

# Using SCALE Software for Analysis of Spaceflight Technologies

## SCALE Users Group Workshop

July 27<sup>th</sup>-29<sup>th</sup> 2020 (virtual meeting)

Michael B. R. Smith

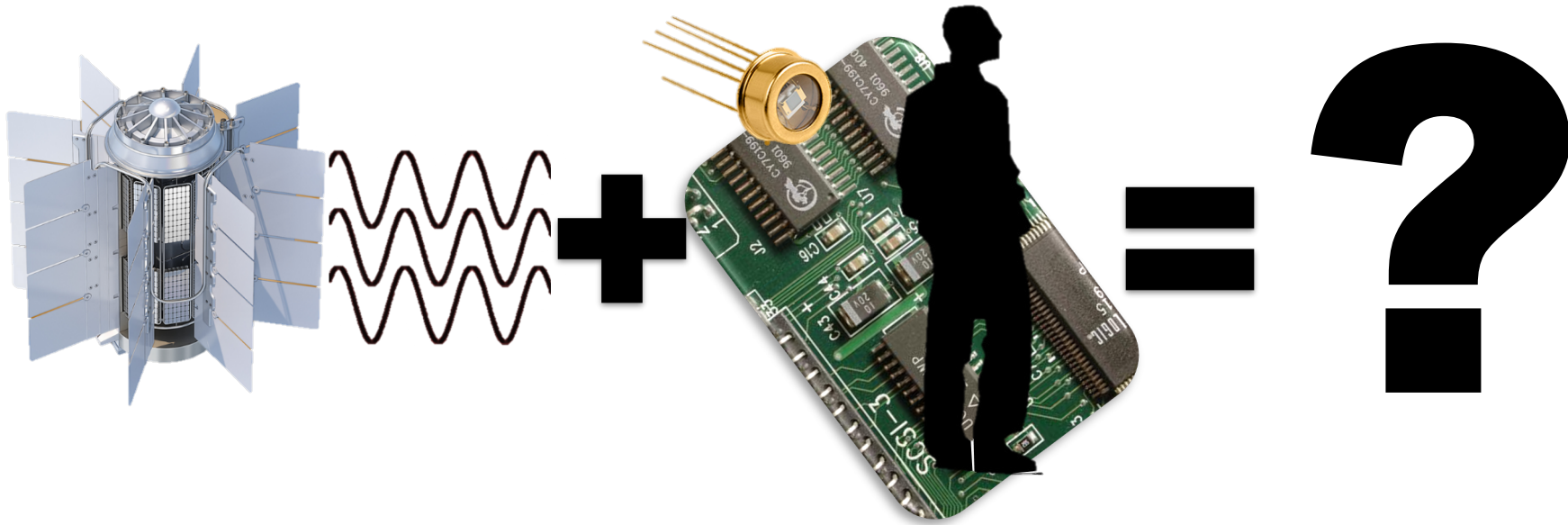
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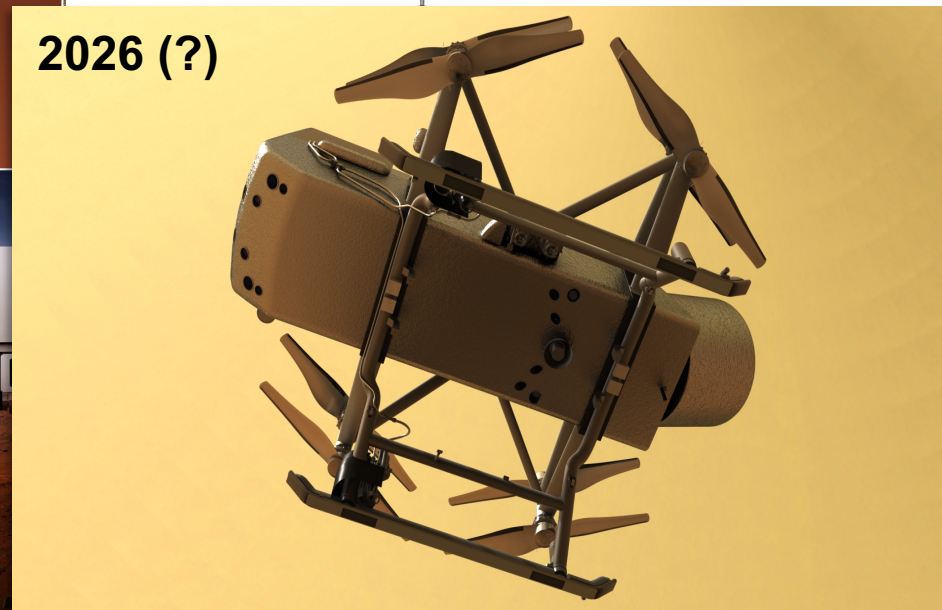
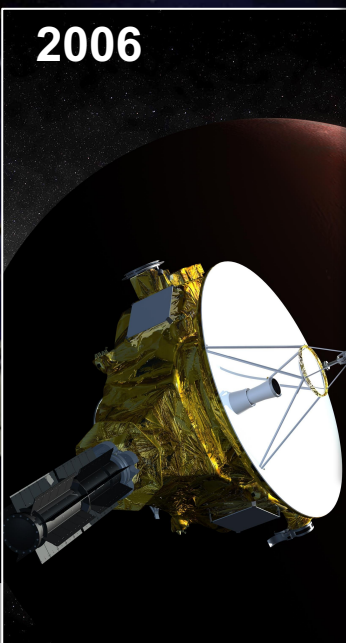
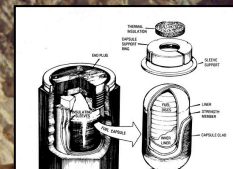
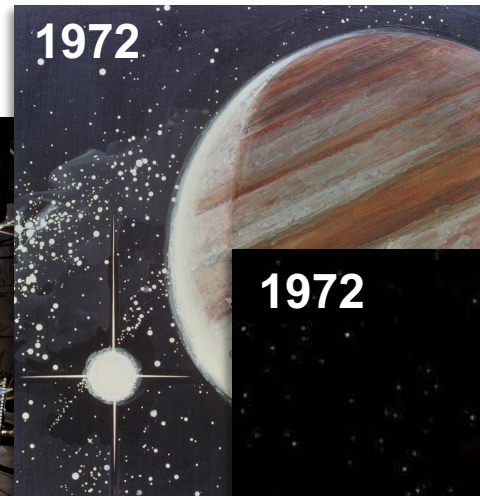
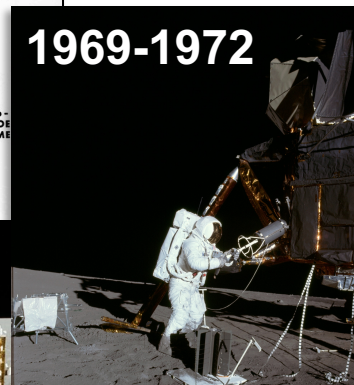
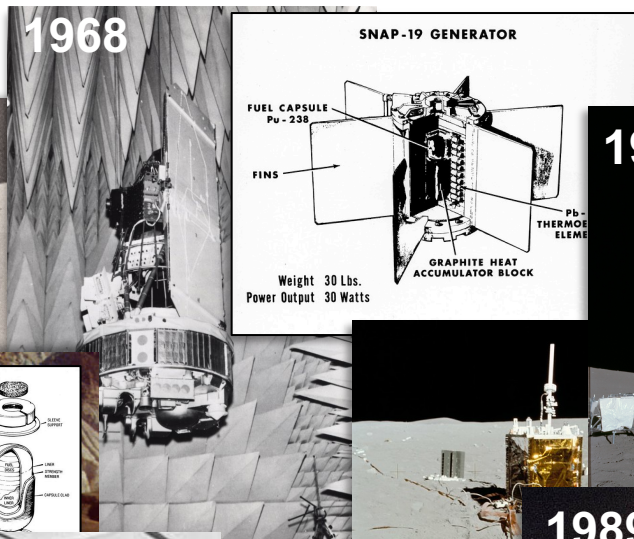
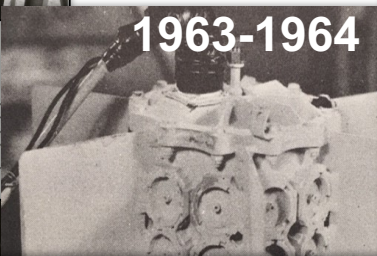
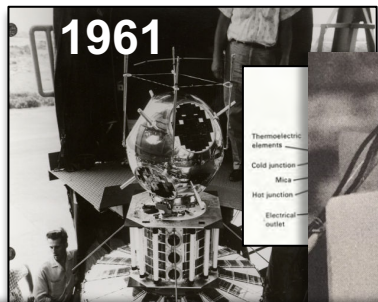
U.S. DEPARTMENT OF  
**ENERGY**

# What is RPS-DET?

**An efficient and accurate simulation tool for estimating radiation effects to people, electronics and materials produced by radioisotope power systems (RPS)**

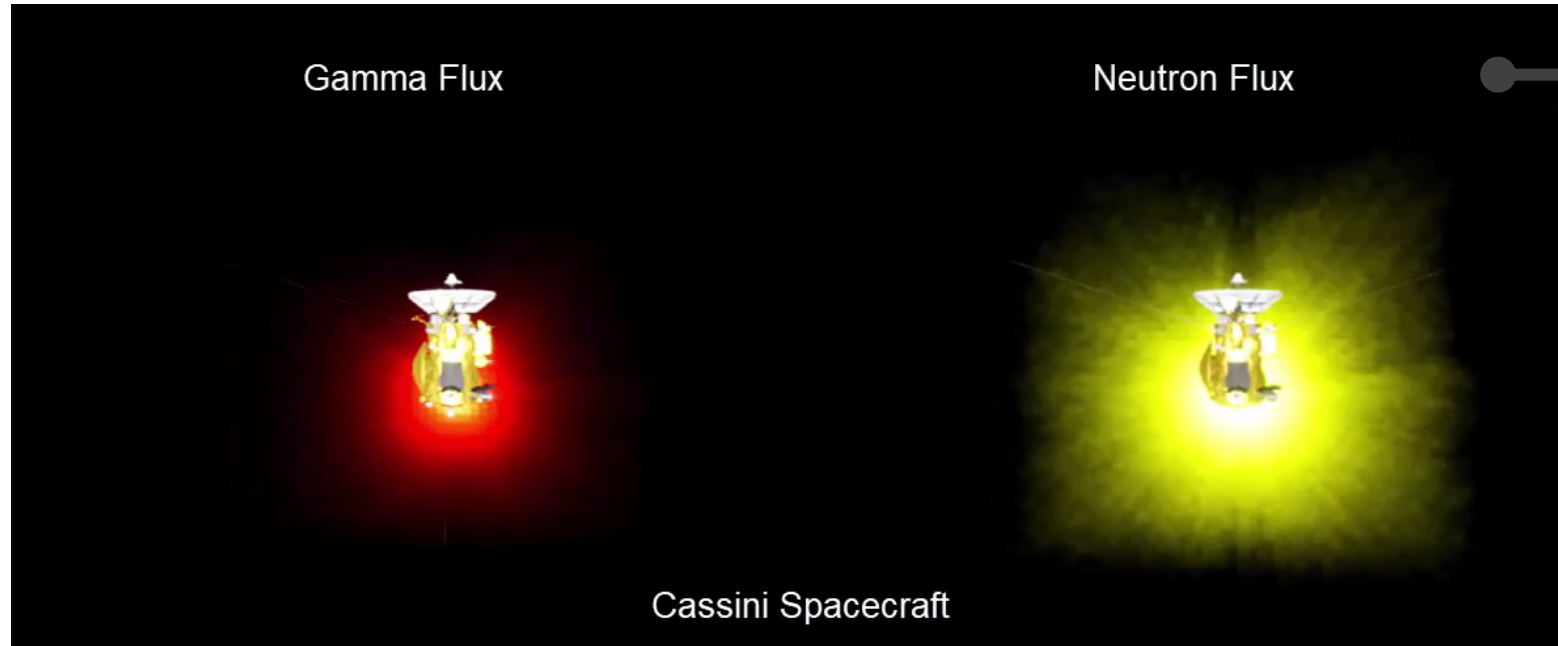






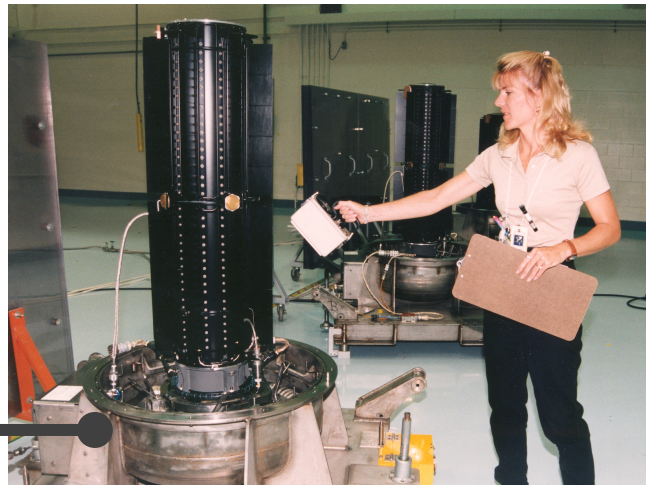


# Turns Out Radioisotope Power Systems Emit Radiation

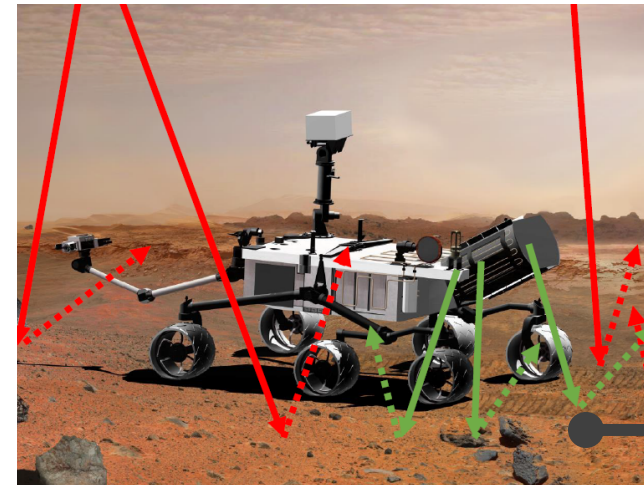


Spacecraft  
design

Occupational  
scenarios

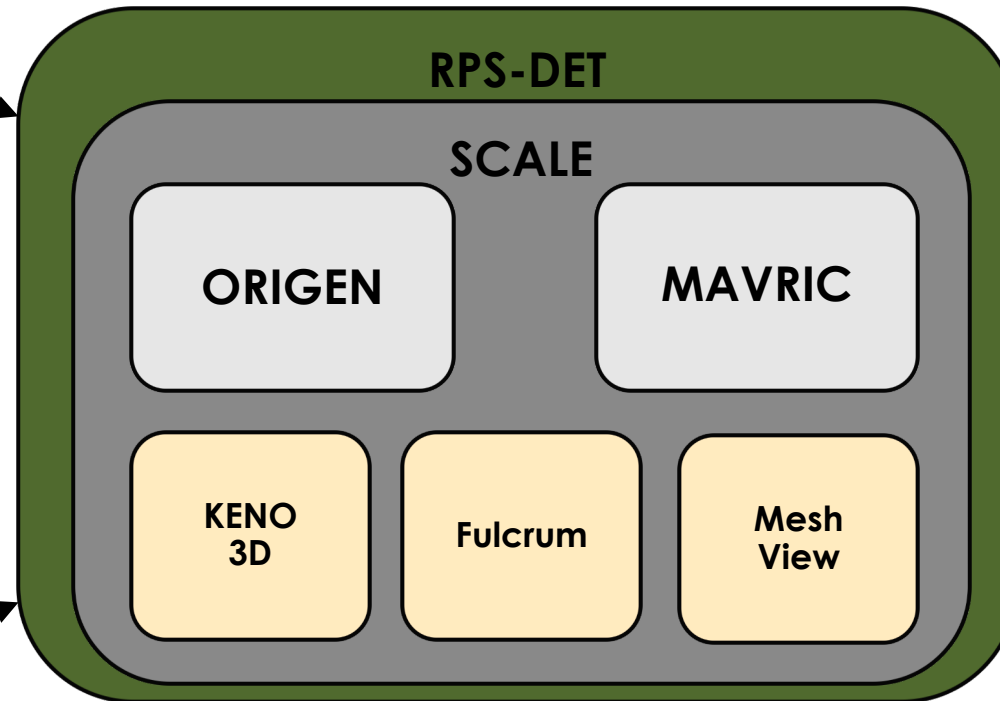
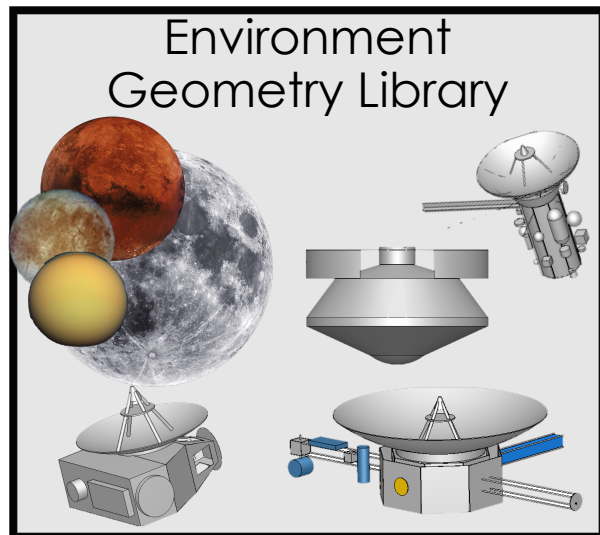
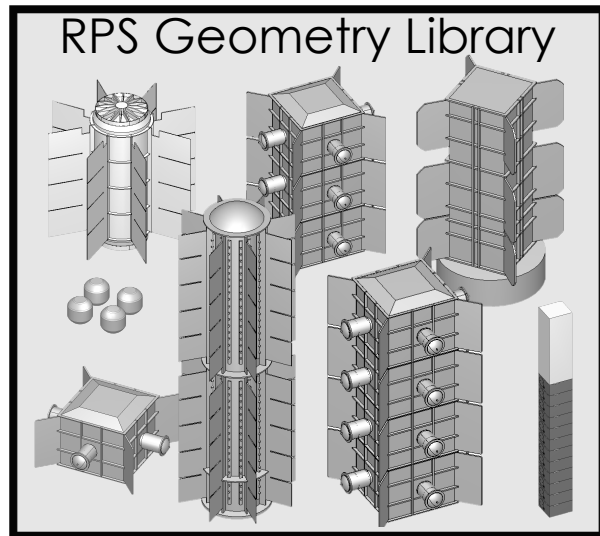


Instrument  
noise

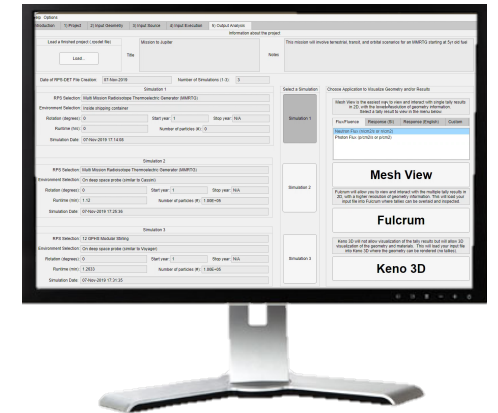




# RPS-DET Structure



**USER**



# Project Development

RPS-DET

Help Options

Introduction1) Project2) Input Geometry3) Input Source4) Input Execution5) Output Analysis

Please load a saved project (left) or begin a new project (right)

Loading Saved Project

Load A Saved Project to Analyze

Saved Project Title:

Saved Description:

Date Created:

Number of Simulations (1-3):

Simulation 1 RPS:

Simulation 1 Environment:

Simulation 2 RPS:

Simulation 2 Environment:

Simulation 3 RPS:

Simulation 3 Environment:

Clear

Load...

Instructions

1) Press the "Load..." button to search for a previously saved RPS-DET project

2) If a valid project is selected, the title, description, source-term, and project date will appear

3) If the desired project is loaded, proceed to the next tab

4) If the desired project did not load, press the "Clear" button and repeat from Step 1

Beginning New Project

Begin A New Project

Enter New Project Title:

Mission to Mars (NO SPECIAL CHARACTERS)

Enter New Description:

This is a project with three simulations of an MMRTG, on the surface of Mars for 27 years. Plutonium assay is representative of default Pu-238 with high neutron emission rate. (NO SPECIAL CHARACTERS)

Clear

Save...


Instructions

1) Enter a title for the project you are about to create

2) Enter a description of the project you are about to create

3) If you are satisfied with the title and description press the "Save..." button and continue to the next tab

4) If you are not satisfied with the title and description, press "Clear" and repeat from Step 1

 OAK RIDGE  
National Laboratory

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# Geometry Selection

RPS-DET

Help Options

Introduction1) Project2) Input Geometry3) Input Source4) Input Execution5) Output Analysis

Input Design

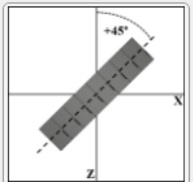
Assign number of simulations and geometries

Select and "Save" RPS and environments for 1-3 simulation choices. If allowed in a given environment, you may also rotate the RPS in the environment as well.

To re-define a simulation, press "Clear", then "Save" the new selections.

Visualize a selected combination of RPS, environments, and rotations by pressing the "Render Geometry" button.

When all simulations are selected and saved, press the "Confirm Selected Geometries" button and proceed to the next tab.



Sim 1Sim 2Sim 3

Simulation 2

RPS

Environment

Rotate RPS about Y-axis (degrees): 0

SaveClear

Render Geometry

Confirm Selected Geometries

Select RPS

Radioisotope Power Systems (RPS)

Current

Multi Mission Radioisotope Thermoelectric Generator (MMR1)

Historic

General Purpose Heat Source Radioisotope Thermoelectric Generator (GP-RTG)

Concept/Future

Advanced Stirling Radioisotope Generator (ASRG)

Modular Stirling (vertical GPHS stack)

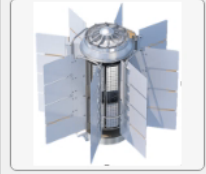
4 GPHS Modular Stirling

8 GPHS Modular Stirling

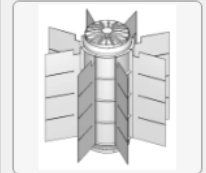
12 GPHS Modular Stirling

16 GPHS Modular Stirling

RPS Photograph/Drawing



RPS-DET RPS Rendering



RPS Specifications

Title/Name: Multi-Mission Radioisotope Thermoelectric Generator (MMR1)

Historic Missions: MSL (11/26/2011), Mars 2020 (TBD/2020)

Nominal Thermal Output at Beginning of Life (W): 1,892

Nominal Electrical Output at Beginning of Life (W): 108

Conversion Efficiency (%): ~2.4

Nominal PuO2 Mass (kg): 4.8

Number of GPHS: 8

Dimensions (fin tip-to-tip or width [cm]): 65

Dimensions (height [cm]): 69.0

Approximate System Mass (kg): 45.0

Select Environment

Earth

On concrete pad

Suspended 1m above concrete pad

Suspended in Earth atmosphere

Inside 10'x10'x10' concrete room

Inside shipping container

Spacecraft and Space

Suspended in vacuum

Inside aeroshell with cruise-stage (similar to MSL)

On deep space probe (similar to Cassini)

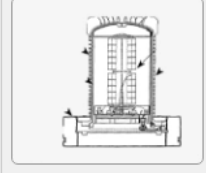
On deep space probe (similar to New Horizons)

On deep space probe (similar to Voyager)

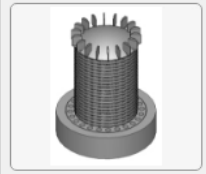
Moon

Mars

Environment Photograph/D...



RPS-DET Environment Ren...



Environmental Specifications

Title/Name: Inside the 9904 shipping container

Planet/Moon: Earth

Surrounding material(s): Concrete, steel, water, and air

Material composition: [Ca3SiO5,H2O],[FeC],[H2O],[N2,O2,CO2]

Density of surrounding materials (g/cc): [2.300],[7.920],[1.000][0.001]

Atmospheric pressure (atm): 1.00

# Source Term Selection

**RPS-DET**

Help Options

Introduction 1) Project 2) Input Geometry 3) Input Source 4) Input Execution 5) Output Analysis

**Define Fuel Here**

☒ Use default fuel settings

**Define Initial Plutonium Oxide Fractions**

Pu-236	1.20E-06	Pu-238	7.48E-01
Pu-239	9.19E-02	Pu-240	2.66E-02
Pu-241	5.66E-04	Pu-242	1.16E-04
Pu Total	0.87	Oxide Total	0.13
PuO2 Total (Includes impurities)		1.00	

☒ Use default impurity settings

**Define Initial Fuel Impurities**

Oxide (ppm) -----  
O-18 108

Actinides (ppm) -----  
U234 1600 Np237 1390  
Th232 7880 Am241 0

Other (ppm) -----  
P 1100 Al 60 Be 1  
Cd 10 B 5 Cu 62  
Ca 175 Mg 13 Cr 40  
Mo 28 Fe 45 Ni 38  
Mn 10 Si 265 Na 205  
Zn 20 Pb 10 Sn 48

Generate Source Reset to Default

**Neutron** **Gamma** **Isotopic**

**Neutron Source**

Neutron Source (n/s)

Time (year)

Save Activity (.csv)

AN

SF

Total

**Neutron Source Energy Spectra**

Neutron Source (n/s/MeV)

Energy (MeV)

Save Spectra (.csv)

AN

SF

Total

Per Gram Year

Per RPS 0 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Sim 1 Sim 2 Sim 3

Simulation 1: Press save to assign the currently selected fuel-type and duration to the simulation

RPS Selection: Multi Mission Radioisotope Thermoelectric Start Year 0 End Year 0 ☐ Check for flux/dose rates (See manual)

Environment Selection: Inside shipping container Use Selected Year Use Selected Year Clear Save

ORIGEN is calculating source term...






# Simulation Execution

RPS-DET

Help Options

Introduction 1) Project 2) Input Geometry 3) Input Source 4) Input Execution 5) Output Analysis

Please confirm that your project is correct and assign simulation time/particle limits

Simulation 1	Simulation 2	Simulation 3
<b>RPS Selection</b> Multi Mission Radioisotope Thermoelectric Generator (MMRTG)	<b>RPS Selection</b> Multi Mission Radioisotope Thermoelectric Generator (MMRTG)	<b>RPS Selection</b> 12 GPHS Modular Stirling
<b>Environment Selection</b> Inside shipping container	<b>Environment Selection</b> On deep space probe (similar to Cassini)	<b>Environment Selection</b> On deep space probe (similar to Voyager)
Fuel Age Start: 1 Fuel Age Finish: N/A Total Duration: N/A	Fuel Age Start: 1 Fuel Age Finish: N/A Total Duration: N/A	Fuel Age Start: 1 Fuel Age Finish: N/A Total Duration: N/A
Select simulation limits (See manual for recommendations) <input checked="" type="radio"/> Number of particles (#) 1000000 <input type="radio"/> Runtime (minutes) 60.0 Save energy dependent fluxes? <input type="checkbox"/>	Select simulation limits (See manual for recommendations) <input checked="" type="radio"/> Number of particles (#) 1.00E+06 <input type="radio"/> Runtime (minutes) 60.0 Save energy dependent fluxes? <input type="checkbox"/>	Select simulation limits (See manual for recommendations) <input checked="" type="radio"/> Number of particles (#) 1.00E+06 <input type="radio"/> Runtime (minutes) 60.0 Save energy dependent fluxes? <input type="checkbox"/>
Incorrect <input checked="" type="checkbox"/> Correct	Incorrect <input checked="" type="checkbox"/> Correct	Incorrect <input checked="" type="checkbox"/> Correct
Start Simulation 1 Stop Simulation 1	Start Simulation 2 Stop Simulation 2	Start Simulation 3 Stop Simulation 3
<b>Simulation 1 Information</b> Simulation started:  Simulation start: <input type="text"/> Estimated finish: <input type="text"/> Simulation finished? <input type="button"/>	<b>Simulation 2 Information</b> Simulation started:  Simulation start: <input type="text"/> Estimated finish: <input type="text"/> Simulation finished? <input type="button"/>	<b>Simulation 3 Information</b> Simulation started:  Simulation start: <input type="text"/> Estimated finish: <input type="text"/> Simulation finished? <input type="button"/>

# Output Analysis

RPS-DET

HelpOptions

Introduction1) Project2) Input Geometry3) Input Source4) Input Execution5) Output Analysis

Information about the project

Load a finished project (.rpsdet file)

Load...

Title

Mission to Jupiter

Notes

This mission will involve terrestrial, transit, and orbital scenarios for an MMRTG starting at 5yr old fuel

Date of RPS-DET File Creation:07-Nov-2019

Number of Simulations (1-3):3

Simulation 1

RPS Selection:Multi Mission Radioisotope Thermoelectric Generator (MMRTG)

Environment Selection:Inside shipping container

Rotation (degrees):0Start year:1Stop year:N/A

Runtime (hrs):0Number of particles (#):0

Simulation Date:07-Nov-2019 17:14:08

Simulation 2

RPS Selection:Multi Mission Radioisotope Thermoelectric Generator (MMRTG)

Environment Selection:On deep space probe (similar to Cassini)

Rotation (degrees):0Start year:1Stop year:N/A

Runtime (min):1.12Number of particles (#):1.00E+05

Simulation Date:07-Nov-2019 17:25:36

Simulation 3

RPS Selection:12 GPHS Modular Stirling

Environment Selection:On deep space probe (similar to Voyager)

Rotation (degrees):0Start year:1Stop year:N/A

Runtime (min):1.2633Number of particles (#):1.00E+05

Simulation Date:07-Nov-2019 17:31:35

Select a Simulation

Simulation 1

Simulation 2

Simulation 3

Choose Application to Visualize Geometry and/or Results

Mesh View is the easiest way to view and interact with single tally results in 2D, with the lowest resolution of geometry information. Select a tally result to view in the menu below.

Flux/Fluence

Response (SI)

Response (English)

Custom

Photon Air Exposure (R/hr or R)

Neutron Kerma in Silicon (rad(Si)/hr or rad(Si))


Mesh View

Fulcrum will allow you to view and interact with the multiple tally results in 2D, with a higher resolution of geometry information. This will load your input file into Fulcrum where tallies can be overlaid and inspected.

Fulcrum

Keno 3D will not allow visualization of the tally results but will allow 3D visualization of the geometry and materials. This will load your input file into Keno 3D where the geometry can be rendered (no tallies).

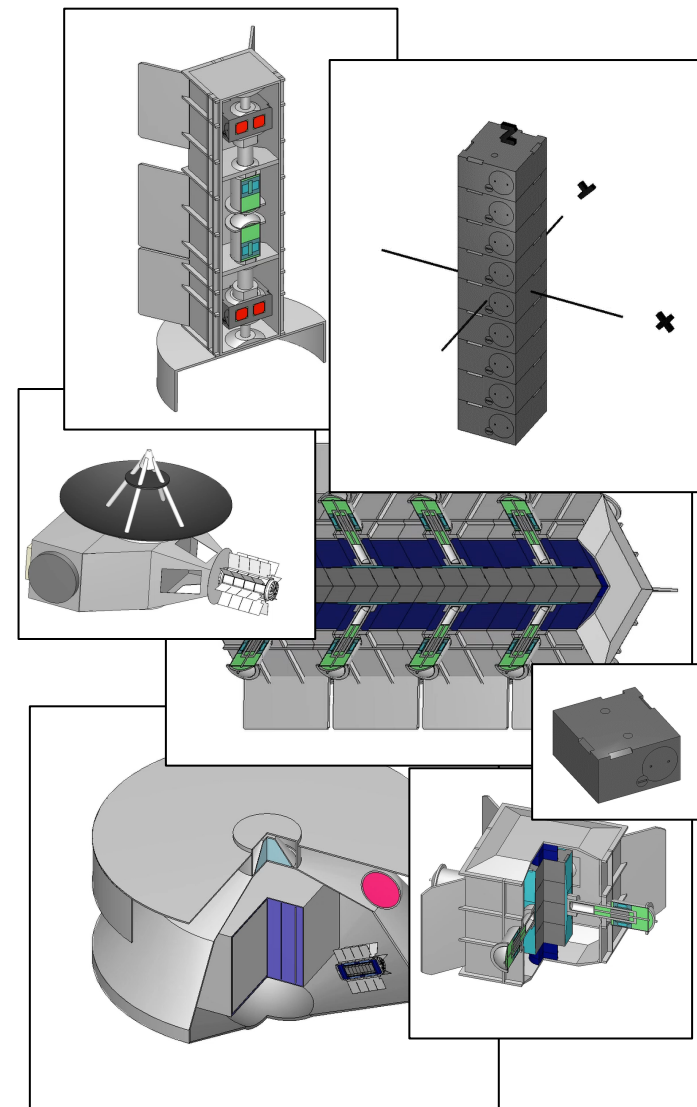
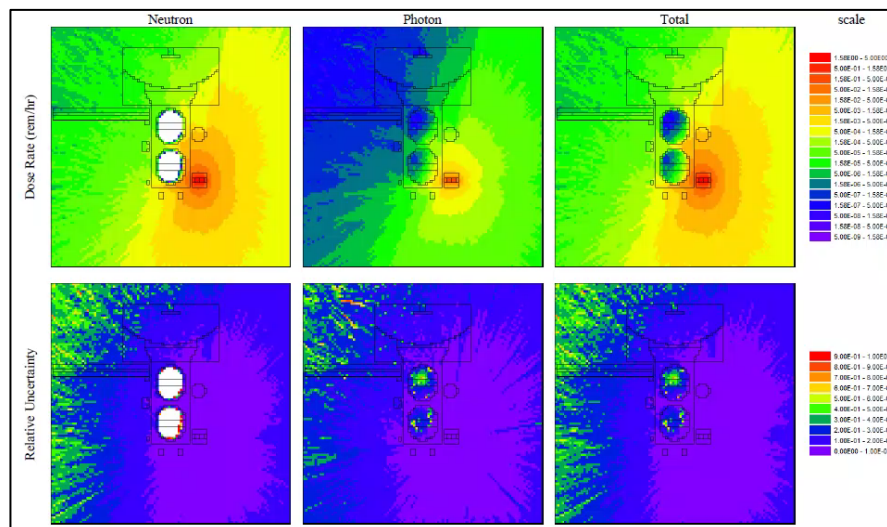
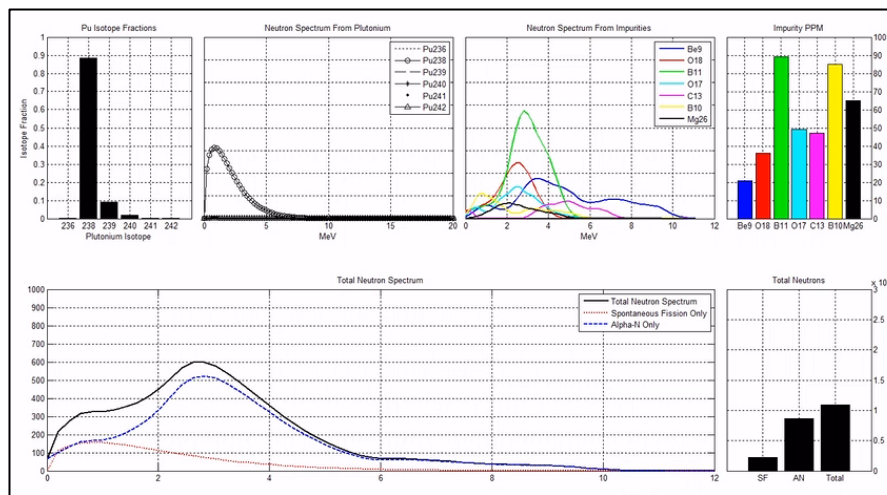
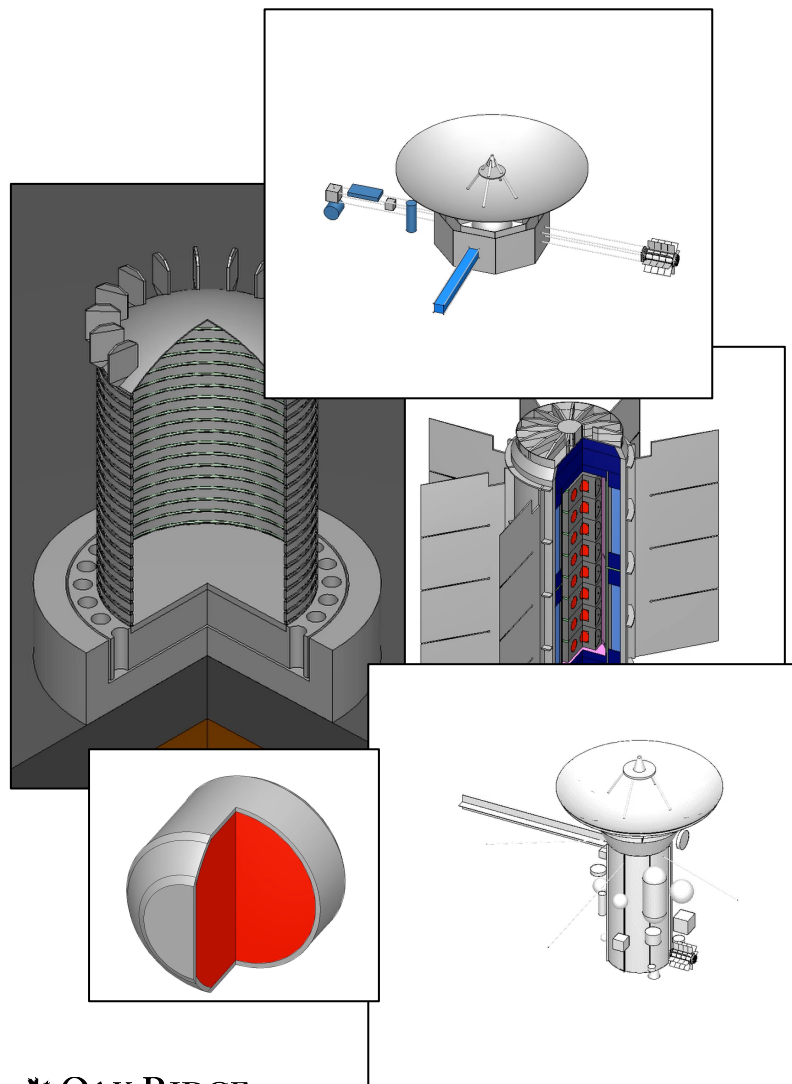
Keno 3D

 OAK RIDGE  
National Laboratory

10

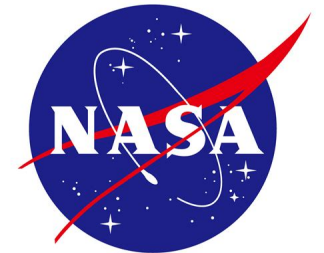
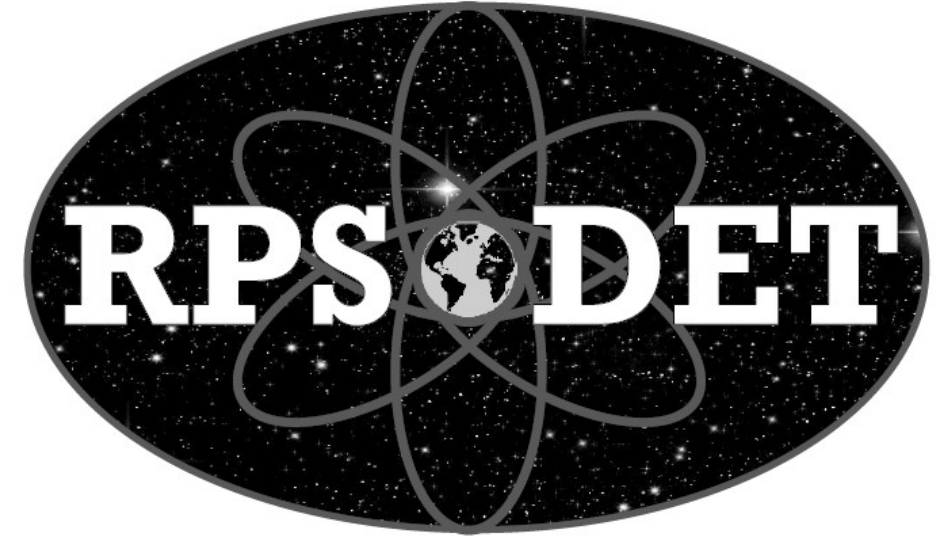


$$29_{OOI} \times 42_{EOI} \times 360_{Rotate} \times 100_{Yr} \times 5_{Pu} \times 12_{Imp} \times \sim 100_{Conc} \times \sim 100_{ppm} = \sim 1E13_{Combinations}$$



# Current Users:

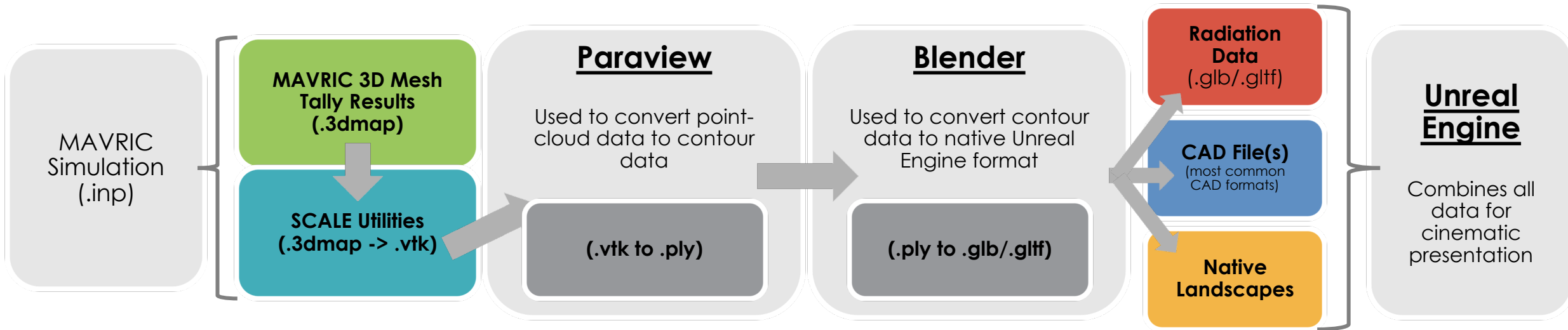
- Oak Ridge National Laboratory (ORNL)
- Idaho National Laboratory (INL)
- NASA Jet Propulsion Laboratory (JPL)
- Johns Hopkins Applied Physics Laboratory (JHU-APL)
- Ball Aerospace
- ...more to come!



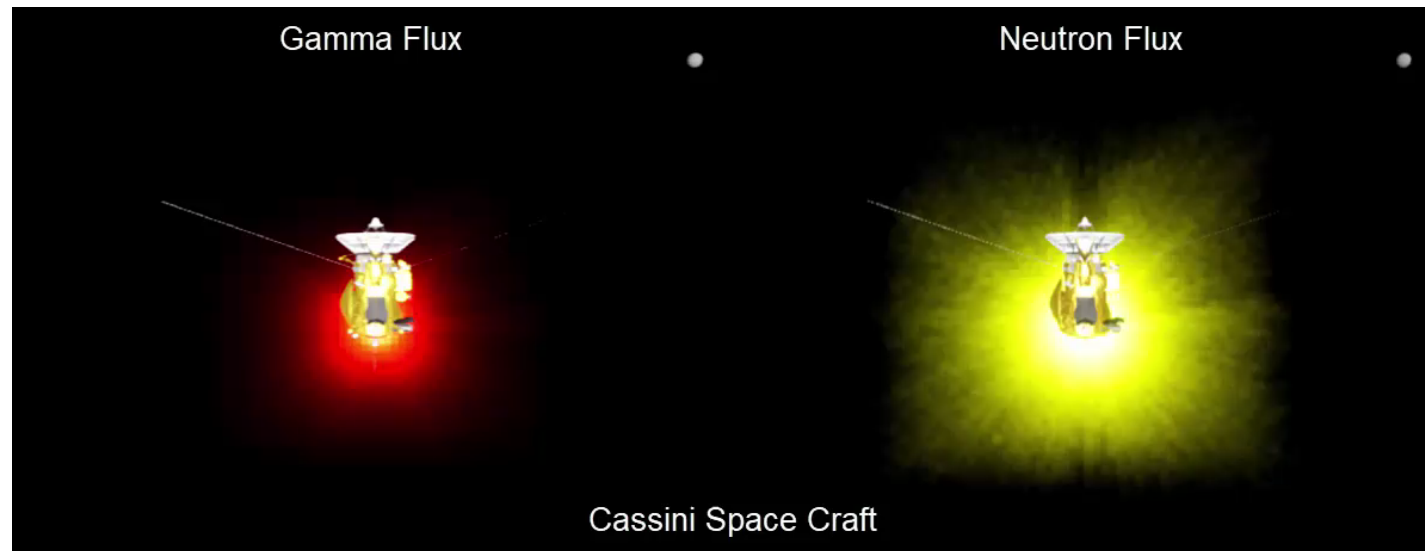
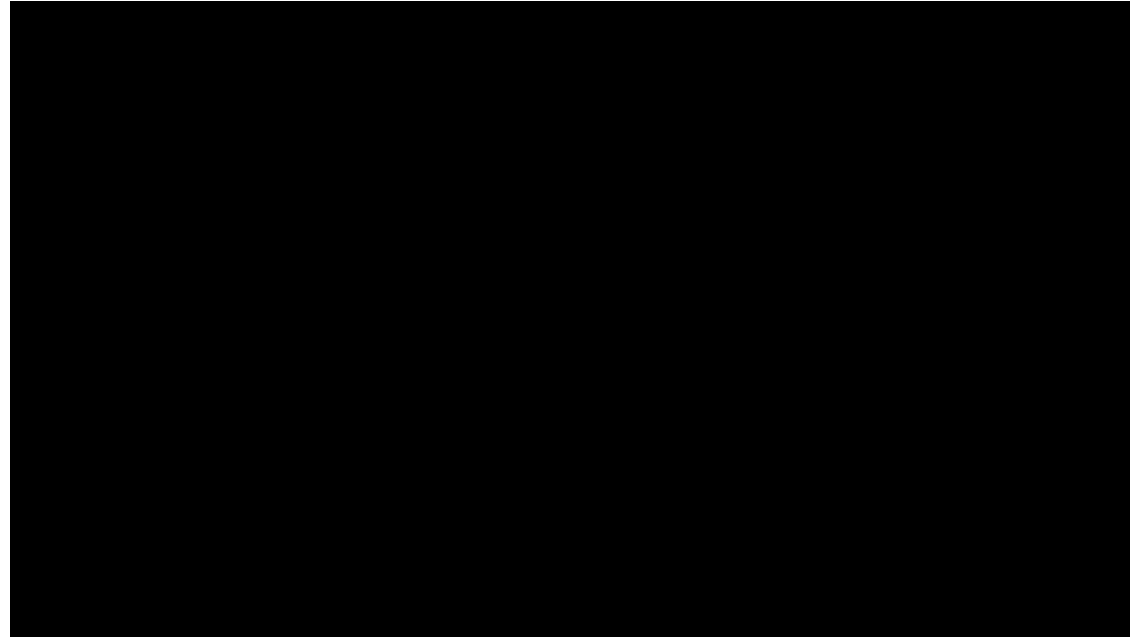


# Data Visualization Developments

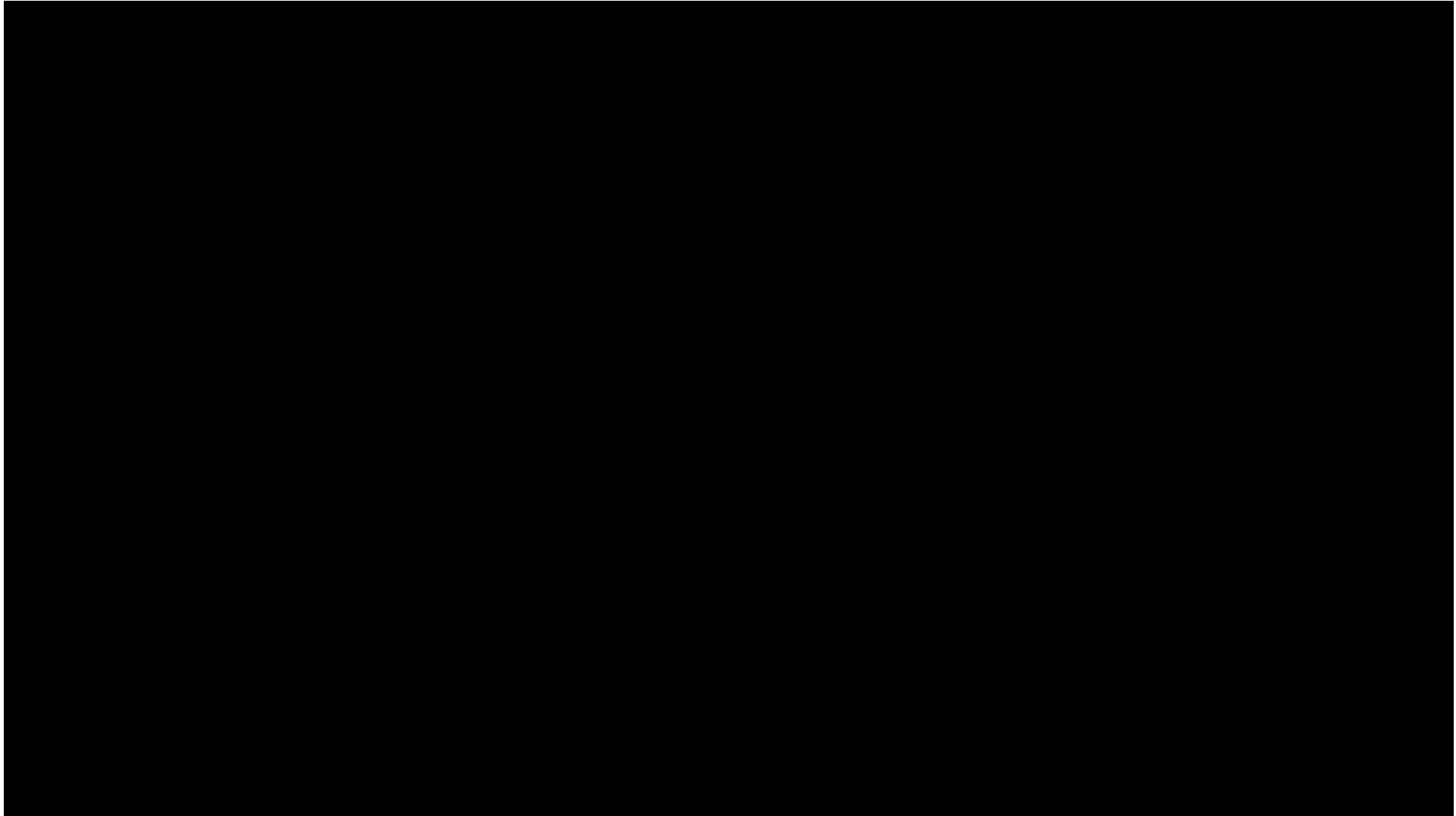
Developing methods for coupling SCALE/MAVRIC radiation transport results with Unreal Engine



# Experimental videos...



# Promotional video...





# Thank You

Michael B. R. Smith

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## Acknowledgements:

Douglas Peplow

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Rob Lefebvre

