



Jet Propulsion Laboratory
California Institute of Technology

X-Ray Computed Tomography: A potentially destructive “non-destructive evaluation” technique

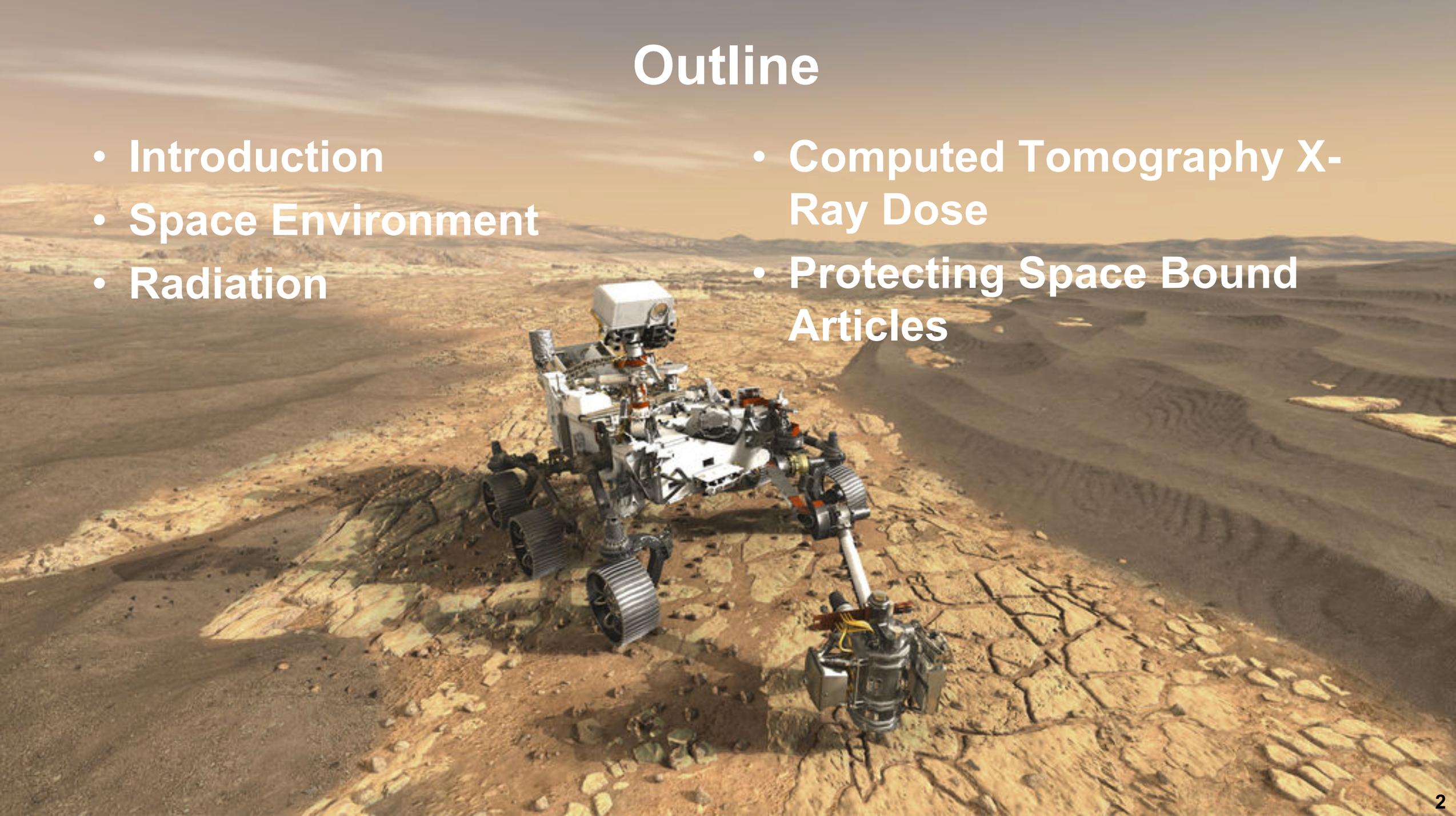
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Outline

- Introduction
- Space Environment
- Radiation
- Computed Tomography X-Ray Dose
- Protecting Space Bound Articles

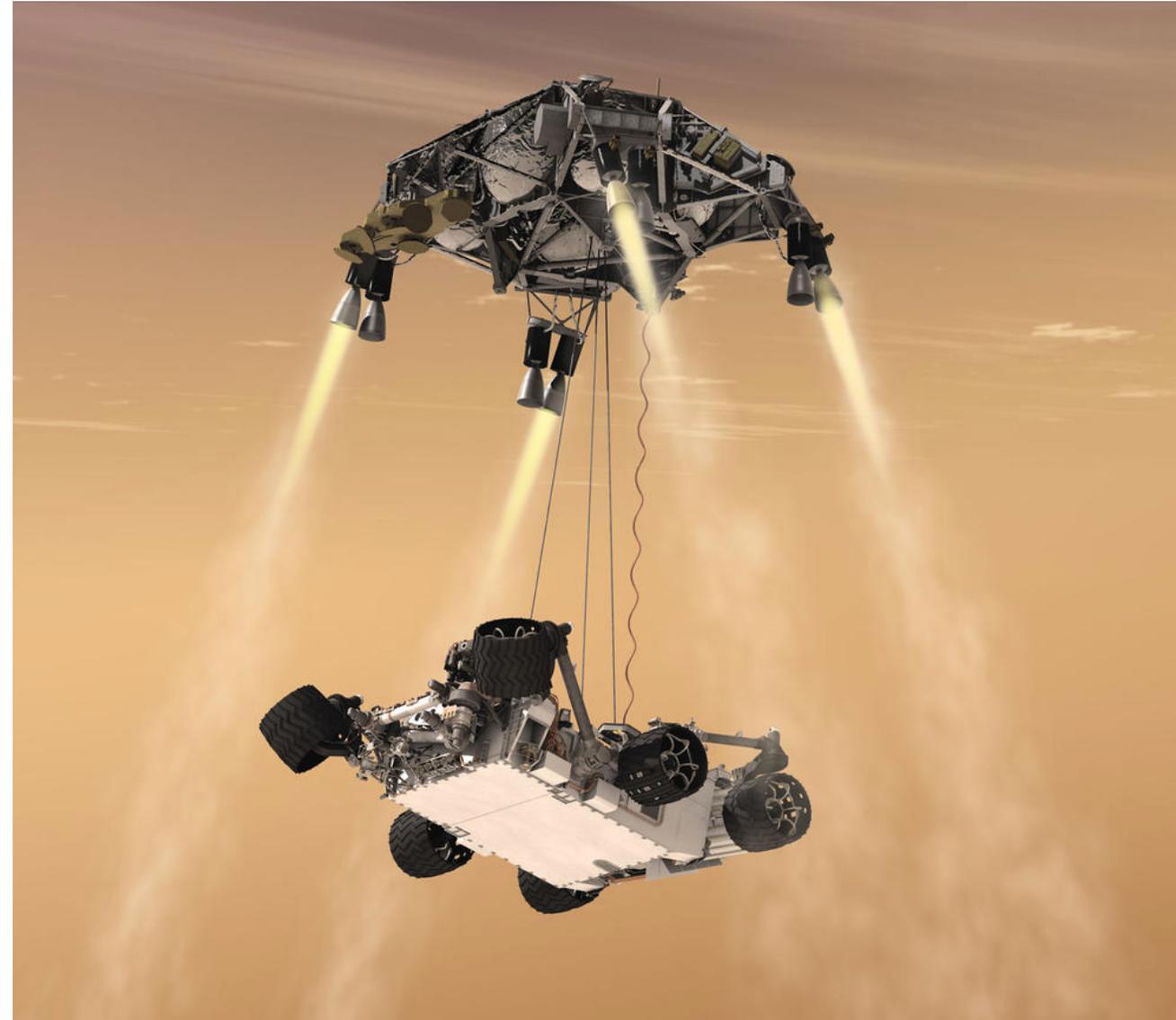


Introduction

- **Environmental conditions are major challenges affecting reliability of electronics in space exploration applications**
- **Any type of "life" or spacecraft reliability consumed on earth must be considered to ensure mission success.**
- **Failure Analysis & inspections can occur on spacecraft assemblies during manufacturing and troubleshooting.**
- **Today we will touch on concerns related to CT X-Ray.**

Space Environments

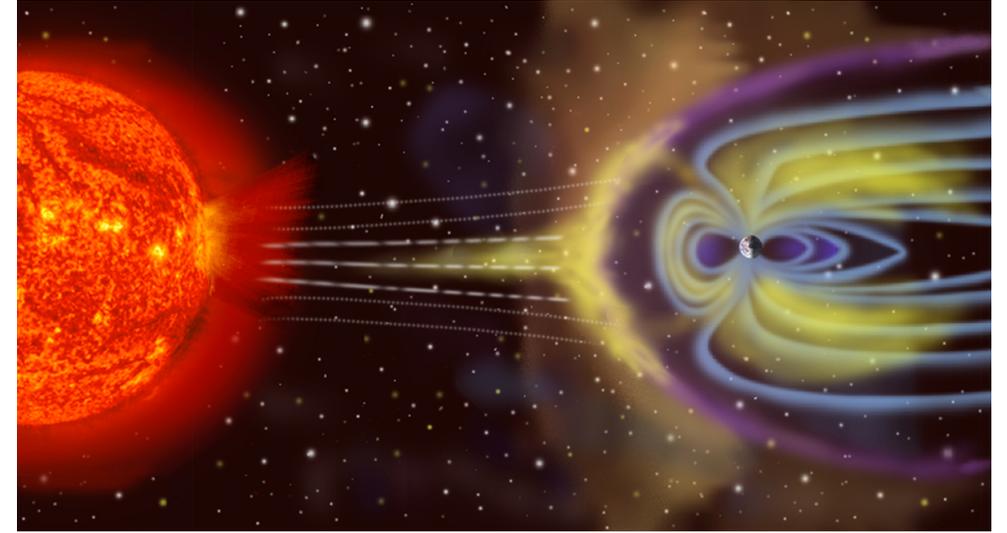
- **Challenges abound**
 - **Temperature / Cycling**
 - Very cold: Mars ~ -130°C , Europa -220°C
 - Very hot: Venus ~ 500°C
 - **Chemical, Gas exposure**
 - **Radiation**
 - **Vacuum / Pressure**
 - **Vibration**



Space Radiation Impact on Electronics

- **Single Event Effects (SEE)**

- Typically soft error, non destructive
- Can induce destructive latchup (SEL)
- Rebooting typically recovers

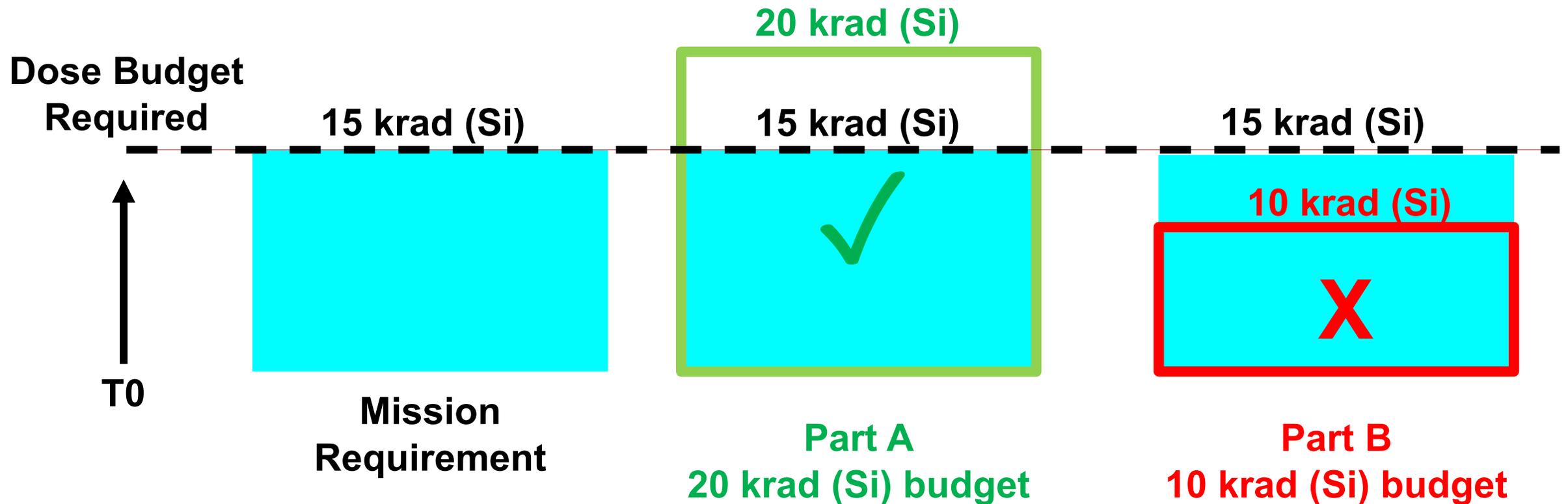


- **Total Ionizing Dose (TID)**

- Long term or cumulative exposure to ionizing radiation causes permanent device damage
- Components typically tested by lot to characterize TID limits
- Computed Tomography contributes ionizing radiation!

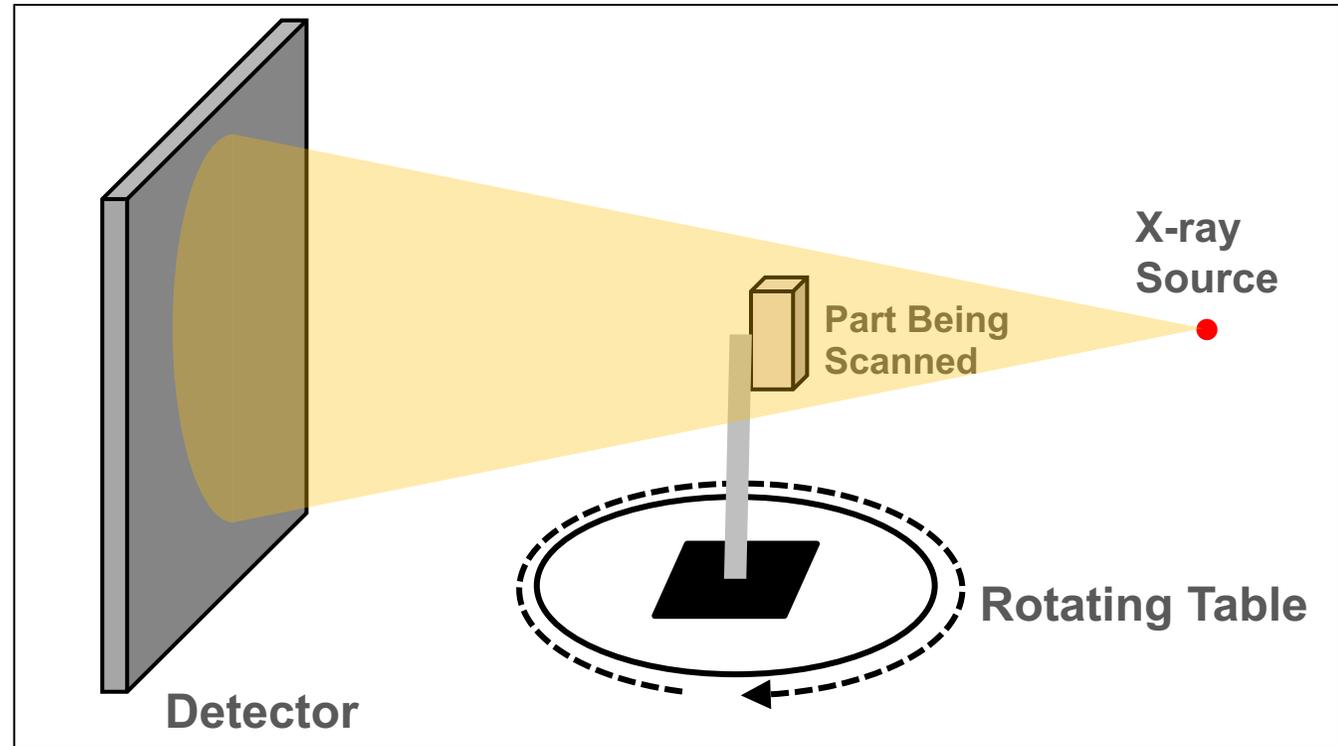
TID Budget

- Total Ionizing Dose (TID) budget example
- Mission example of 7.5 krad, w/ 2x life requirement = 15 krad



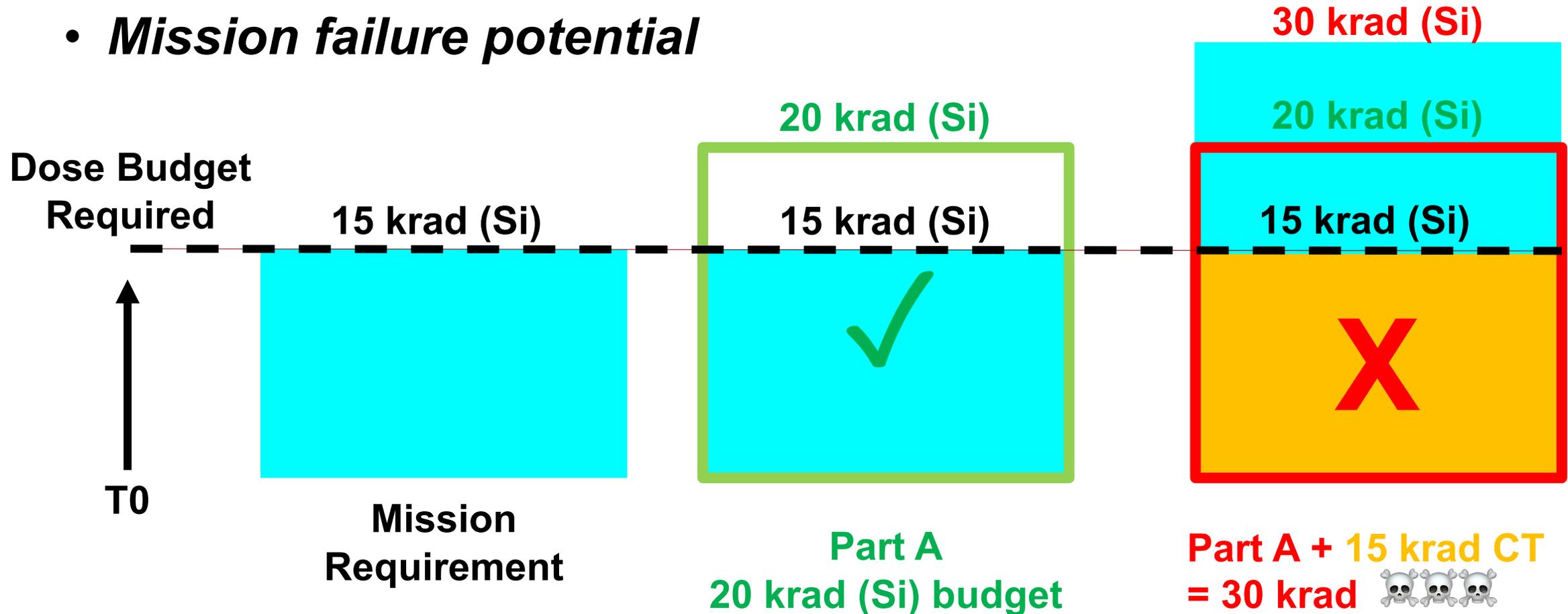
Computed Tomography X-Ray

- Sample indexed 360 degrees capturing 1000's of images.
- 3D data set enables inspection without physical deconstruction
- *Ionizing radiation applied to sample*



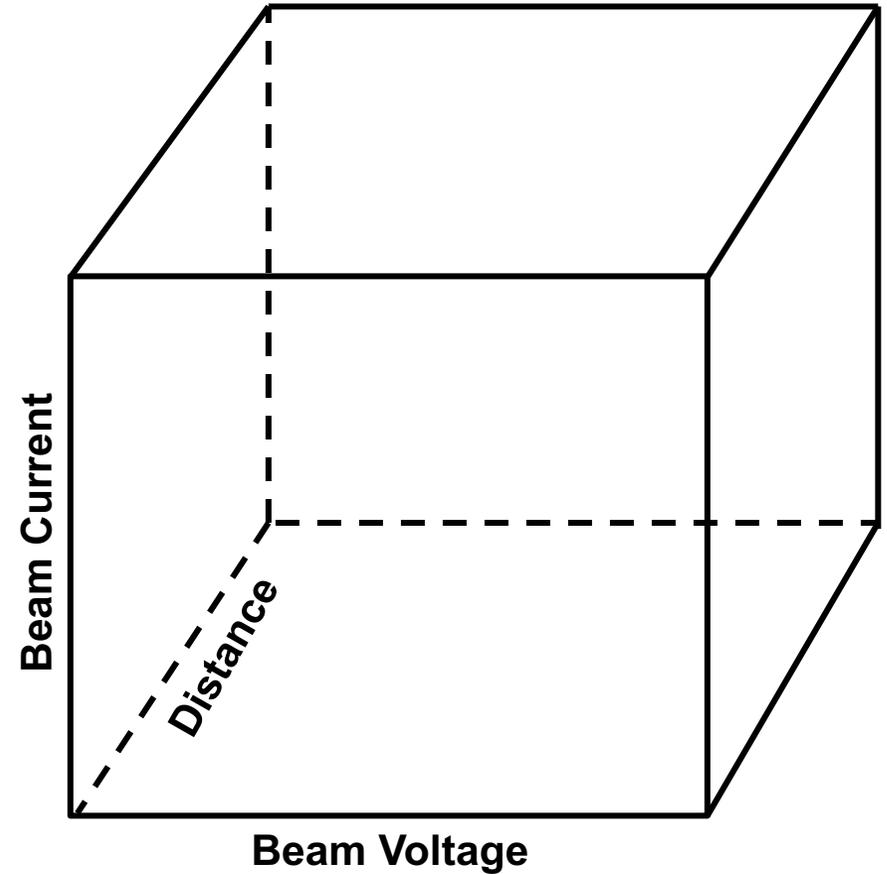
Example CT impact on TID Budget

- Mission example of 7.5 krad, w/ 2x life requirement = 15 krad
- *CT on critical hardware can consume life*
- *Mission failure potential*



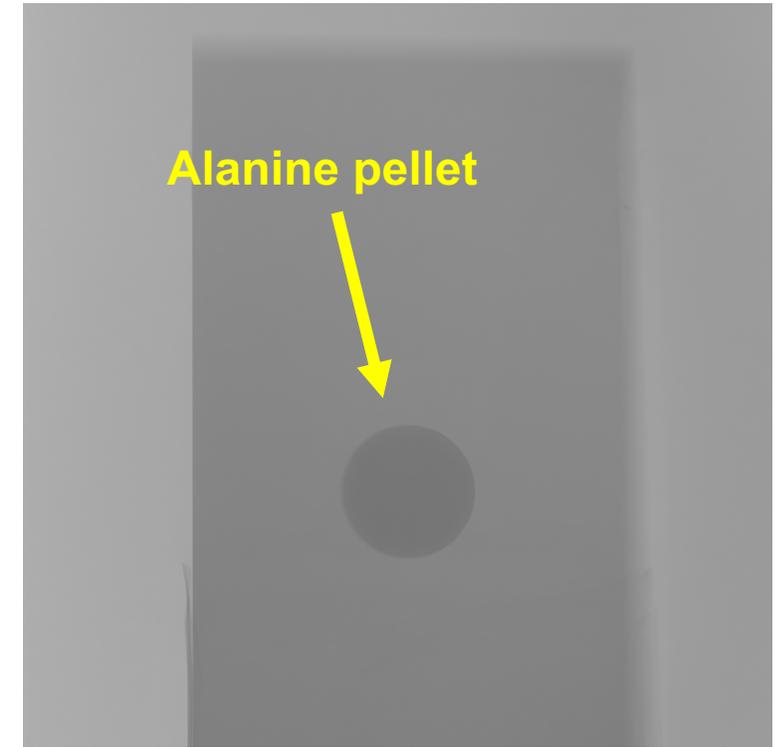
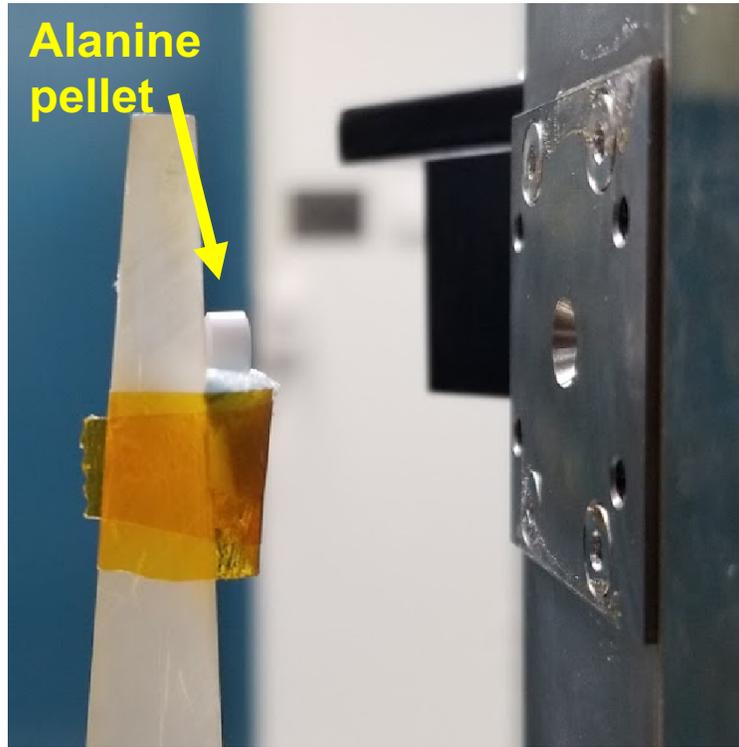
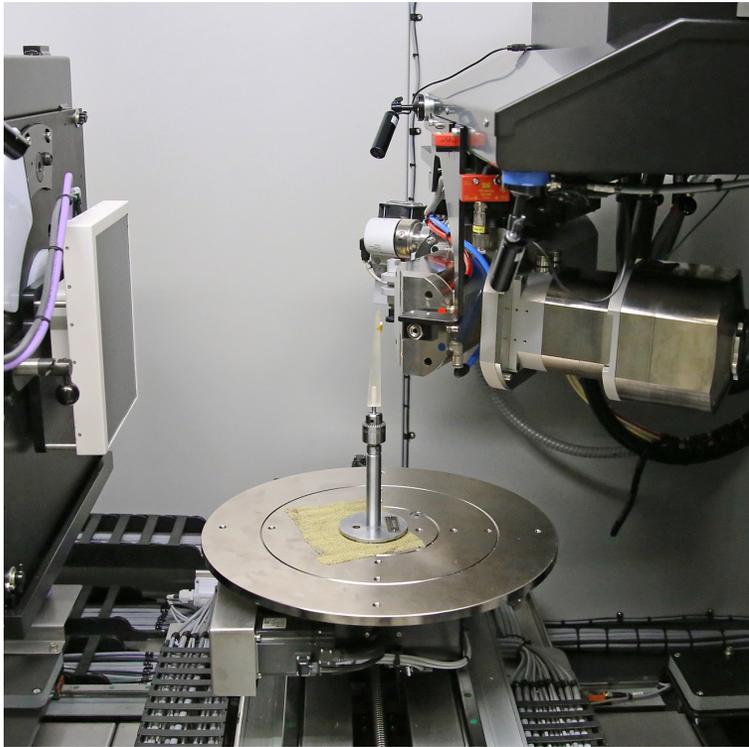
Computed Tomography X-Ray Dose Characterization

- **Experiment designed to expose alanine pellets under varying conditions:**
 - **6 Beam Voltages**
 - **7 Beam Current**
 - **3 Distances from X-Ray source**
 - **2 Different X-Ray sources**
 - **29 total exposures**



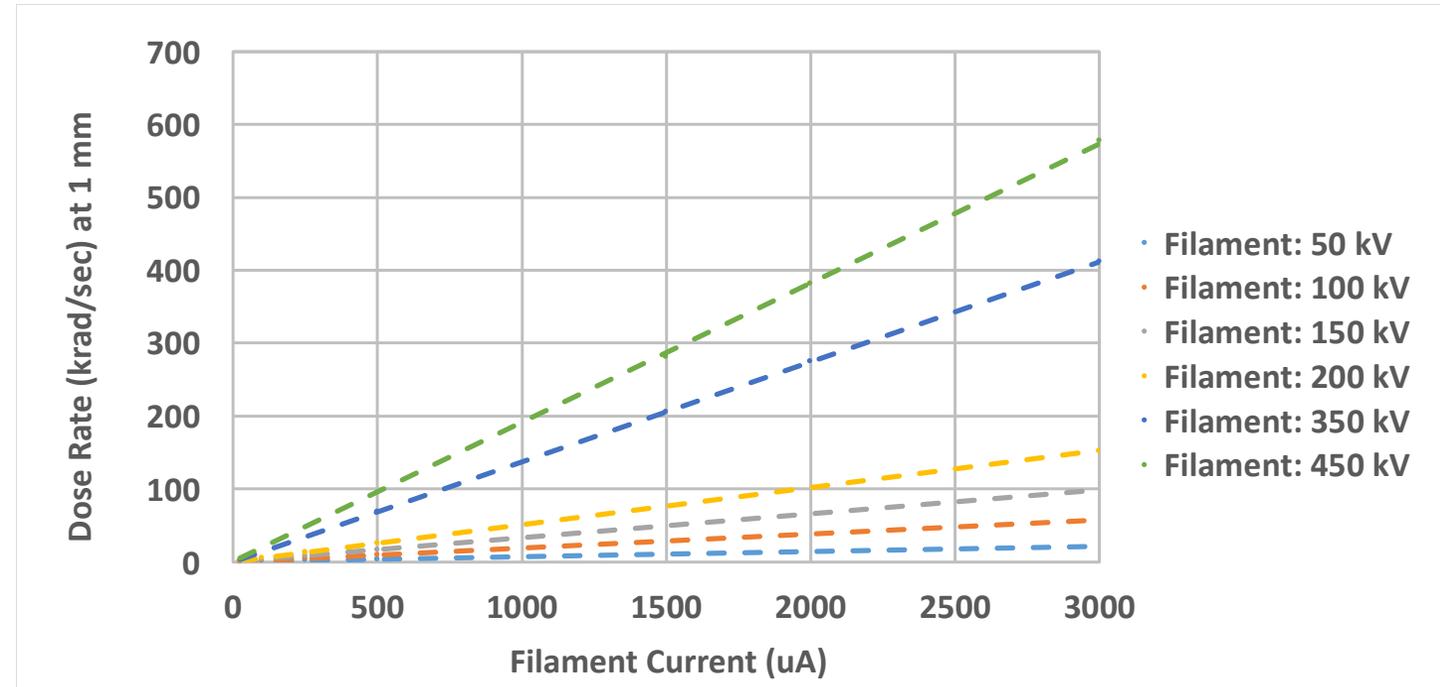
Computed Tomography X-Ray Dose Characterization

- Experiment dosing example in 225kV configuration



Computed Tomography X-Ray Dose Curves

- **Sample distance has inverse square effect on total dose**
 $I=1/(D^2)$
 - I: radiation intensity
 - D: distance
- **Given varying distances, lines are calculated using $E/T=m(C)$**
 - E/T: exposure over time
 - m: slope
 - C: beam current



Protecting Space Bound Articles



1. Establish sample dependent parameters to generate dose estimate
 - Sample distance, kV, beam current, scan time

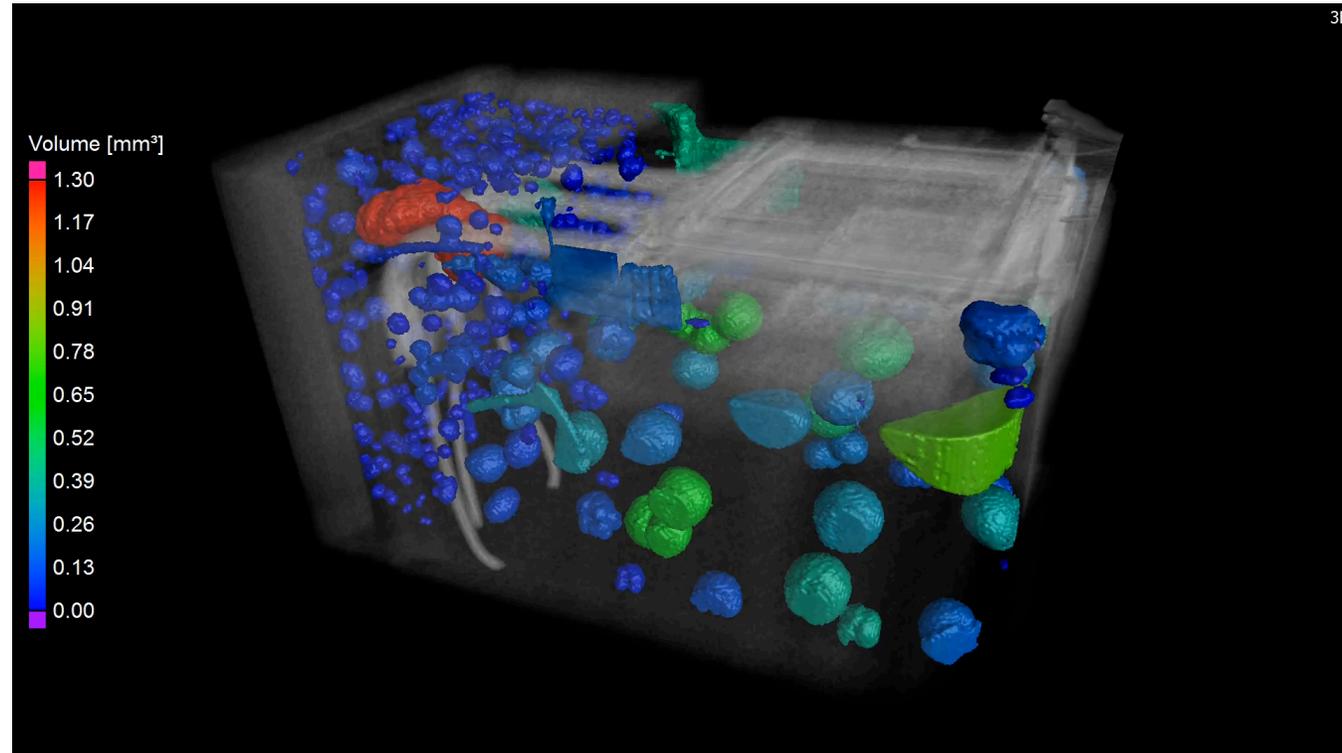
Protecting Space Bound Articles

JPL		CT X-ray Radiation Safety Form		
Date:	9/12/19			
Manufacturer:	Confidential			
IBAT#:	Confidential	Optional		
JPL IR #:	Confidential	Optional		
Part #:	Confidential			
Is or could the part become flight?				Yes
Is there concern about a potentially destructive radiation dose?				Yes
If yes what is the approved radiation dose limit for this part?				100 Krad
Is the part JCI / ESD sensitive?				Yes
If yes to what voltage is it sensitive to (50V, 250V, etc)?				50V
What is the minimum feature size to be visualized?				10 micron
What are the part X,Y,Z dimensions ?				10cm x 5cm x 10mm
What materials is the part made of and what are their approximate thicknesses?				Al
Describe any special handling instructions below:				
Radiation Exposure Details				
Source	Xrayworks 225			
KV	160			
uA	165			
Distance (mm)	50			
Time (hours)	2.00			
Dose (Krad)	17.4			
The hardware submitted for CT scanning can safely sustain the estimated radiation dose				
		Approved (Yes/No)	Date	
3X M&P:		Yes	13-Sep	
5X Rad Effects:		Yes	13-Sep	
COGE:		Yes	13-Sep	
MAM:		Yes	13-Sep	
Office 514 - Analysis and Test Laboratory				
Rev 1.3				



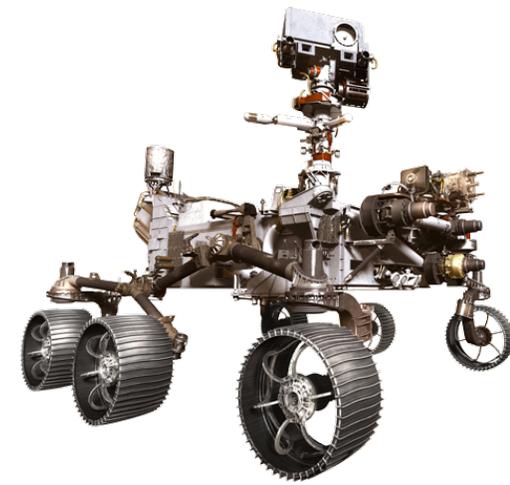
2. **Generate dosage estimate, review with stakeholders**
 - Typically radiation effects, materials & processing, cognitive engineer & mission assurance manager

Protecting Space Bound Articles



3. Capture & Analyze CT data, document key parameters & update estimate dosage per sample

Summary



- **Electronics have varying sensitivities to radiation**
- **FA and troubleshooting of space bound electronics prior to launch with CT X-Ray can consume TID budget and reduce lifetime.**
- **It's strongly recommend to consider TID budget & CT X-Ray contributions prior to CT scanning flight electronics & materials.**