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SPACE NUCLEAR SYSTEMS LAUNCH SAFETY OVERVIEW

SNSLS
Space Nuclear Systems Launch Safety

Sandia National Laboratories

Seminar January 25, 2022

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LAUNCHES CAN FAIL

Atlas Fallback-1965

Titan 34D-Apr 18, 1986

Antares-Oct 28, 2014

Delta 241-Jan 27, 1997

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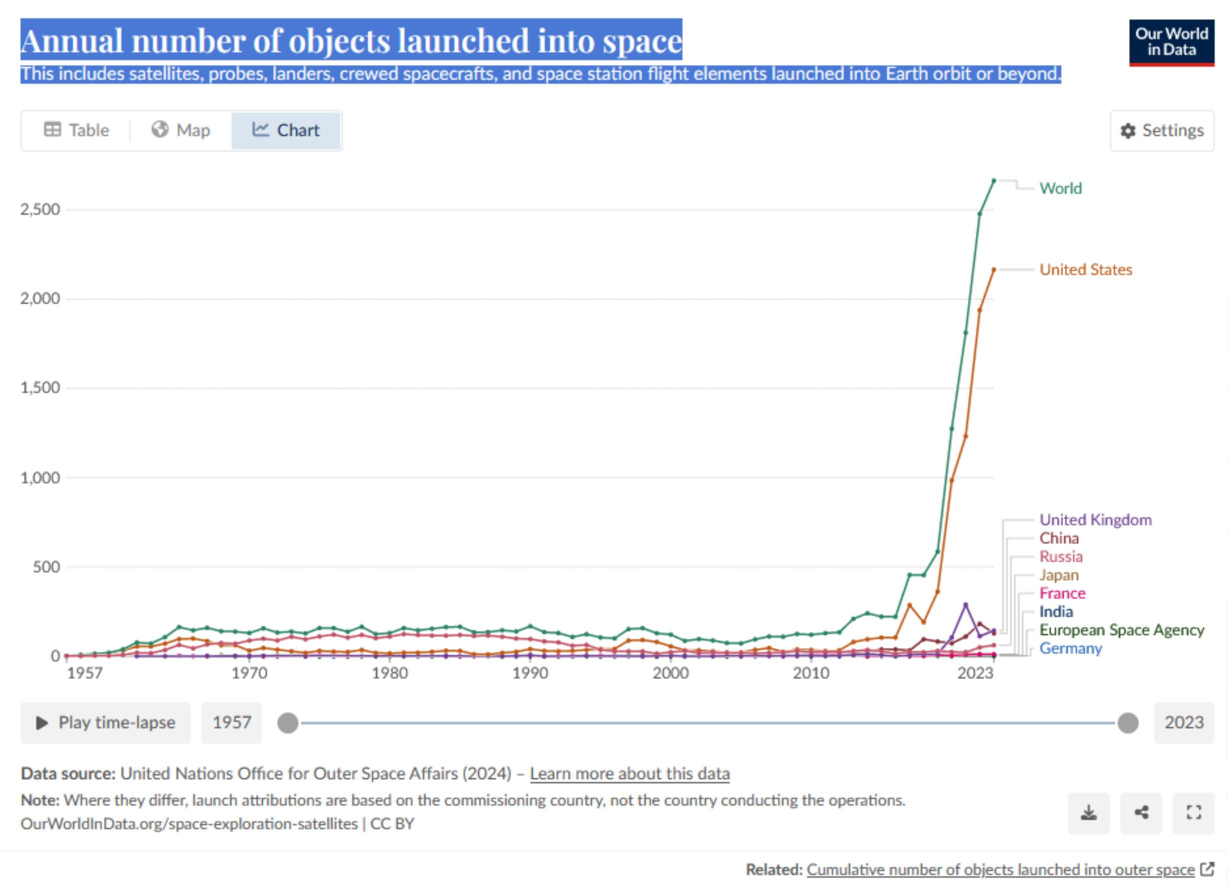
Space is Booming

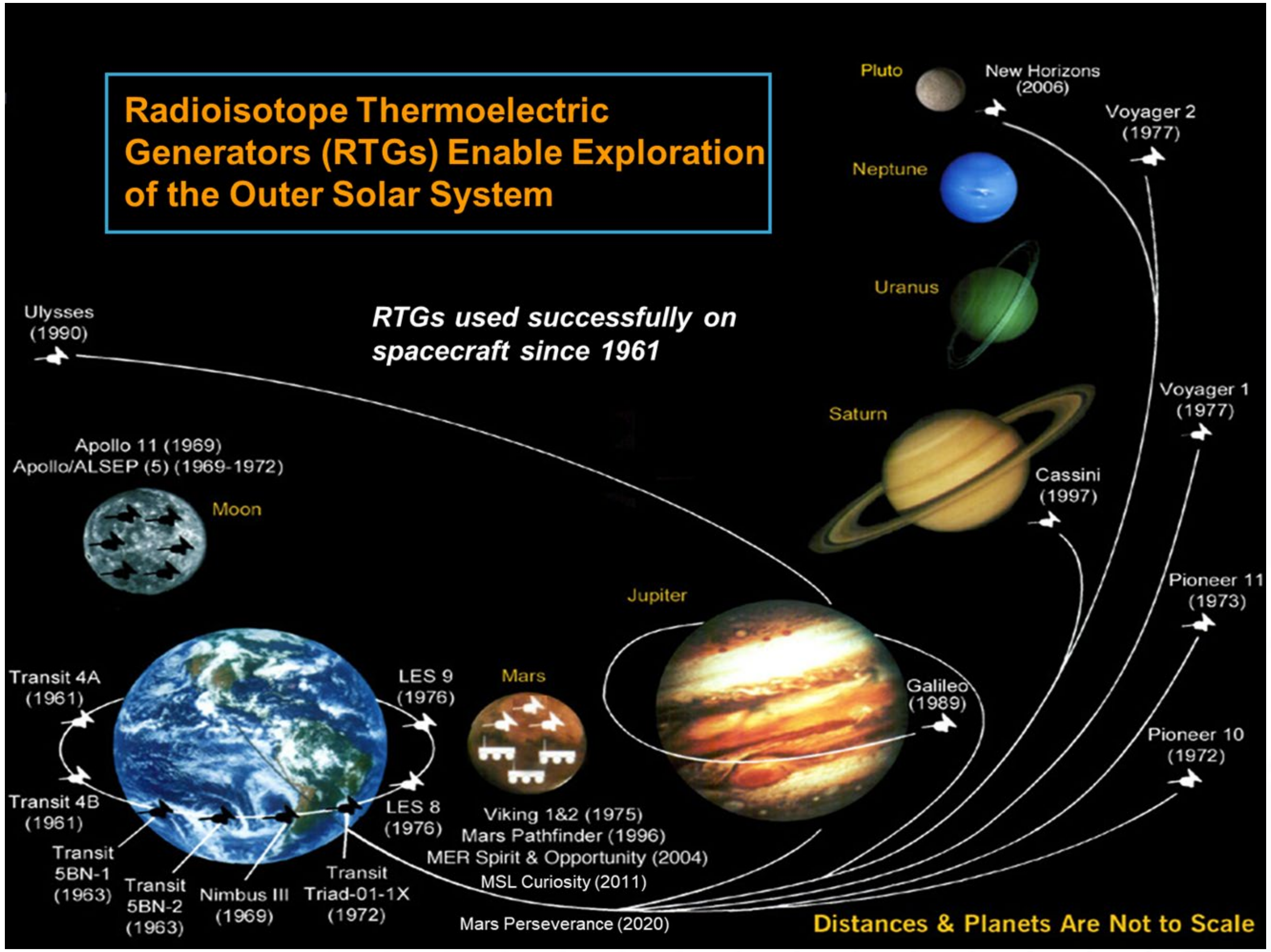
	2020	2021	2022	2023	2024
Launches	112	146	182	219	320 (est).
Satellites	1774	1813	2478	2664	3900 (est.)

- Cumulative Space object 1957 to 2020: **10308**
- Cumulative Space object 2021 to 2024: **10855**
- More satellites were launched in the last 4 years than the previous 64 years combined.



Krebs, Gunter D. “Chronology of Space Launches”. Gunter's Space Page. Retrieved May 16, 2024, from https://space.skyrocket.de/directories/chronology.htm
Satellite numbers from United Nations Office of outerspace affairs (estimated to only capture 88% of all objects)

SPACE NUCLEAR SYSTEMS HISTORY-NASA/DOE



2006

Pluto New Horizons Mission

Supported DOE's review of Lockheed Martin's FSAR (2005)

2011

Mars Science Laboratory Mission

Produced Final Safety Analysis Reports (FSARs) (2008, 2010).

2020

Mars 2020 Mission

Produced Final Safety Analysis Report (FSAR) for Launch Approval (2019)

Produced Nuclear Risk Assessments (2013, 2019)

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CURRENT ACTIVITIES

Space nuclear is **growing** beyond NASA/DOE RTG systems to

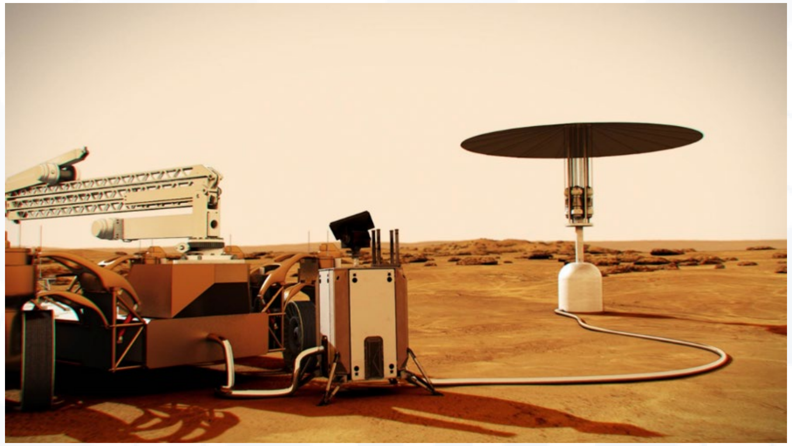
- Nuclear thermal propulsion missions
- Surface fission power
- DOD engagement
- Purely commercial enterprises

Providing **software** and **training** for launch approval

- Ultra Safe Nuclear Company – Technologies (USNC-Tech)

Sandia is currently Performing **analyses** and **documenting** for launch approval

- DARPA & NASA's DRACO mission
- Charles Stark Draper Laboratory mission
- Lockheed Martin Space Systems mission
- Zeno Power Systems missions
- Air Force Research Laboratories proof of concept
- City Labs mission



In process – Dark Fission, Air Force, and Applied Physics Laboratory **also pursing** space nuclear missions /activities

NATIONAL SECURITY PRESIDENTIAL MEMORANDUM-20

SNSLS
Space Nuclear Systems Launch Safety

This Memorandum establishes an updated and risk-informed **process** for launching **space nuclear systems** by

- Structuring launch authorization for space nuclear systems to follow a **tiered process** based on system characteristics, level of potential risk, and national security considerations
- Establishing **safety guidelines** to assist mission planners and launch authorization authorities in ensuring launch safety across the full range of space nuclear systems.
- Directing that safety analyses incorporate **past experience** to maximize effectiveness and efficiency.
- Replacing the mission-specific **ad hoc** Interagency Nuclear Review **Panel** (INSRP) with a **standing** Interagency Nuclear Safety Review **Board** (INSRB).

LAUNCH SAFETY ANALYSIS APPROACH

Identify **main sources** of risk, to allow for potential **mitigating actions**, to **reduce** the overall mission **risk**

Goal: **Quantitative** estimate of the risk that is **defensible** and **credible**

- Mean probability of an accident
- Mean probability of release of radioactive material
- Mass of material released (“source term”)
- Health effects (doses, latent cancer fatalities)
- Land, crop contamination
- All expressed as mean values, percentile values, and exceedance probability graphs
- Quantify uncertainty

LAUNCH SAFETY CODE SUITE

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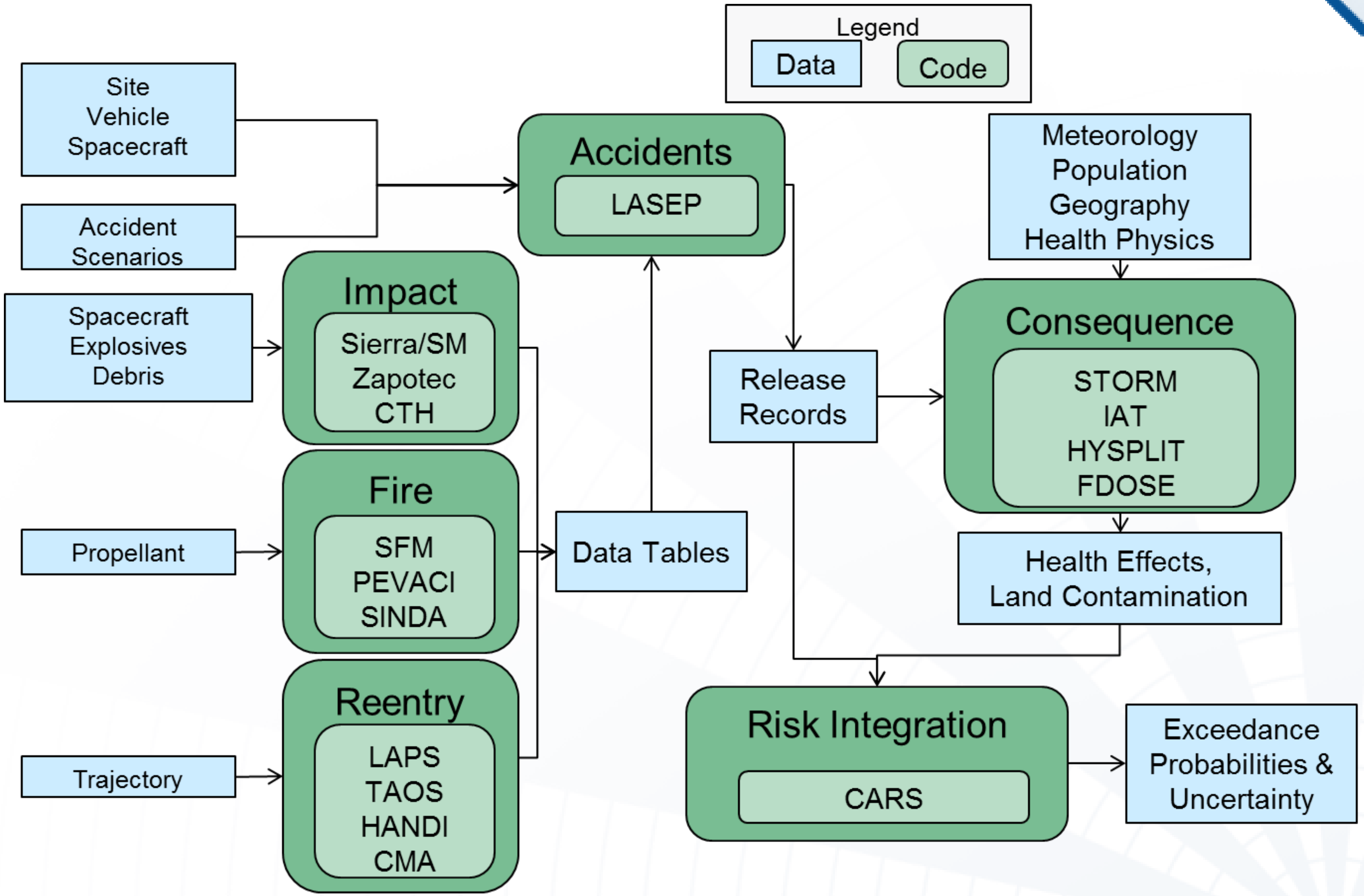
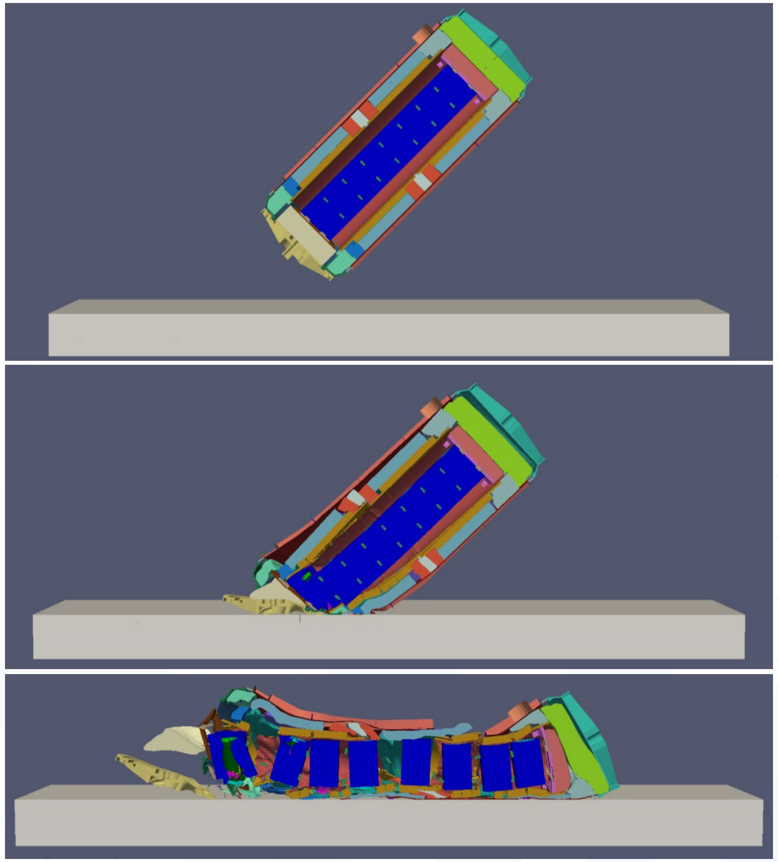


BLAST & IMPACT

Some blasts and impacts have the potential to breach the multiple layers of protection

Determine range of end states

- **Blasts**
  - Launch destruct
  - Shockwave from ground impact of propellant tanks
  - Shockwave from ground impact of solid propellant fragments
- **Impacts**
  - Ground surface
  - Spacecraft and launch vehicle debris/fragments
  - Solid propellant fragments

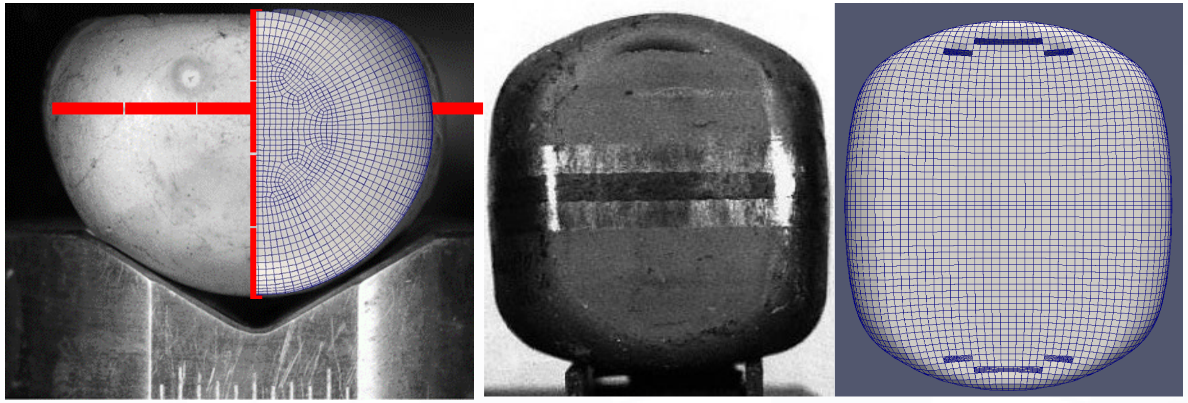


MMRTG 45° Impact at 100 m/s
(terminal velocity is 60 m/s)
No fuel release

MATERIAL AND MODEL CALIBRATION

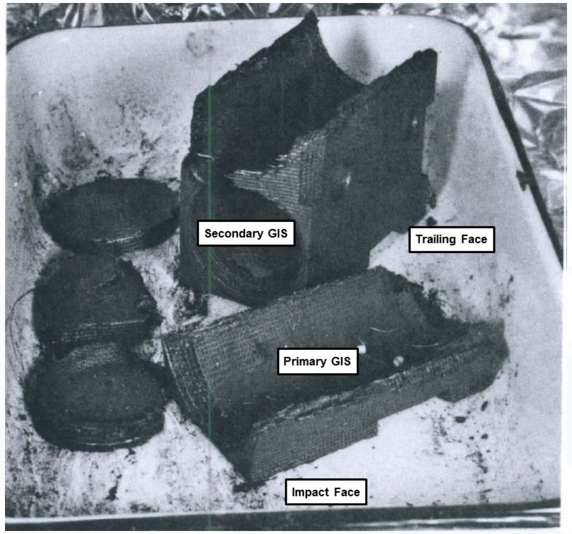
Many material models populated with basic test data

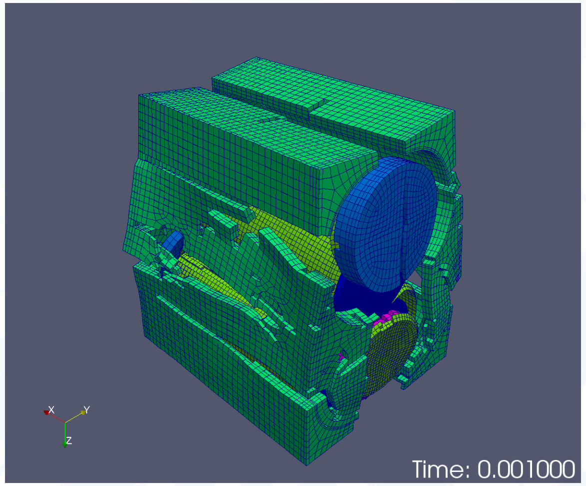
Limited data for nuclear materials and systems



More sophisticated modeling approaches for some materials

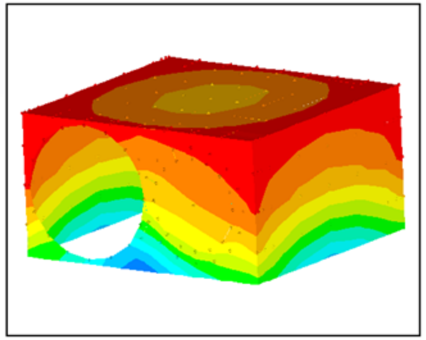
Iterative calibration to infer unknown properties





FIRE & THERMAL

Solid Propellant Burn Test



Liquid propellant fire temperatures can exceed radioactive material vaporization temperatures

Solid propellant fire temperatures exceed material melt temperature and radioactive material vaporization temperatures

Determine effect of potential fire environments on the range of radioactive material vaporized and resulting **particle size** changes due to the vaporization and condensation

Module with all components simulated with SINDA

Atmospheric **reentry** effects have the **potential to breakup**

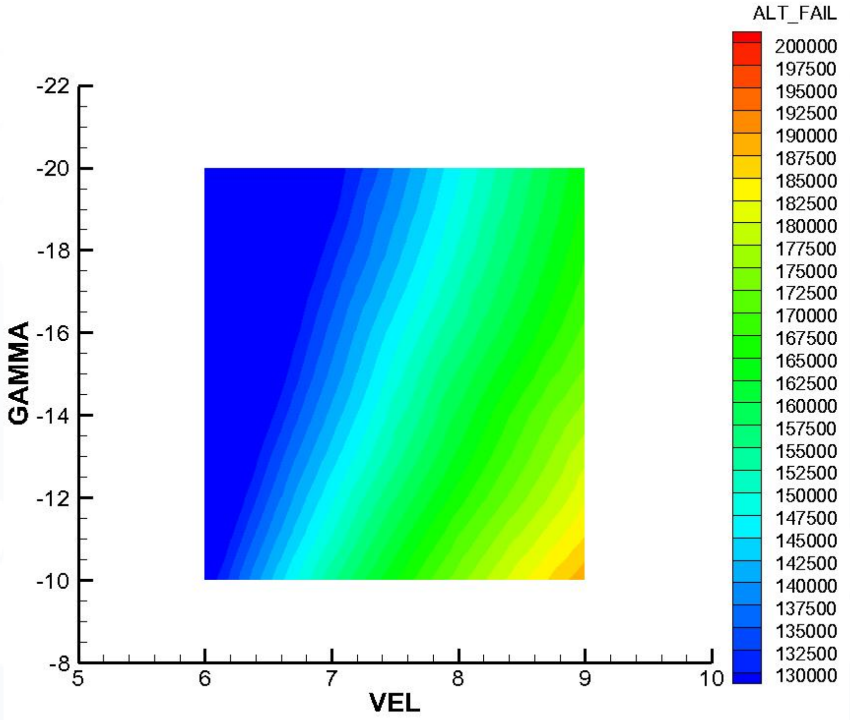
- Launch vehicle
- Space vehicle
- Space nuclear system

Determine **effect** from the **range** of the **reentry environments** on the configuration

- Trajectory
- Heating of components
- Ablation

MMRTG Breakup V-gamma Map

(gamma is entry angle)

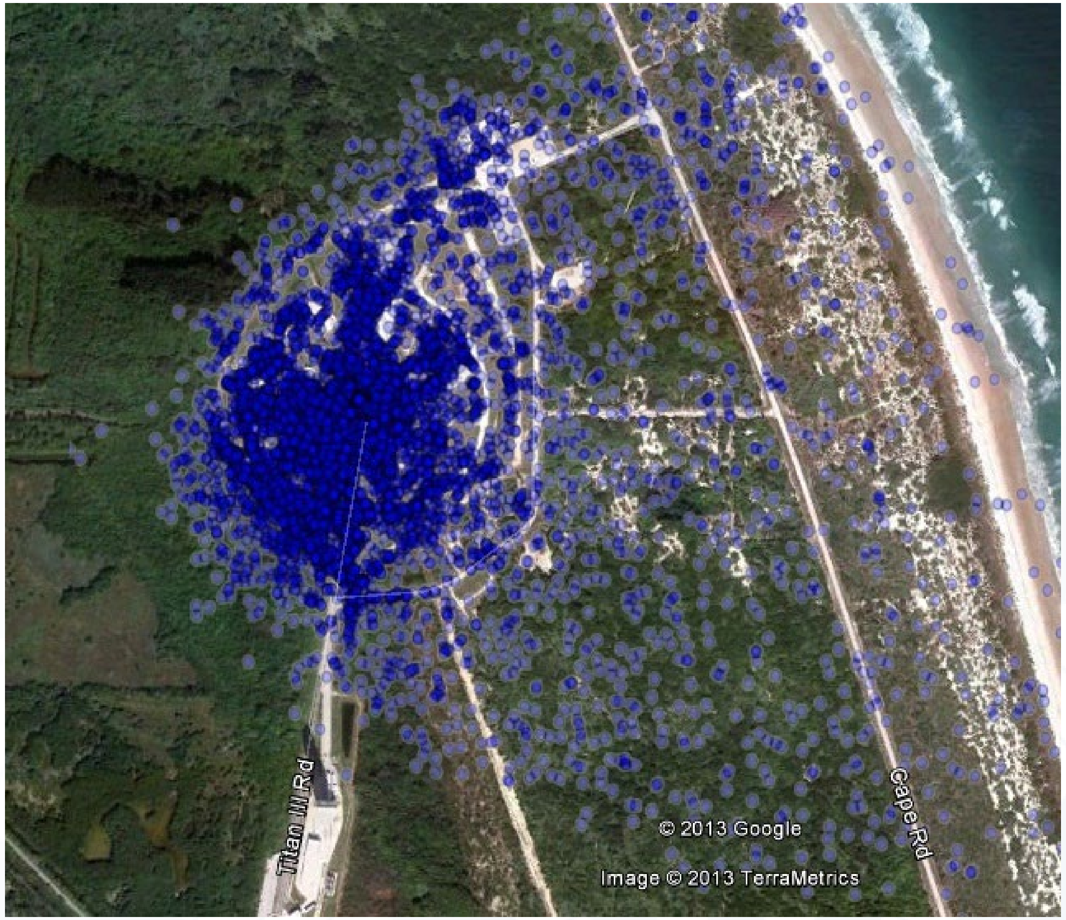


RELEASE LOCATIONS AND AMOUNTS

LASEP (Launch Accident Sequence Evaluation Program) **models** numerous potential **scenarios**, randomly choosing time of failure, explosion characteristics, etc.

Release location and amounts determined mechanistically

Probability distributions for releases are determined



Potential release locations from numerous LASEP launch simulations

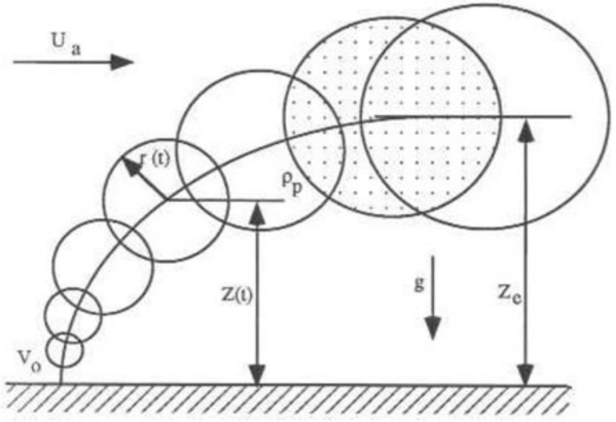
ATMOSPHERIC TRANSPORT & CONSEQUENCES

Establish **transport** and **deposition** of source terms

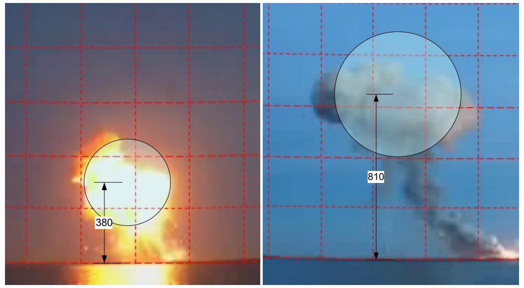
- Puff/plume height (IAT)
- Meteorological effects (HYSPLIT)

Determine potential **health effects** from release (FDOSE)

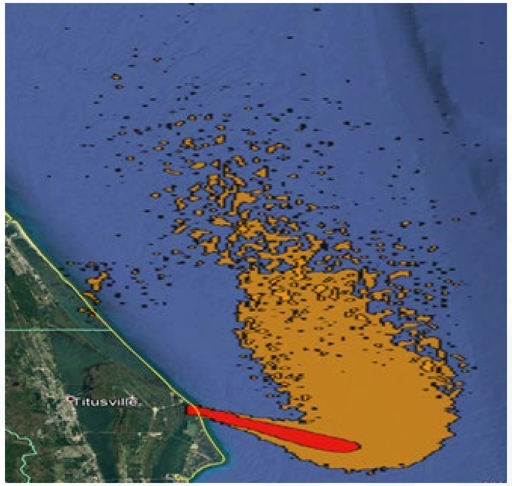
- Inhalation, resuspension, ingestion, cloudshine, and groundshine
- Doses, land contamination, crop sequestration



Fireball Rise Height



Comparison between calculations and observation



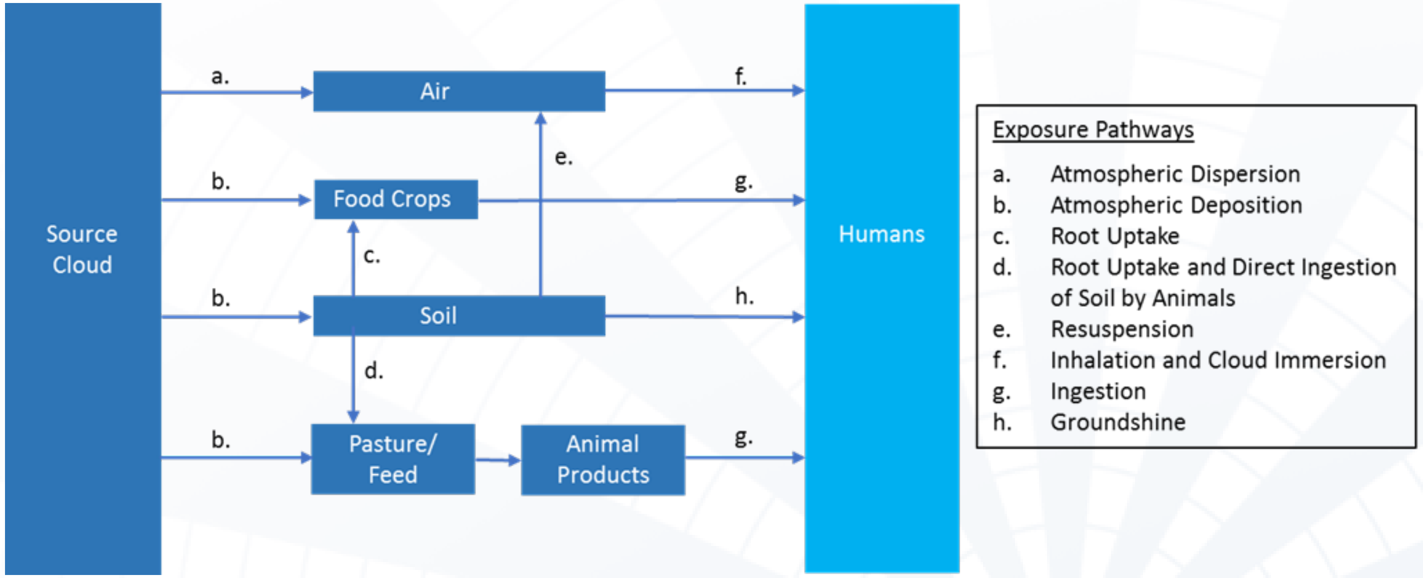
Particle Transport

EXPOSURE PATHWAYS

Plume pathways
- External exposure from plume immersion ("cloudshine")
- Internal exposure from inhalation of plume

Ground pathways
- External exposure from deposited material ("groundshine")
- Internal exposure from inhalation of resuspended material

Ingestion of contaminated food



SUMMARY

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Space Nuclear Systems Launch Safety

Safety analyses are **required** by NSPM-20, and **enabling**, for the use of space nuclear systems

Detailed simulations are used to develop the **probabilistic risk analysis** by **multi-disciplinary** teams and expertise

The **response** to potential **accident scenarios** is modeled in a **stochastic manner** with a **Monte Carlo simulation**

- Results are combined and weighted by appropriate likelihood values
- Estimated consequences calculated

This information is used to **guide** power system or spacecraft **designs**, mission **architecture** or launch **procedures**

- Potentially reduce risk
- Inform decision makers