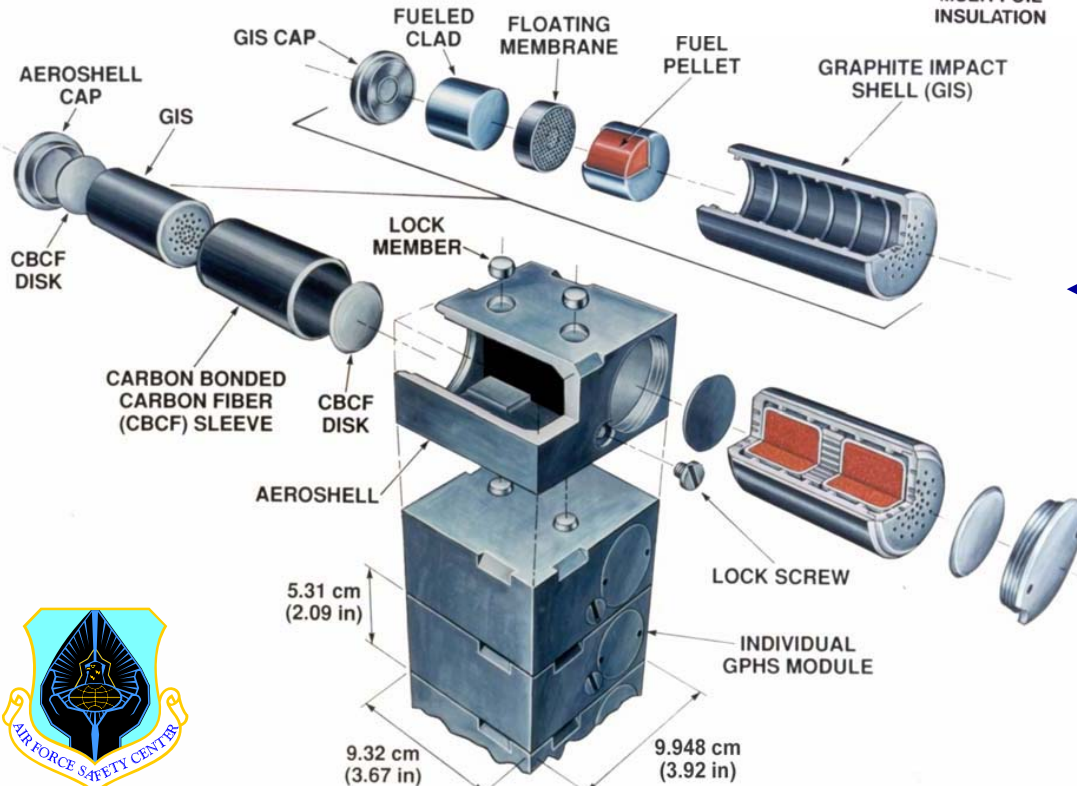
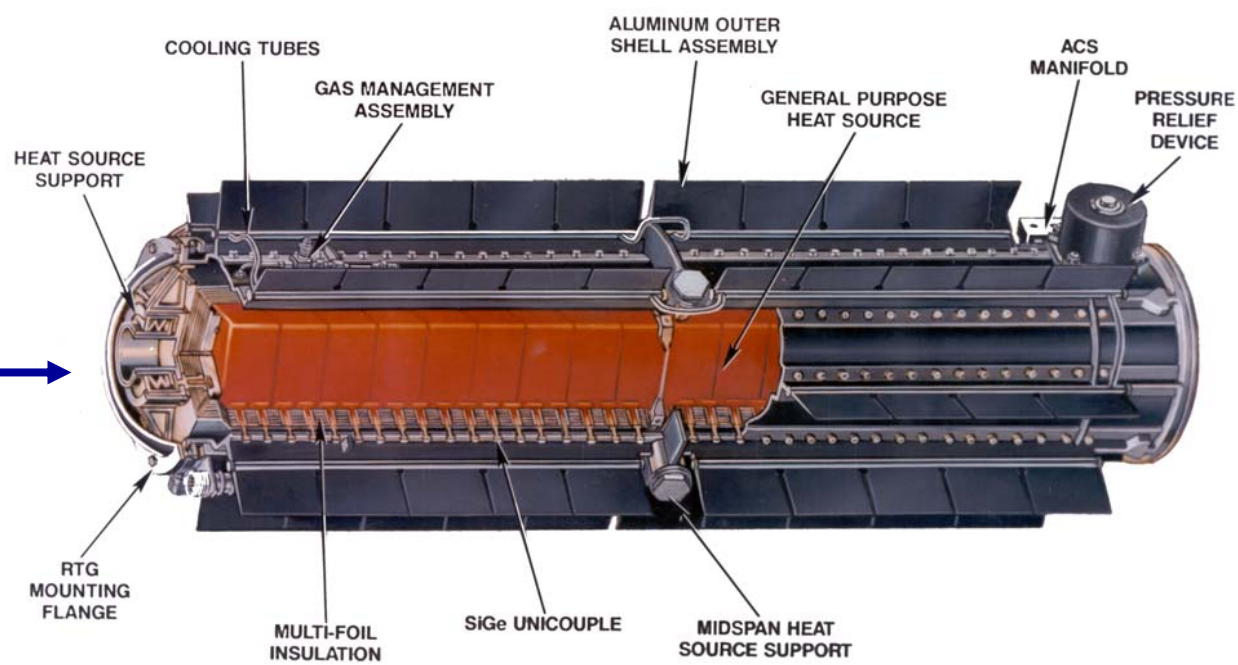
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Outline

- Risk Assessment for Nuclear Missions
- Launch Approval for Nuclear Missions
- Applications
 - The Pluto New Horizons Mission
 - The Proposed Mars Science Laboratory Mission
- Summary



Cutaway view of an RTG →

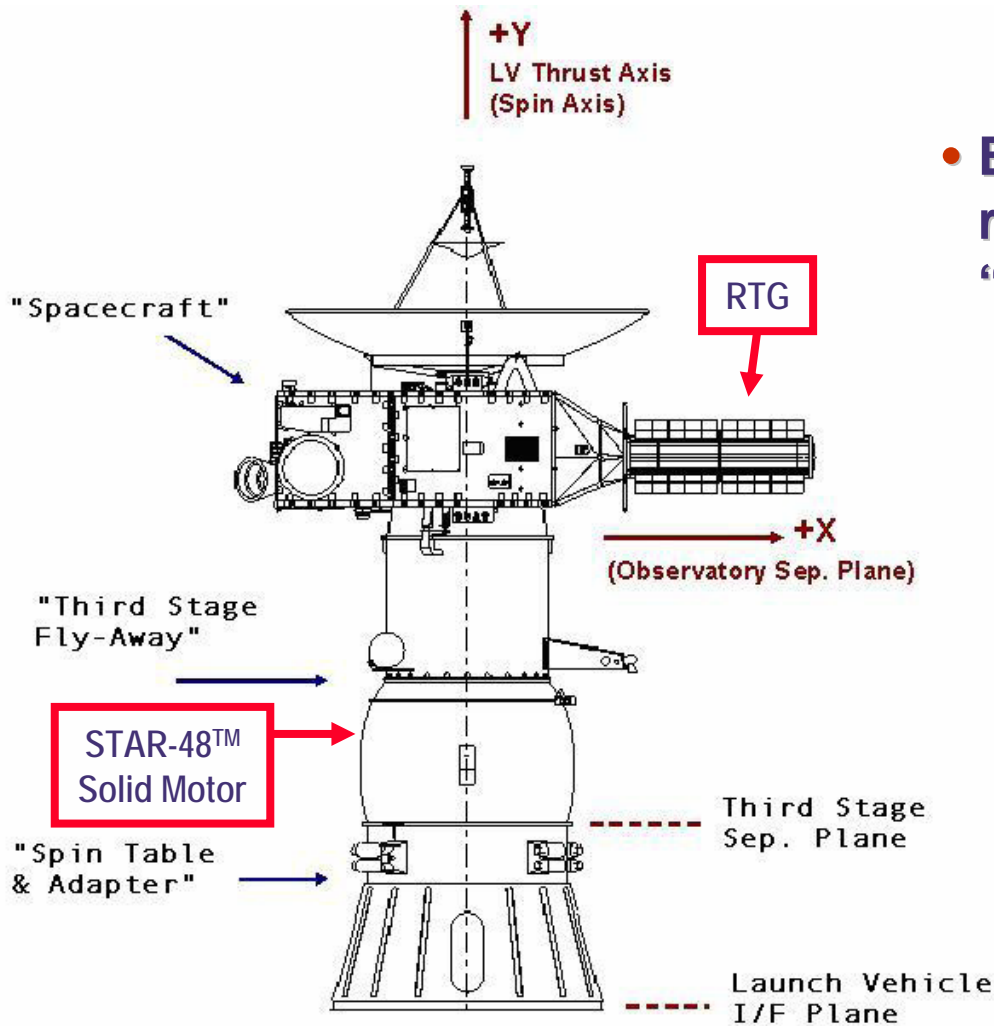


← **Cutaway view of a General Purpose Heat Source (GPMS) Module**

**(often called an "aeroshell")
18 modules are used in an RTG**



Typical Insult Environments

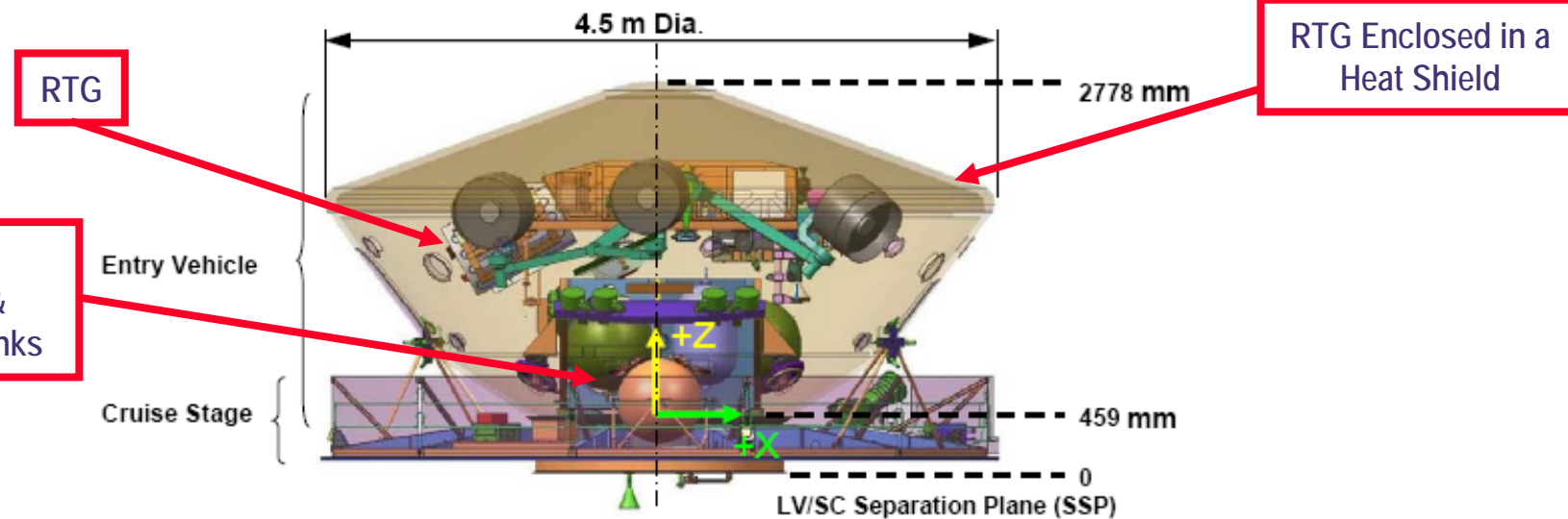


- Energy that can threaten the radioactive material is called an “insult environment”
 - **Overpressure**
 - Burning liquid propellants
 - **Thermal**
 - Burning liquid propellants
 - Burning solid propellants on ground
 - Heat of atmospheric reentry
 - **Impacts and Accelerations**
 - Launch vehicle fragments in air or on ground
 - Impact of material with ground
 - Deceleration of atmospheric reentry



Pluto New Horizons Spacecraft
(Launch Vehicle is Below)

Mission-Specific Insult Environments



Proposed Mars Science Laboratory Spacecraft
(Launch Vehicle is Below)

- Mission-specific characteristics can provide new insult environments
 - Unique placement of energetic materials
 - Mission profile features that challenge previous design or analysis assumptions

Accident Likelihood

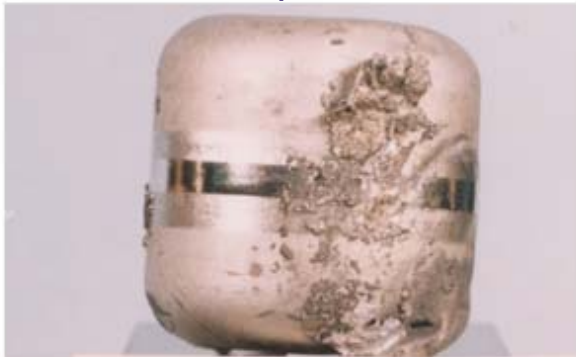
- **Identify insult scenarios**
 - Opportunities to apply insults to radioactive material or containment
 - Time-dependent between & within mission phases
- **Each mission is first-of-a-kind – how to assess scenario likelihood?**
 - Historical data – which prior accidents apply?
 - Component testing
 - Insult characterization experiments
 - Probabilistic risk assessment
- **Characterize $P(\text{accident})$, and $P(\text{insult} \mid \text{environment})$**



Radioactive Release Characterization

- **Release characteristics must be relevant to material transport and health effects calculations**
 - **P(Release | Insult) and amount (mass) of release**
 - **Chemical composition & particle size distribution**
 - **As released from the protective structure**
 - **As altered by the environment**
 - **Surrounding thermal environment (plume lofting)**
- **Experimental database is sparse**
 - **Strongly nonlinear function of insult type and magnitude**
 - **Significant uncertainties**

Example of clad radioactive material that has been breached during an impact test.



Radioactive Material Transport & Health Effects Estimation

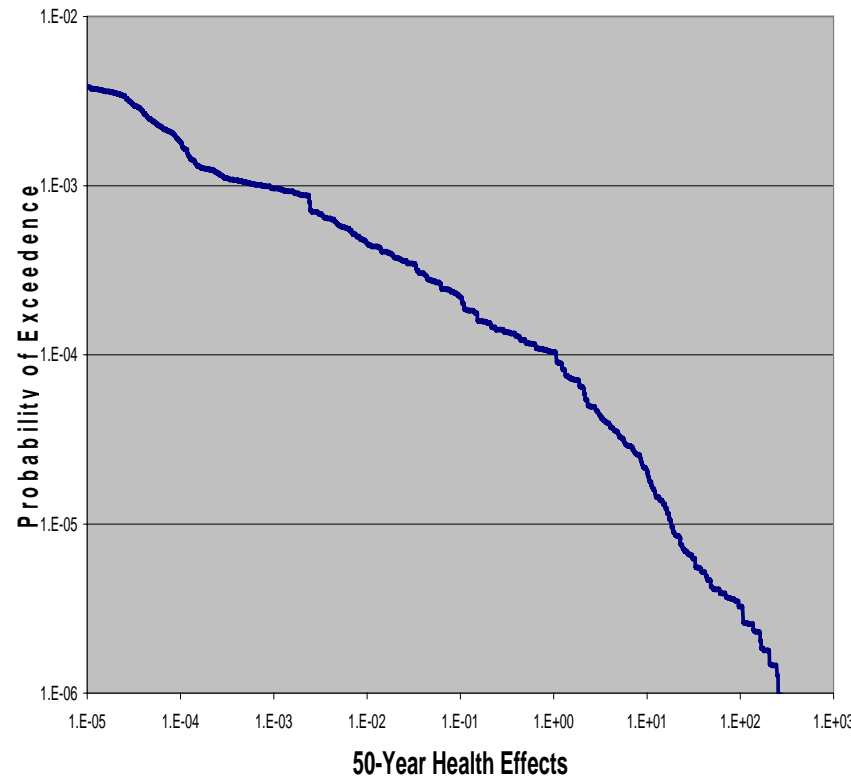
- **Material transport in the environment**
 - Strongly dependent on weather & plume lofting
 - Particle size dependence of dispersion and deposition
- **Health effects estimation**
 - Ingestion, inhalation, groundshine, cloudshine
 - Resuspension of previously deposited material
 - ICRP-60 and ICRP-67 organ-specific estimation of doses and health effects (primarily latent cancers)
- **Consequences can vary by orders of magnitude for the same release characteristics**
 - Significant uncertainties in all of the above
 - Complete enumeration of all combinations is not feasible so we evaluate a statistical subset of combinations.



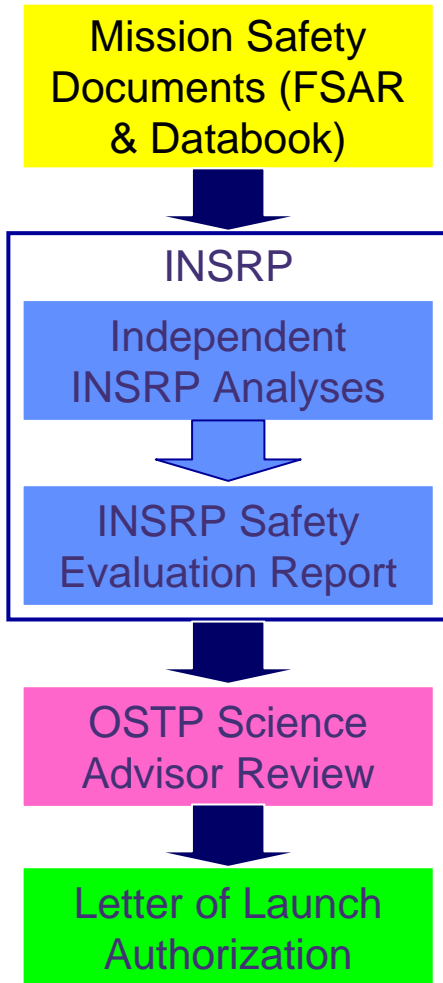
Risk Integration

- Dispersion can cause micro-doses to very large populations
 - If *de minimis* exposure level assumed, it can have significant effect on risk
- Risk is displayed as a complementary cumulative distribution function
 - Population of accidents, releases, and consequences sorted and integrated
 - Visually shows that large consequences are very unlikely
 - Shows differences between risk profiles among alternatives
 - Can't be seen comparing mean risk
 - Answers common risk questions, e.g.,
 - “What is probability for at least one person to die due to this mission?”
 - “How bad could a one-in-a-million accident be for this mission?”

Mission Risk for the Pluto New Horizons Mission



Launch Approval Process for Nuclear Missions



- U.S. Launch of radioactive material requires Presidential authorization
 - PD/NSC-25 requires an independent Interagency Nuclear Safety Review Panel (INSRP)
 - Ad hoc panel for each mission with representatives from NASA, DoD, DOE, EPA, NRC
 - INSRP prepares a Safety Evaluation Report (SER)
 - President's science advisor in the Office of Science & Technology Policy (OSTP) gives launch authorization
 - INSRP SER describes mission risks to OSTP
 - High-level document with technical appendices



Interagency Nuclear Safety Review Panel

- **INSRP is supported by technical experts from “working groups” to address specialized topics**
 - **Launch Abort → Thermal and fragment environments**
 - **Reentry → Environment & performance during reentry**
 - **Power Systems → RTG performance & rad release**
 - **Meteorology → Atmospheric transport & rad dispersal**
 - **Biological Effects → Dose pathways & health effects**
 - **Uncertainty → Risk integration & uncertainty estimation**
- **INSRP SER is based on data from many sources**
 - **Independent research and analysis**
 - **Programmatic safety documentation (FSAR, Launch Vehicle Databook, etc.)**
 - **Historical data from other programs and launches**



Interagency Nuclear Safety Review Panel (cont.)

PNH Program Safety Documents

Launch Vehicle Data Book

Characteristics of launch vehicle: incl. failure modes, event timing, likelihoods, blast environments, fragment fields, thermal environments, ...

Interim analyses & working papers on various safety-related subjects

Final Safety Analysis Report

Spacecraft design, mission profile, launch accident descriptions & models, analysis of reentry accidents, RTG response to accident env'ts, radiological releases, transport, contamination, health effects, integrated mission risk & uncertainty

PNH INSRP Activities

Launch Abort Working Group
Accident probabilities & environments

Reentry Working Group
Environments, performance, probabilities

Power Systems Working Group
RTG performance & rad. releases

Meteorology Working Group
Atmospheric transport & rad. dispersal

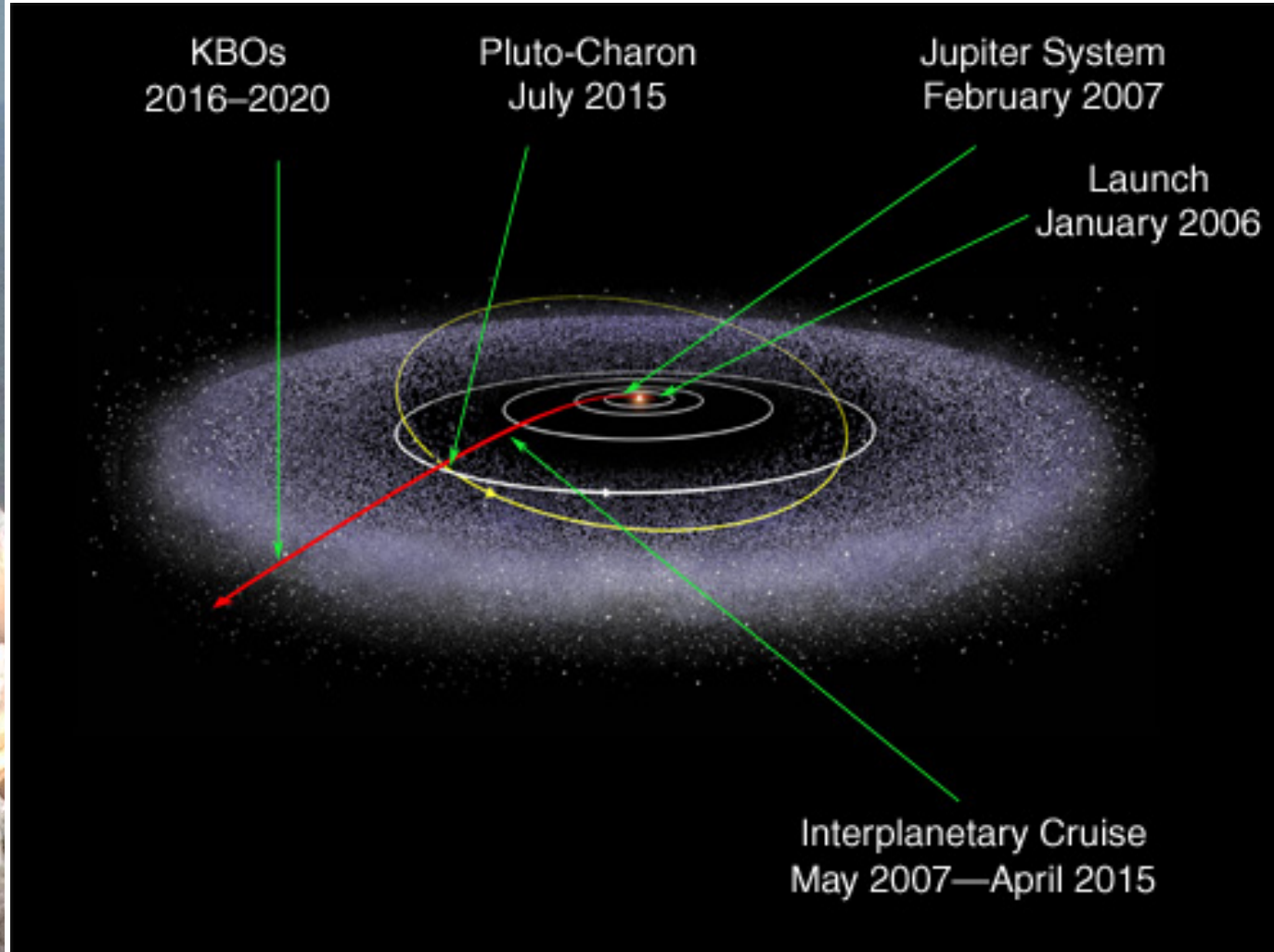
Biological Effects Working Group
Dose pathways & health effects

Uncertainty Working Group
Risk integration & uncertainty estimation

Safety Evaluation Report

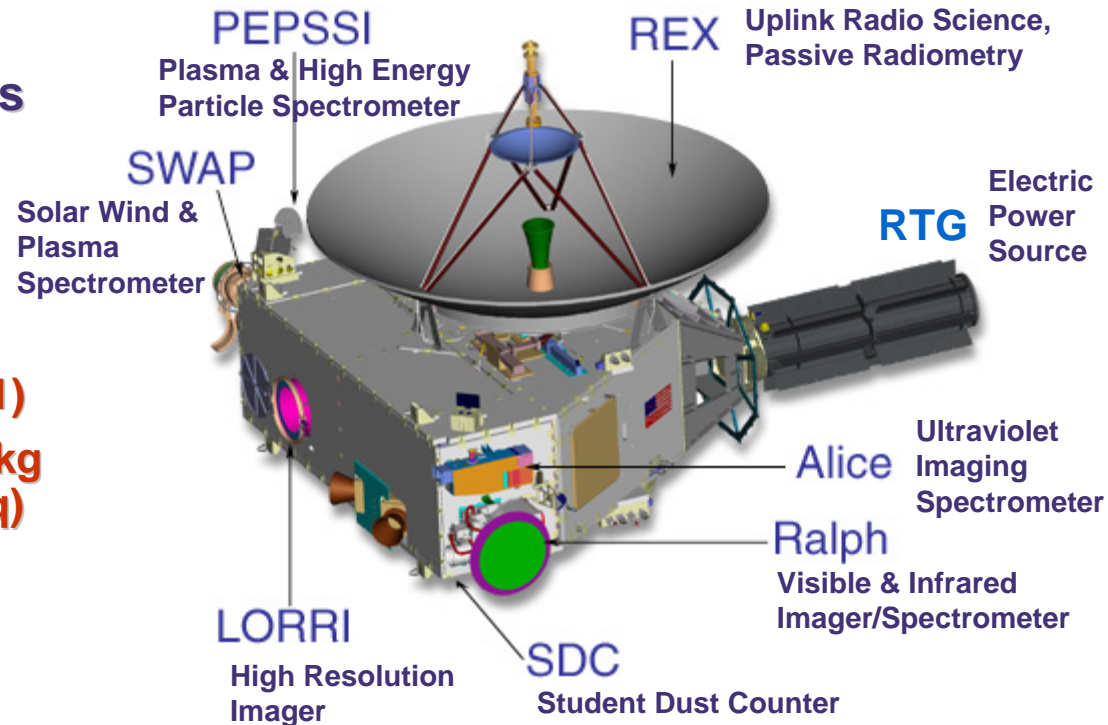


The Pluto – New Horizons Mission



The Pluto – New Horizons Mission (cont.)

- **Launch: Jan. 19, 2006**
- **Destination: Jupiter, Pluto, Charon, & Kuiper Belt Objects**
- **Statistics**
 - ~8 ft across (2.5 m)
 - 1025 lbs (465 kg) incl. fuel
 - Atlas V / Centaur Launch (551)
 - RTG power source with 10.8 kg $^{238}\text{PuO}_2$ (121,000 Ci, 4500 TBq)
- **Mission**
 - Gravity assist from Jupiter
 - ~9½ yr travel time to Pluto – 3.1×10^9 mi (5.0×10^9 km)
 - Visit Kuiper Belt Object(s) after passing Pluto



Fastest spacecraft ever to leave earth orbit
Passed lunar orbit in less than 9 hrs
Encountered Jupiter in 13 months

Safety Background for the PNH Mission

- **Much is similar to past RTG-powered missions**
 - **Similar RTG design**
 - This RTG was the “backup” for Galileo & Cassini missions
 - Extensive experimental record on safety performance
 - Designed to withstand orbital reentry; with only impact on hard surfaces (rock, concrete, etc.) causing small releases
 - **Improvements to some GPHS modules adds strength**
- **Principal safety concerns:**
 - **Early mission – land impacts**
 - Modules or RTG impact hard surfaces at high speeds
 - Fire environment from chunks of solid propellant
 - Scenarios where destruct system does not activate
 - Impact from fragments of launch vehicle or solid propellant
 - **Reentry**
 - Modules (ablated by reentry) impact hard surfaces



Mars Science Laboratory



Summary

- **Using radioactive materials is mission-enabling**
 - **Some missions or measurements impossible by other means**
 - **Risks to environment and human health must be assessed, understood, and managed**
- **Risk assessment involves many disciplines**
 - **Understanding insult environments that can lead to release of materials (scenario, likelihood and magnitude)**
 - **Modeling characteristics of release**
 - **Material transport & health effects estimation**
- **Formal launch approval process by Presidential directive**
 - **Formal independent risk review process and independent risk estimate by interagency panel (INSRP)**
 - **Ensures both technical and political risks are weighed**

