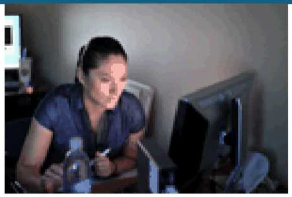
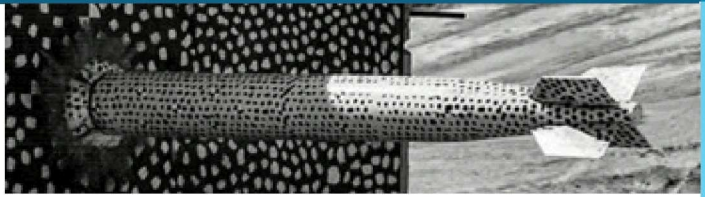
SAND2020-9380PE

Radiation Shielding of the Europa Lander Concept Terminal Sterilization System (TSS)





Aaron She

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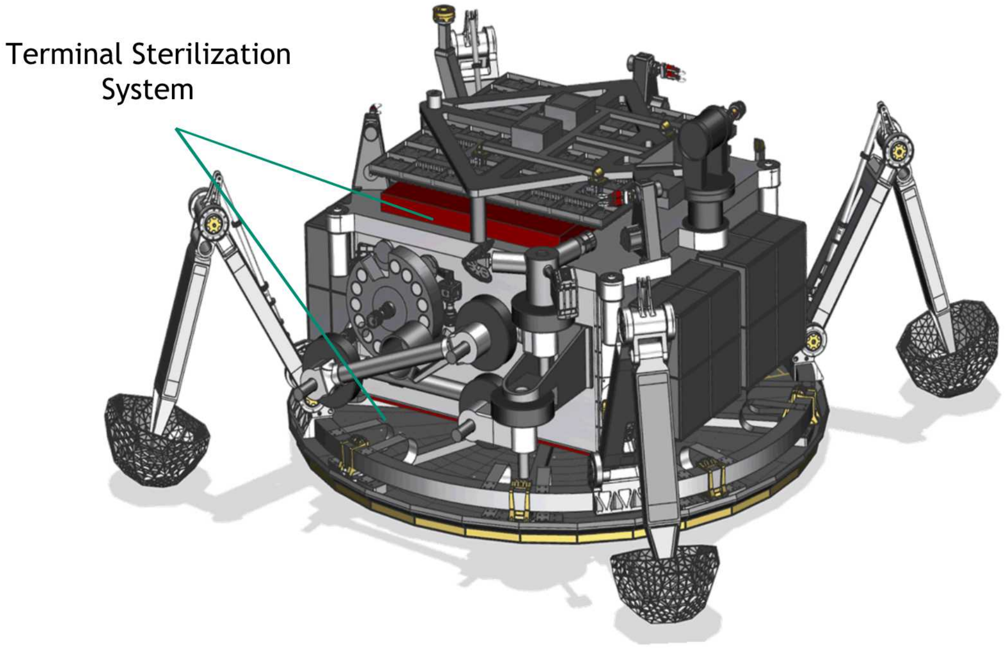
What is Planetary Protection?

Planetary protection is the limiting or prevention of celestial bodies from forward or backwards biological contamination as required by international treaty and NASA policy

Depending on the mission destination, the planetary protection requirements can be more or less stringent

Europa is a strong candidate for finding biosignatures of life outside of Earth – planetary protection therefore is a high priority requirement for the Europa lander mission concept

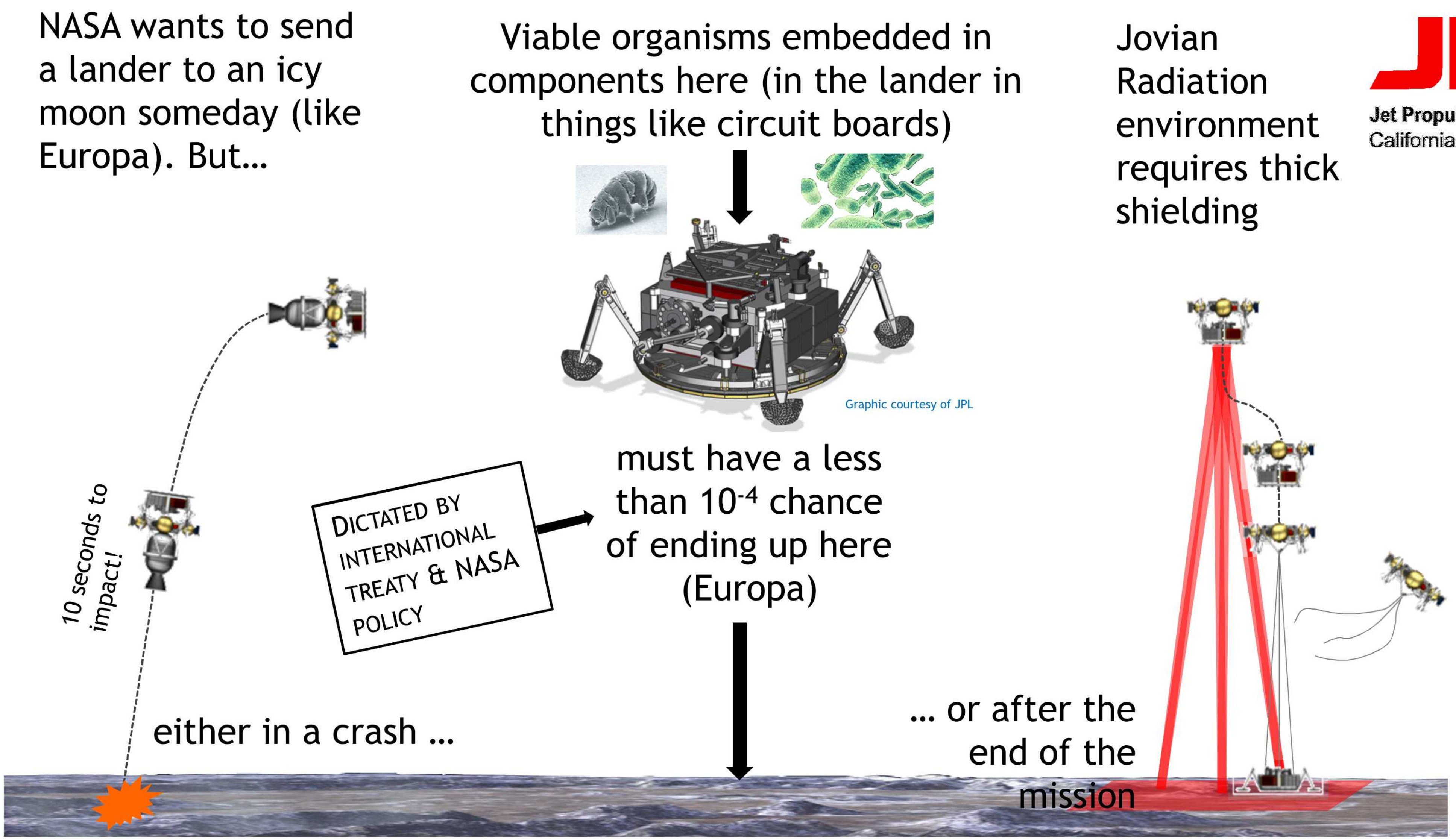
The Terminal Sterilization System (TSS) is the Sandia developed solution for planetary protection requirements



Artist's concept of the Europa Lander
Courtesy of JPL

JPL
Jet Propulsion Laboratory
California Institute of Technology

The Terminal Sterilization System (TSS)



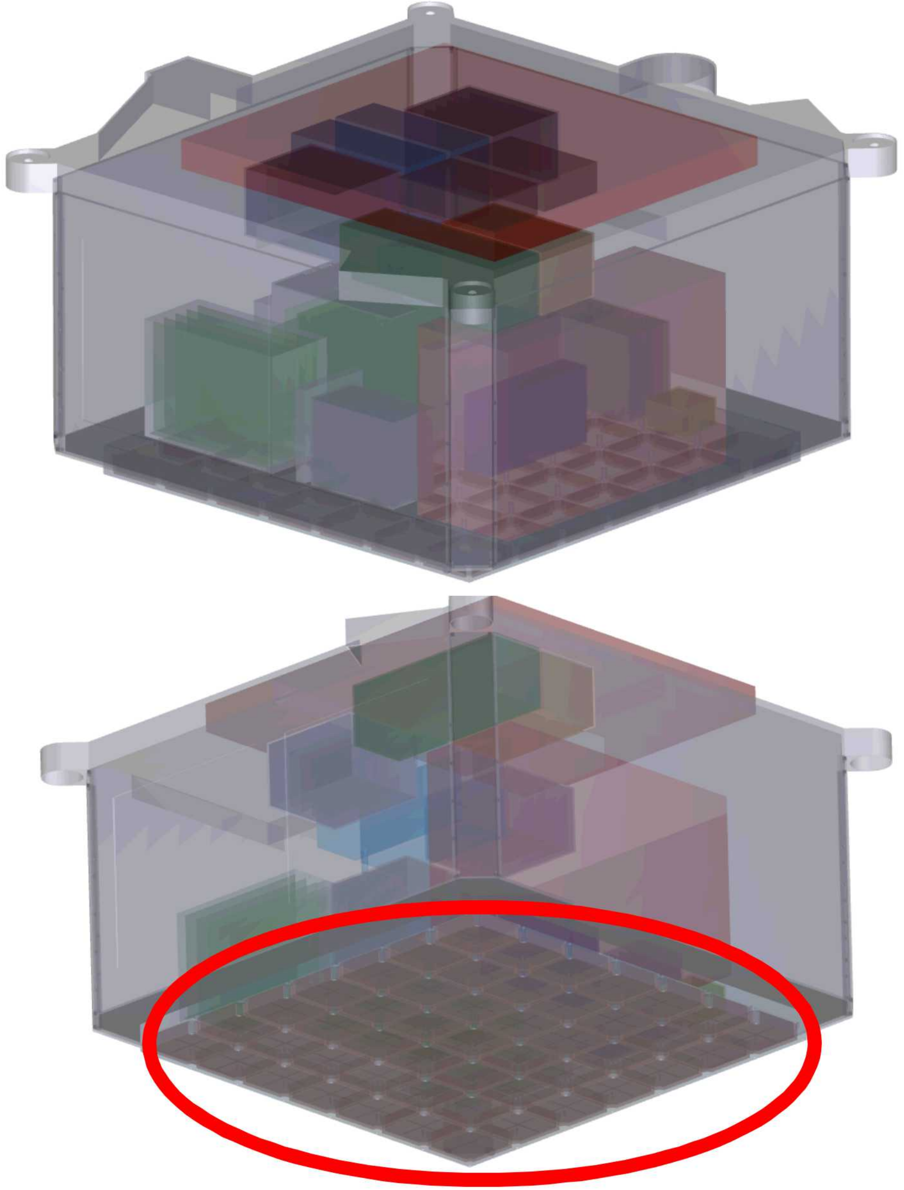
Jet Propulsion Laboratory
California Institute of Technology

Mission Concept

The TSS consists of an energetic material and oxidizer that uses the lander materials as fuel

Heats the interior of the lander's radiation vault electronics housing to 500 ºC for 0.5 seconds within 10 seconds to sterilize the lander at the conclusion of the scientific mission

Mission duration is provisionally planned for 22 days on the surface of Europa + several flybys and vehicle descent stages



TSS tray in red highlight

Radiation Environment

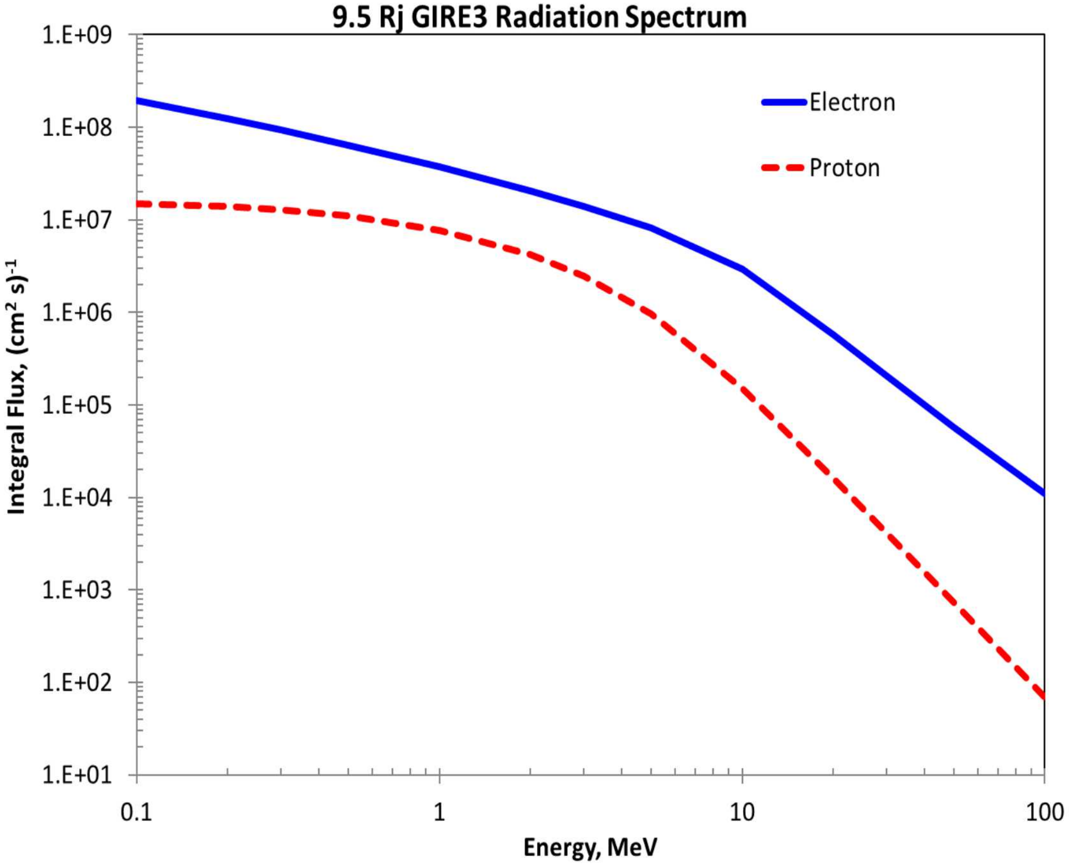
The Jovian trapped radiation belt environment consists mostly of high energy electrons trapped by Jupiter's magnetic field

The radiation environment within Europa's orbit is one of the most hazardous radiation environments in the solar system

Materials can undergo material property changes under high doses of ionizing radiation

High energy electrons also deposit charge in materials – if the charge buildup exceeds the dielectric strength of the material, it can cause arcing (possibly premature ignition of the TSS!)

Further complications: radiation tends to increase the conductivity of materials and there does not exist any analytical or theoretical models that accurately predict this effect – requires testing of energetic materials in electron beam irradiation facilities



Radiation environment spectral data courtesy of JPL

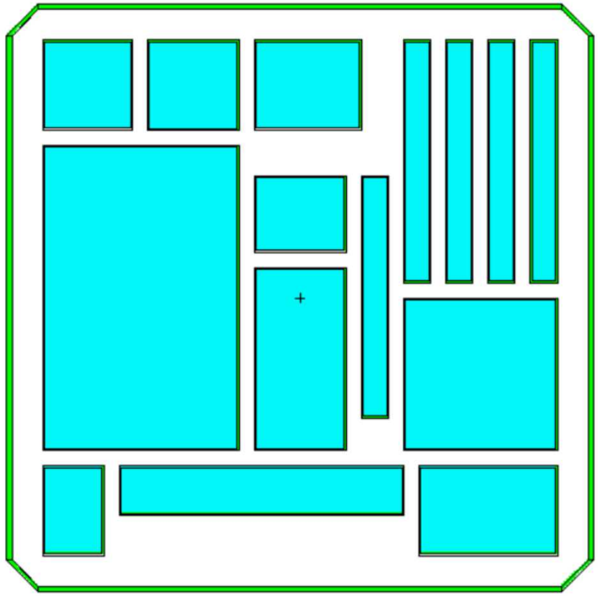
Modelling and Simulation work

Interior of radiation vault modelled with several electronics aluminum electronics boxes filled with 15% density SiO2 to approximate electronics

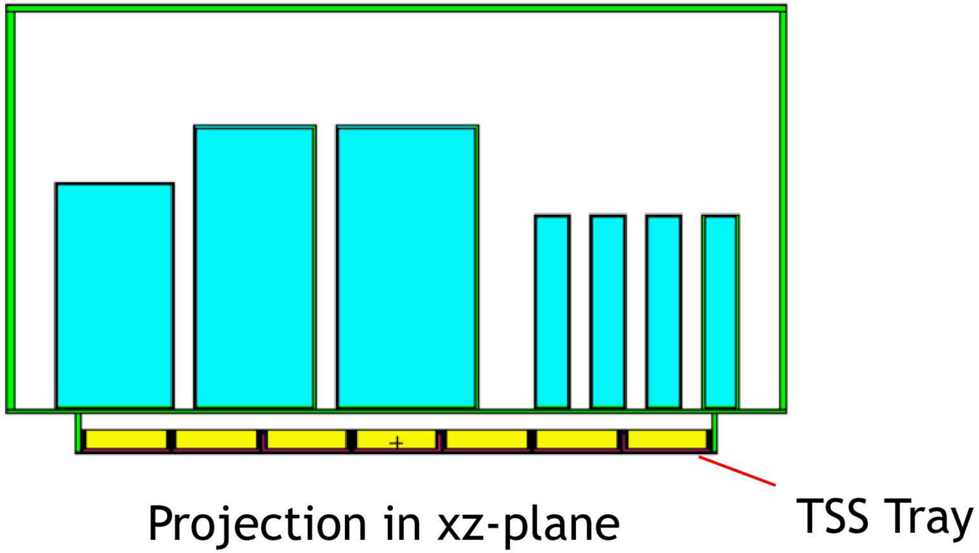
Mixture of free space and heavy materials – some particles will miss all boxes then impact the TSS with high energy, and some particles will scatter erratically as they traverse through the vault

Radiation transport code MCNP6.2 (Monte-Carlo N-Particle) was used to simulate the radiation environment and calculate the radiation dose in the TSS

Pictures at right are cutaway views of the lander vault



Projection in xy-plane

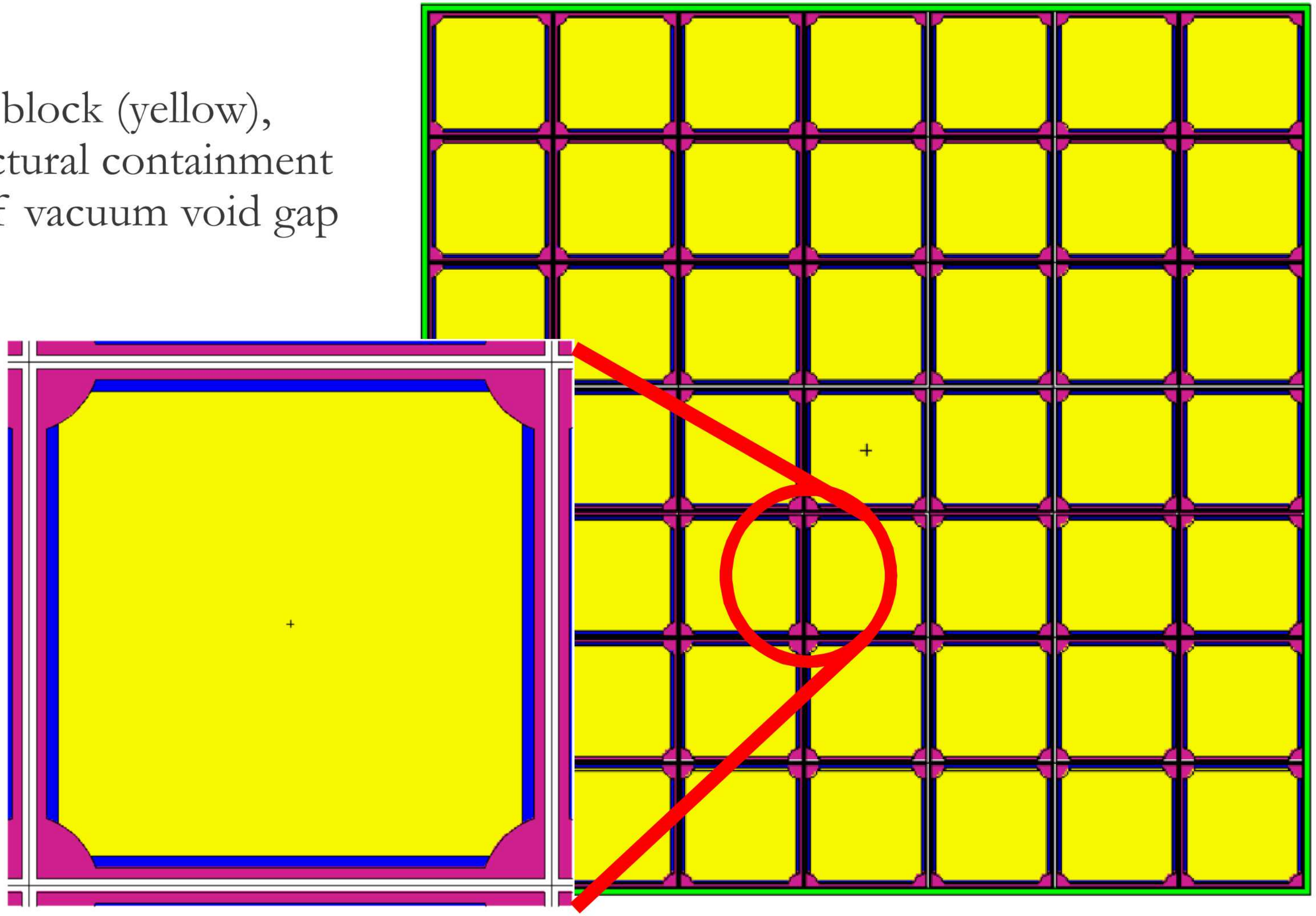


Projection in xz-plane

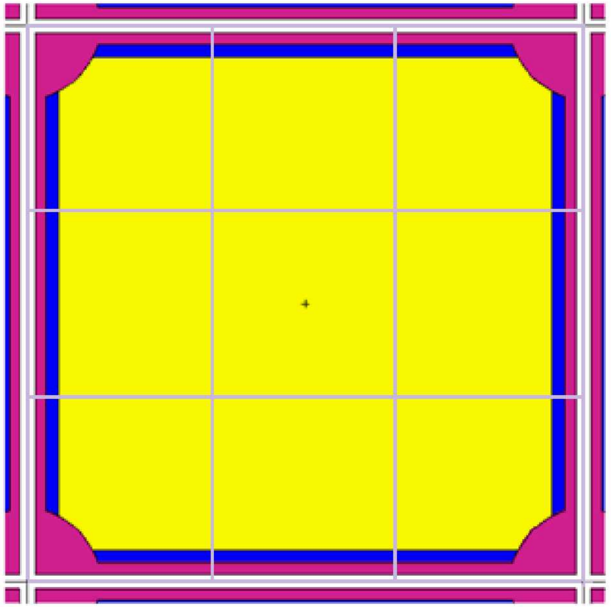
Modelling and Simulation work

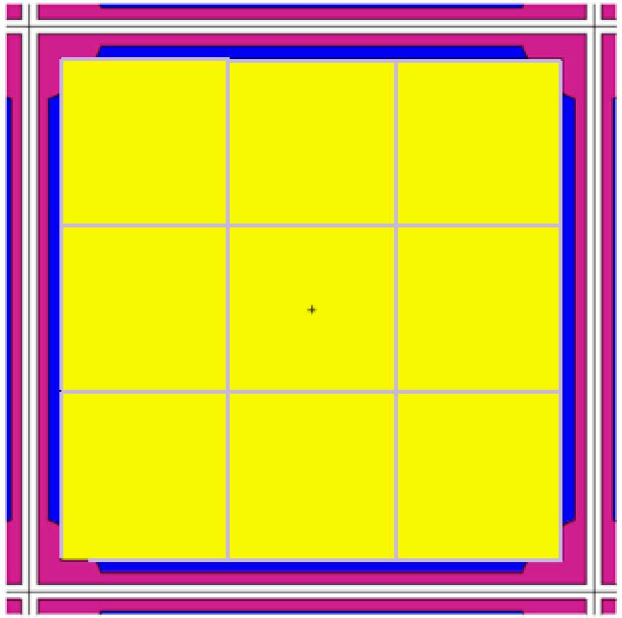
Cutaway view of the TSS

Consists of energetic material block (yellow), thermal insulation (blue), structural containment material (purple), and 3 mm of vacuum void gap between elements (white)



Real vs. Idealized





TOP: model with accurate geometry

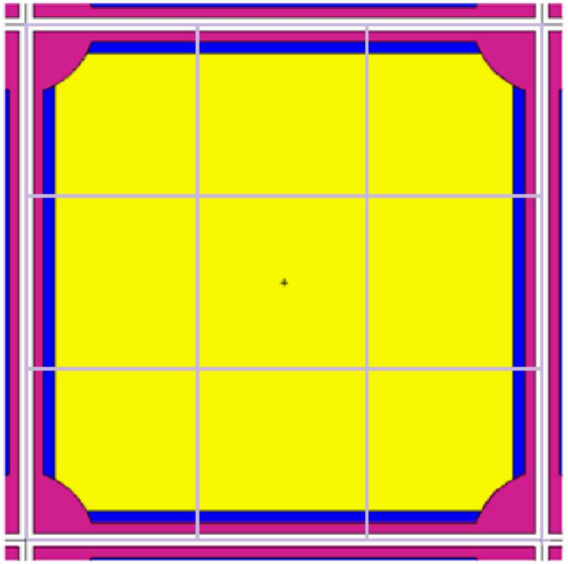
BOTTOM: idealized geometry for dose calculation in the energetic

- A mesh was superimposed over the TSS to calculate dose
- In the top closeup, the superimposed mesh captures non-energetics regions (insulation and structural materials, void space between elements)
- Led to a fictitiously high dose calculated in the corner and edge bins of each element; middle bin contains only energetics
- Led to a "checkerboard" patterning where dose calculations were erroneously high on the corners and edges of every element

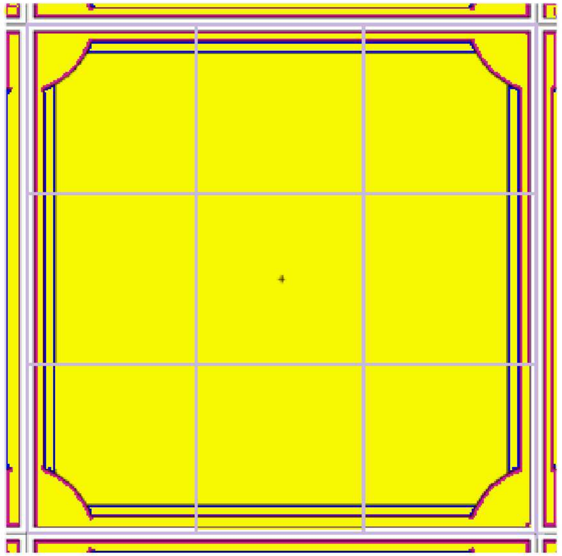
- In the idealized case, the corners are carved in square and the mesh is only superimposed on the boundaries of the energetic material

- A few other runs with homogenized materials and removed void gaps were done for testing and validation purposed (included in next slide)

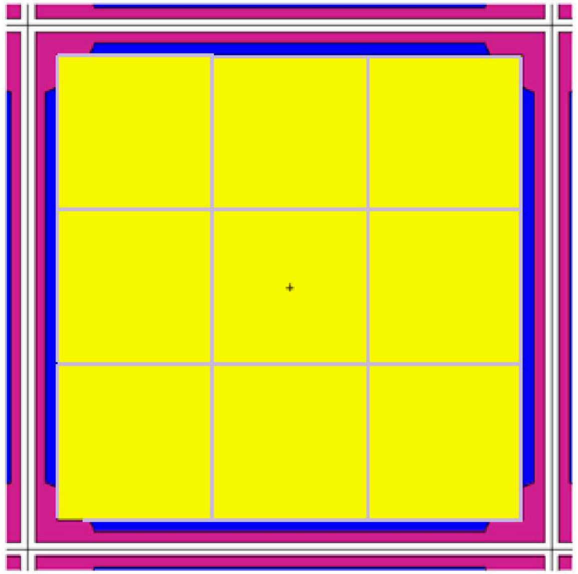
Differences between runs with superimposed mesh grid



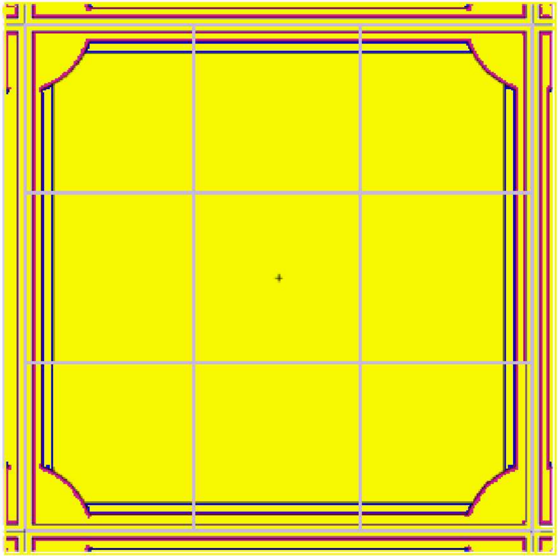
Baseline



Homogenous + gaps

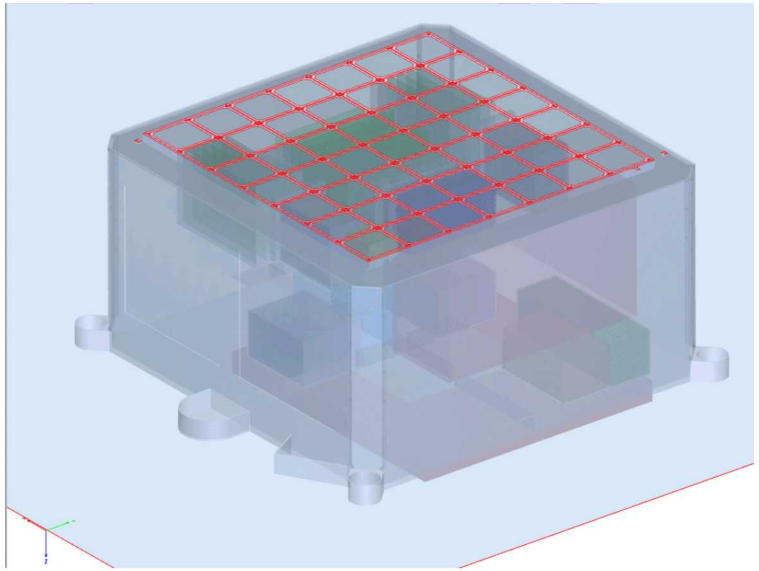


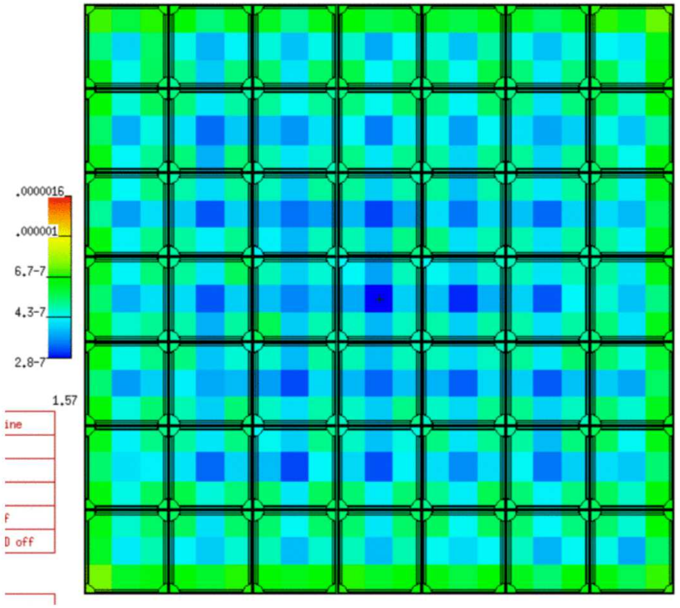
Non-uniform mesh



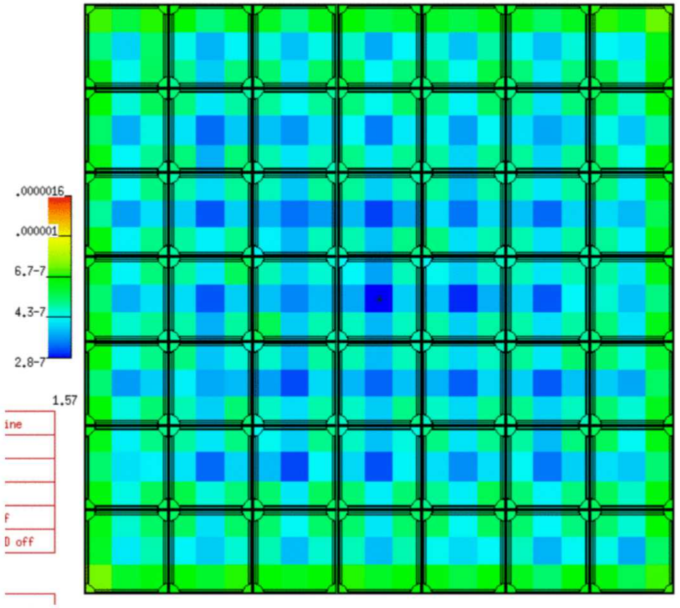
Homogenous + no gaps

Mesh tally results





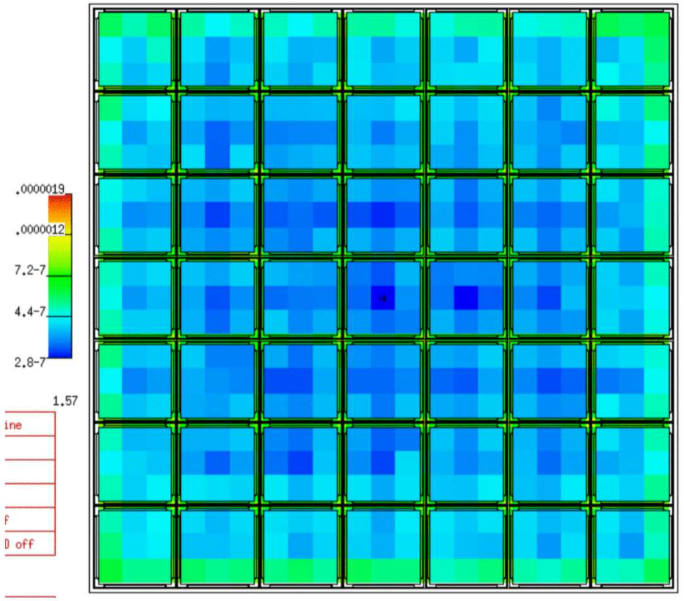
Baseline



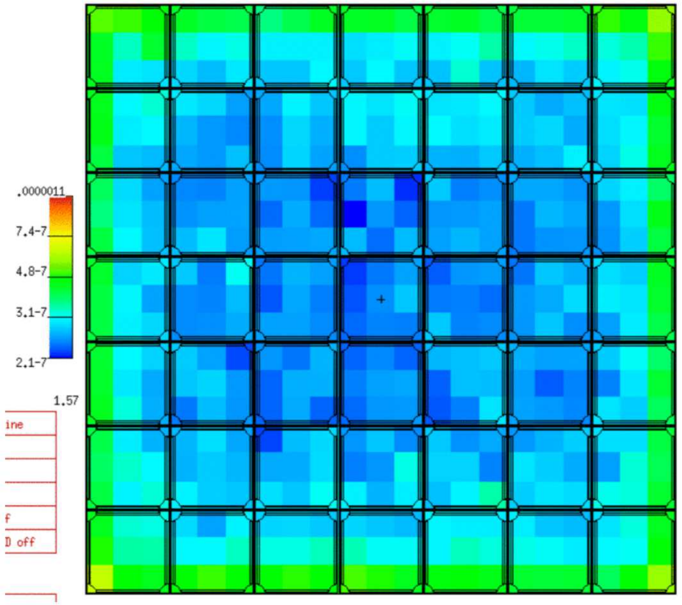
Homogenous, gaps

Dose units in MeV/g/src.

Next slides for conversions & discussions



Non-uniform mesh



Homogenous, no gaps

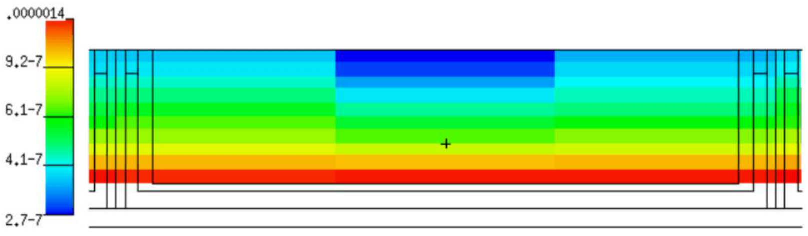
Slide 10

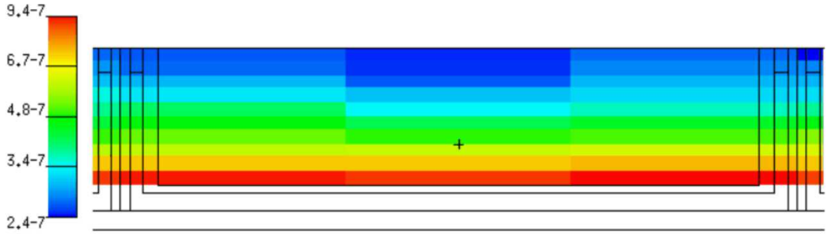
SAZ1 She, Aaron Ziyuan, 8/3/2020

Dose depth curve

Another motivation to use a mesh tally is to quantify the dose wrt. depth in the energetic

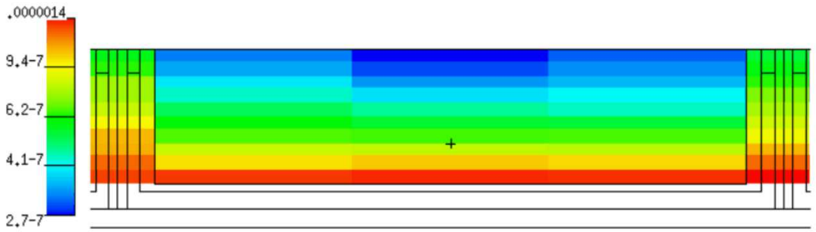
Plots are dose as a function of EM depth (z direction) for the center-most mesh bin of the center-most EM element (0, 0, z)

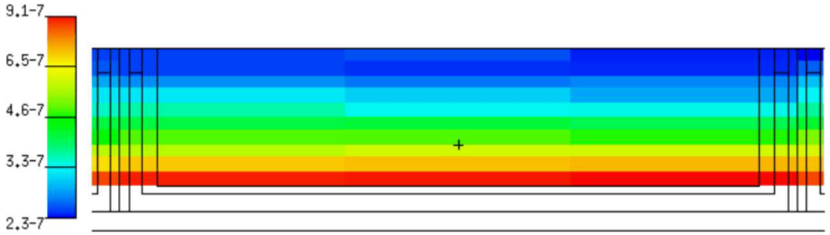




Baseline

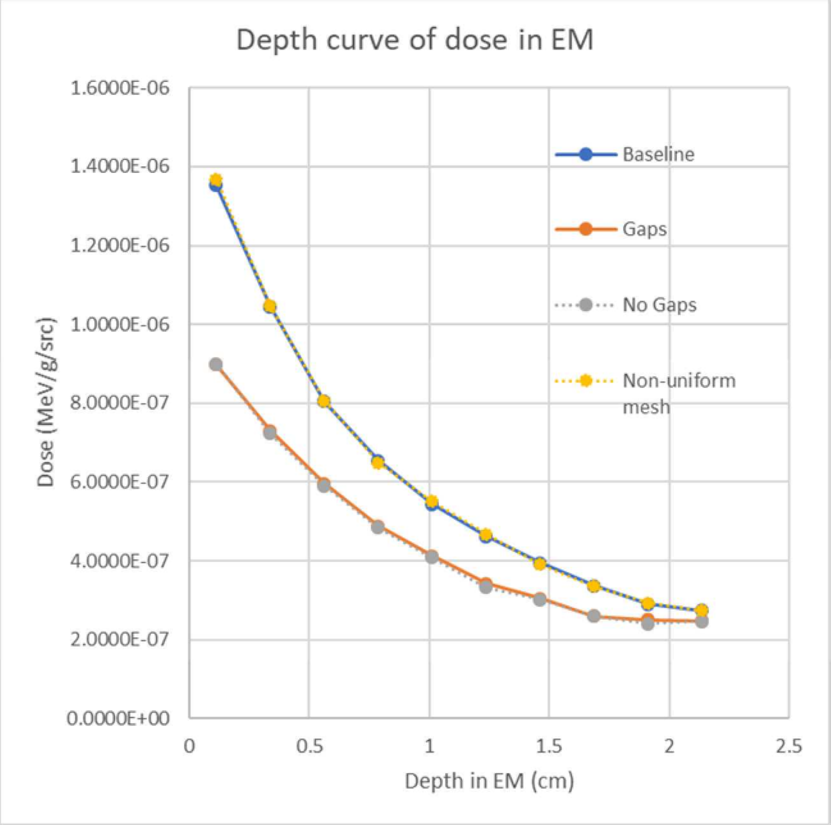
Homogenous + gaps





Non-uniform mesh

Homogenous + no gaps



Other tallies

Two other types of dose tallies were used: F6 type and F4 type

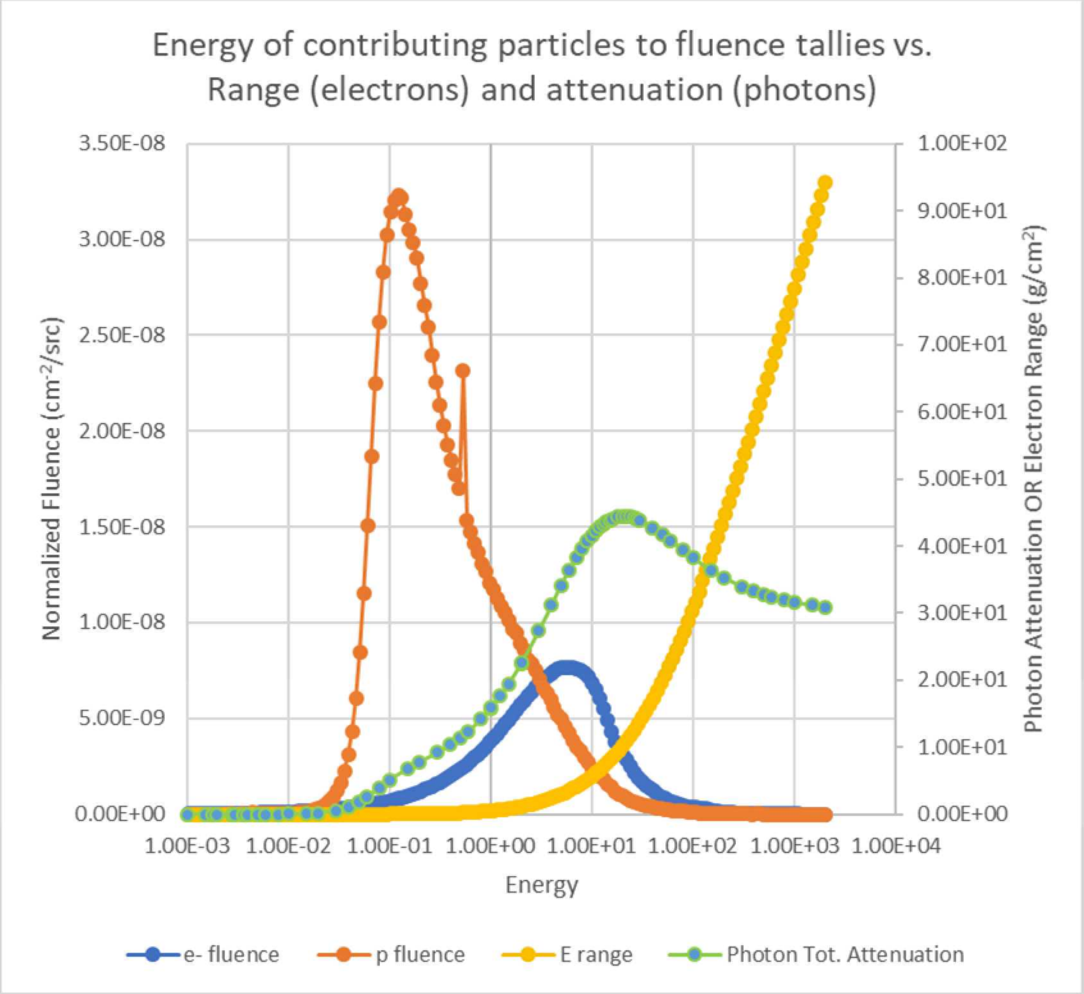
Both these tallies have the advantage of only tallying over the EM and excludes all other materials. Ignored irregularities in geometry, which is both a good and bad thing (hence the motivation to also use a mesh tally to inspect any spatial effects)

F6 is considered the **most reliable** result generated

- Collision heating tally, well tested and validated in the MCNP code
- All other tally results should be compared to the results of the F6 tally as the baseline

F4 is less reliable but still useful

- F4 is the track-length fluence estimator tally (track length / cell volume = fluence [cm^{-2}/src])
- Combined with linear energy transfer (LET) and mass stopping power (LET/dens.) conversion treatments to calculate dose
- **Useful to determine which energy** (or LET) **electrons contribute the most dose**
- **Range / Attenuation of electrons / photons at their respective peaks are comparable. Since photon fluence >> electron fluence, this suggests most of the dose is from photons – needs more testing!!**



Comparisons & Discussions

	Baseline		Homogenous + Gaps		Homogenous + No Gaps		Non-Uniform Mesh	
Dose (krad/day)	Result	Rel Err %	Result	Rel Err %	Result	Rel Err %	Result	Rel Err %
F-type Tallies								
F6	7.832	0.11	5.562	0.16	5.454	0.16	7.845	0.10
F4 LET	8.955	0.11	6.357	0.16	6.231	0.16	8.971	0.11
FMESH								
Avg Dose	13.40	3.0604	9.244	4.6438	8.637	4.7331	11.98	3.6313
Max Dose	28.27	2.0882	21.18	4.8318	19.84	4.3674	26.97	2.3311
Min Dose	4.796	4.2974	4.013	5.9134	3.569	6.2458	4.775	4.7516
Relative to F6 tally								
F4 LET/F6	1.1435		1.1428		1.1425		1.1487	
FMESH/F6	1.7115		1.6620		1.5836		1.5277	

- F6 is considered the most reliable tally and is the baseline other tallies are compared to
- F4 results systematically overestimate the F6 dose by about 14.3%, likely attributed to needing more data fitting points in the mass stopping power conversion factors used
- FMESH greatly overestimates the F6 dose by 50+%
  - However the fit gets better as we eliminate spatial effects that fictitiously tally higher dose in non-EM regions (ultem, fiberfrax, voids)
  - The last two runs (homogenous + no gaps, non-uniform mesh) eliminated the spatial discrepancies entirely but are still off by a significant margin due to differences in the DE/DF dose response functions required by mesh tallies compared to the tally treatment in F4

Projection of Radiation-Induced Conductivity

Radiation induced conductivity (RIC) changes the threat posed by internal charging

Conductivity increases as dose rate increases:

$$\sigma_{RIC}(T,x,y,z,t) = k_{RIC}(T)\dot{D}(x,y,z,t)^{\Delta(T)}$$

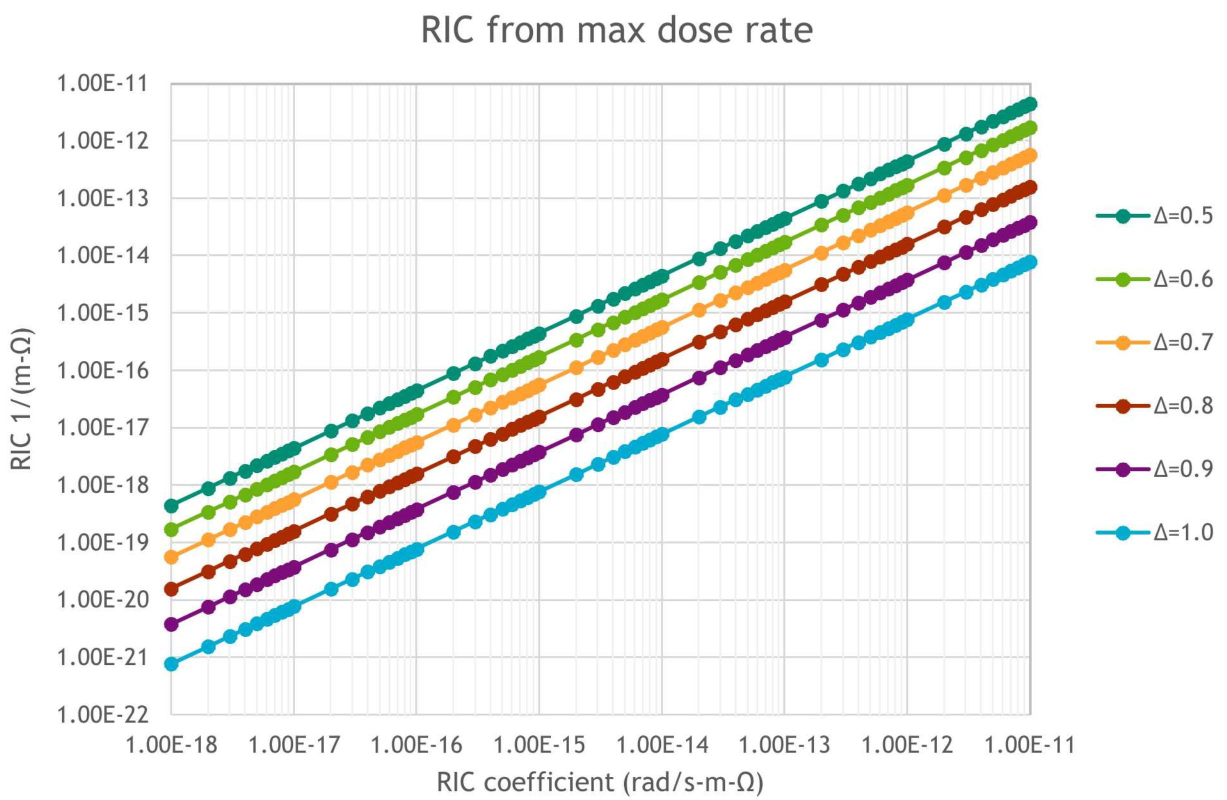
Using the max dose rate, the radiation-induced conductivity coefficient is scoped out from E-18 to E-11 (rad/s-m-Ω)

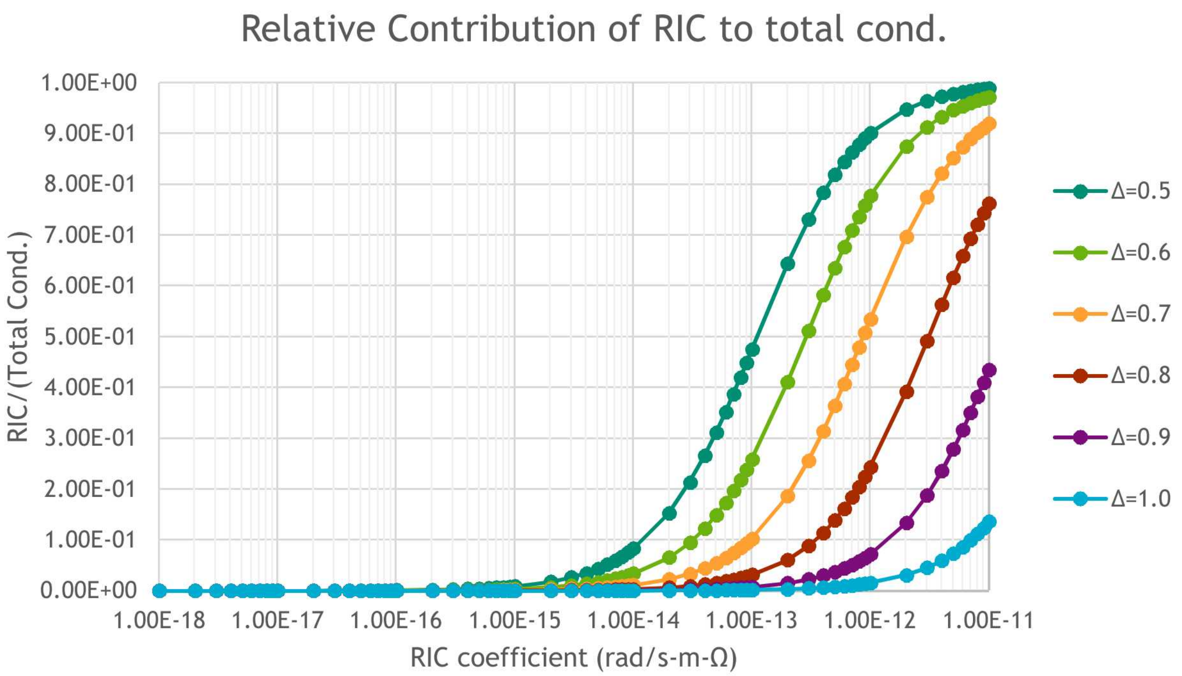
This will hopefully inform future experiments to measure RIC with the TSS materials

Worst-case occurs when RIC is zero or negligible – internal charging is only mitigated by the dark conductivity of the material

Need to consider other effects like temperature and electric field on conductivity

Importance of RIC to internal charging



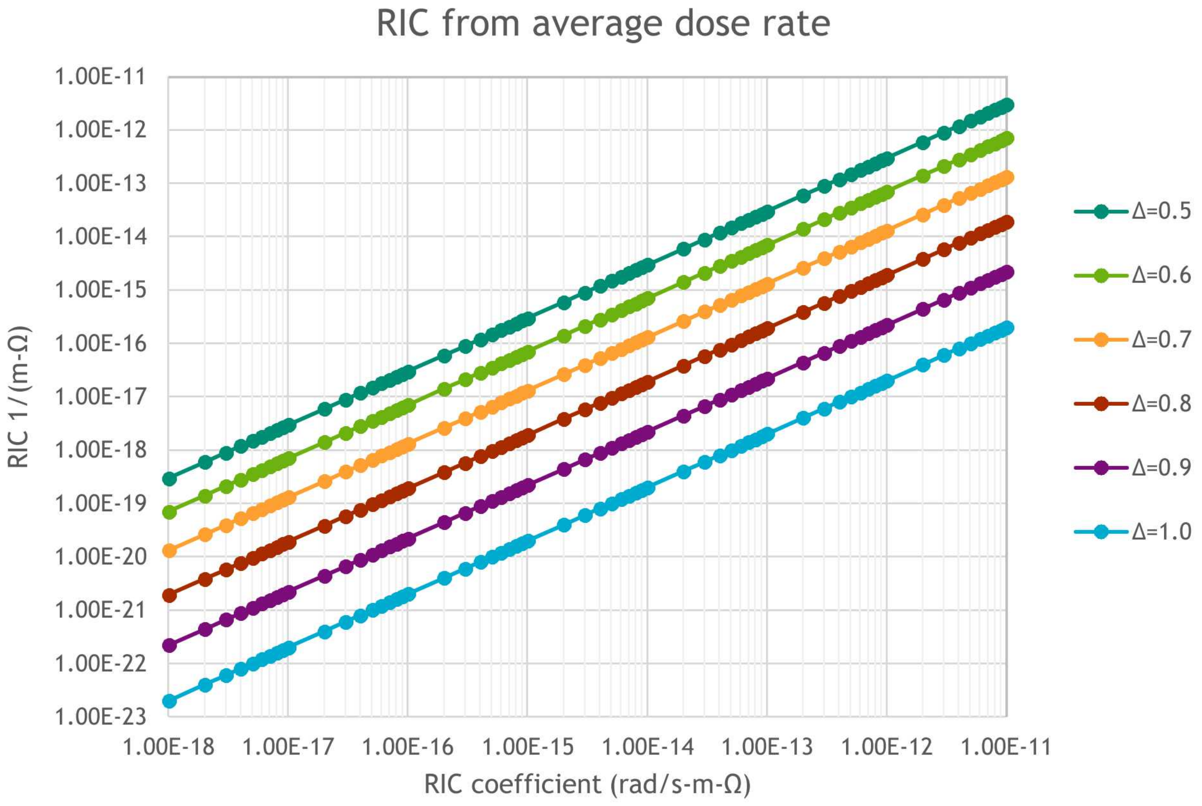


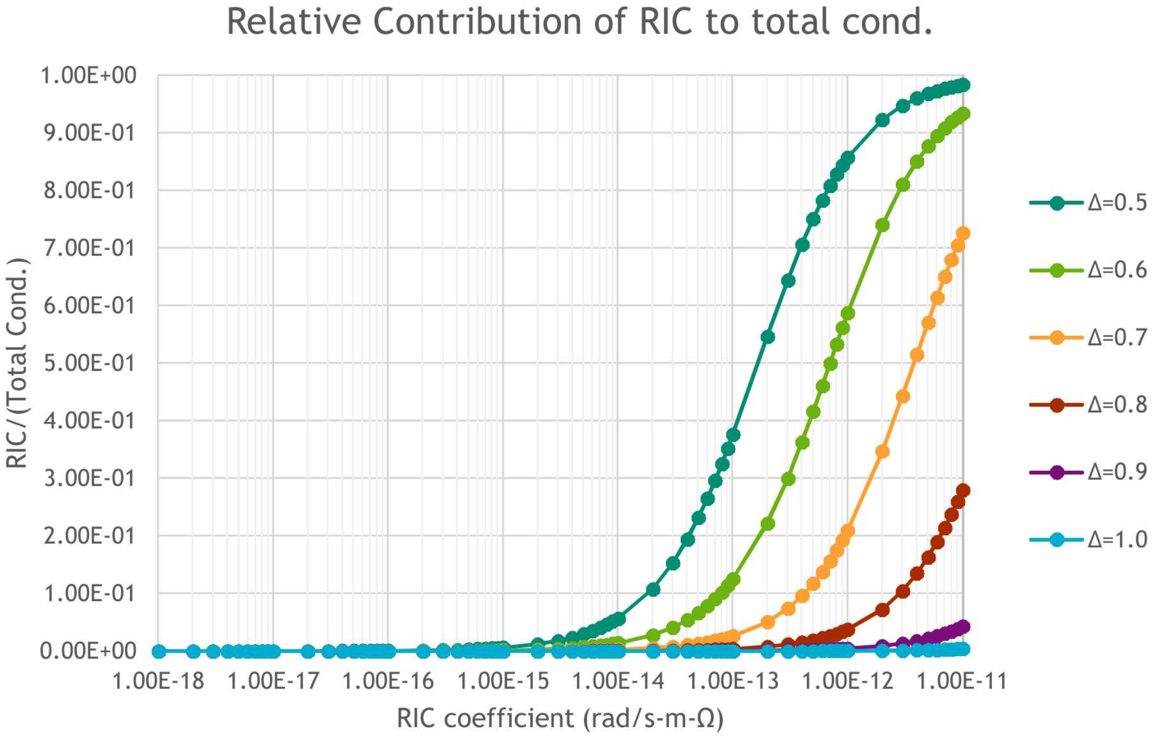
RIC coefficient and exponent not known, must be experimentally measured

Depending on the values, RIC can have a significant impact on IESD or none at all, but we will not know until an experiment to measure them the coefficients is conducted

RIC calculated at max dose rate is the 'greedy' approach – high RIC reduces IESD threat

Importance of RIC to internal charging





RIC calculated from average dose is the more conservative effect – since (Avg Dose Rate) << (Max Dose Rate)
In this case, RIC is negligible until relatively high values of the RIC coefficient and exponent (E-14 or so)
More reliant on dark conductivity to prevent IESD

NUMIT Internal Charging

Beam was treated as a monoenergetic source

Incident electron flux was normalized to energy flux, found the average electron contributes ~0.5511 MeV to the surface of the target, which is the energy of the monoenergetic source

Unrealistic, should use spectrum source instead

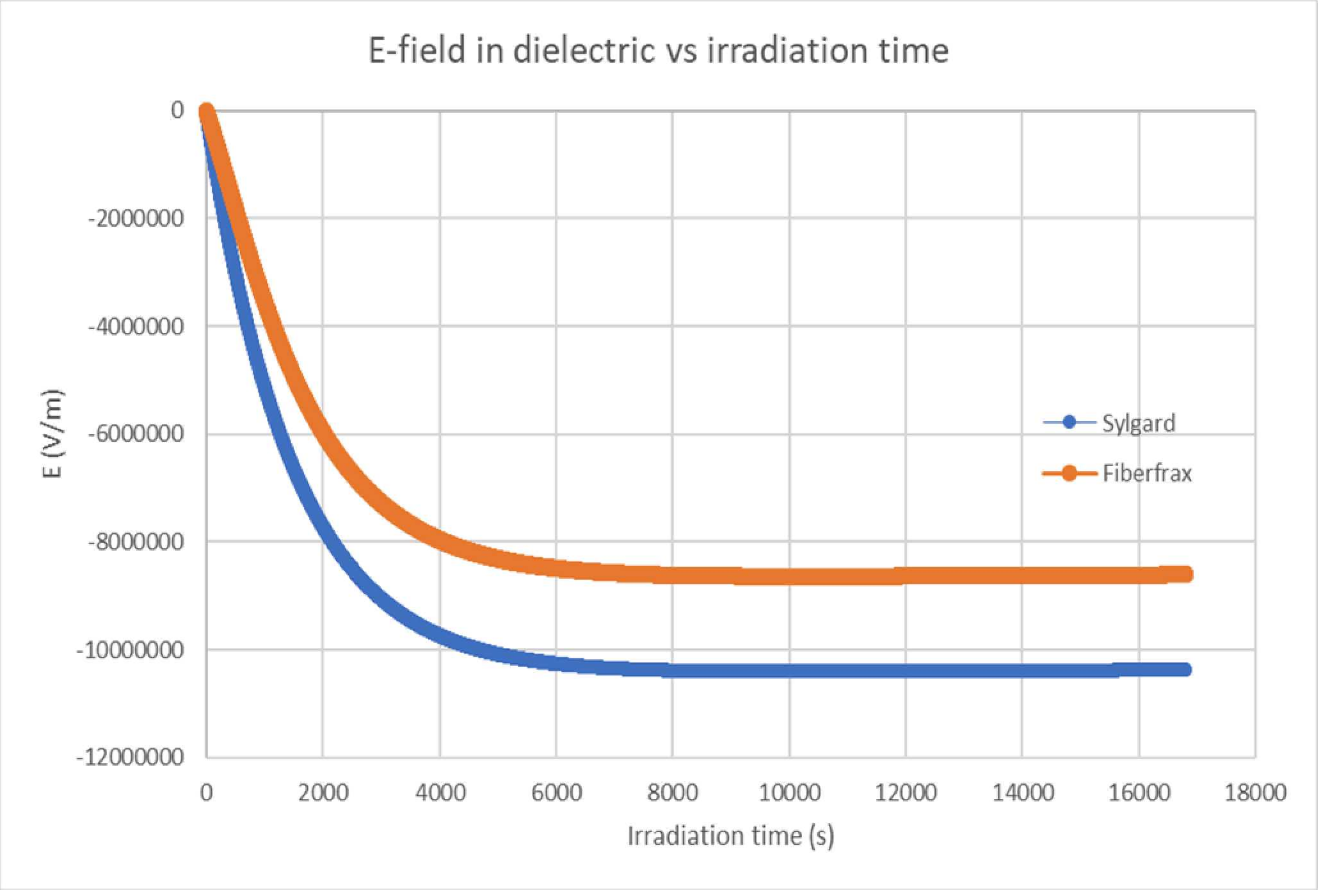
Essentially, the incident energy flux is the same, but consisting wholly of 0.5511 MeV electrons instead of a spectrum of energies

Likely greatly underestimates surface charging

May be overestimating deep charge deposition(to the depth of 0.5511 MeV electrons' penetration) since higher energy electrons are much lower in magnitude in the spectrum

Dielectric strength EM epoxy: 1.90E+7 V/m
Dielectric strength fiberfrax: 1.06E+6 V/m

Suggests fiberfrax dielectric strength exceeded – IESD
Epoxy reaches about 55% of its dielectric strength – warrants more investigation



Conclusions

Performed simulations to predict radiation related effects in the TSS energetic materials

Transition to year-round intern to continue working on this project while in school

Write new simulations for other mission stages such as the transit from Earth to Jupiter, various flybys of Jupiter, vehicle descent stage, and Europa surface operation

Radiation induced conductivity – needs physical testing

IESD – Write and run NUMIT code with spectral procedures to predict internal charging

NUMIT uses a 1-D calculation for dose-depth profiles (Tabata's algorithm), but a more sophisticated 3-D dose calculation with Monte Carlo methods (like MCNP) can be used as input for NUMIT

Discrimination of particles contributing to dose in energetic materials, perhaps via LET for electrons and energy for photons

Questions?