Radiation Analysis of Candidate Structures for Moon-to-Mars Planetary Autonomous Technology (MMPACT)

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Overview

- Candidate structures for future lunar missions are analyzed to quantify their radiation shielding effectiveness.
- CAD Models of these structures are provided by ES22.
- Calculate the dose and dose-equivalent exposure per year at selected positions within the structures
- Two simulation codes are being used: GEANT4(open source) and OLTARIS (LaRC)
- Simulations use the Galactic Cosmic Ray (GCR) model BON2020 at the last solar minimum (maximum GCRs) in 2010: it is a worst-case scenario for GCRs. This is consistent with the MMPACT Lunar Environments document that references the DSNE.

Radiation Units and Limits

Dose (Gray, G) & Dose Equivalent (Sievert, Sv)

- Dose is a physical quantity: energy absorbed per unit mass
  - Useful to quantify the radiation exposure for both human and materials
- Dose-Equivalent is a calculated quantity: Dose×Biological_Effectiveness
  - Used to assess the impact of the exposure on biological systems.

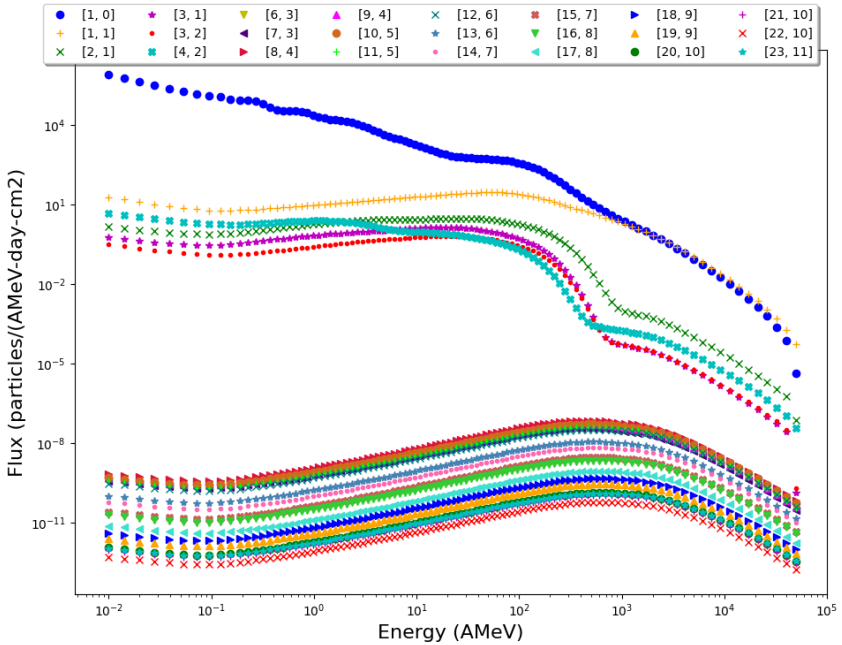
Ref. Radiation Exposure limits: Space Radiation iBook, NASA Human Research Program Engagement and Communications

Radiation Exposure Limits

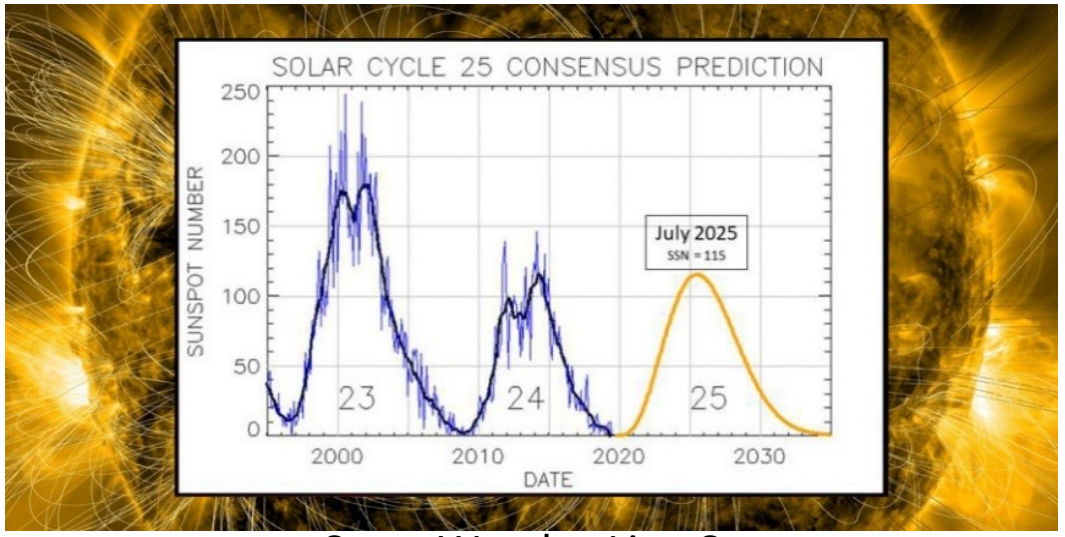
- Crew exposure limits have **not** yet been set for exploration missions.
- The NASA limit for radiation exposure in **low-Earth orbit is 50 mSv/year**
- NASA has commissioned the National Academy of Science to evaluate radiation limits and provide a recommendation

Environment

Elemental Particle Flux on the Lunar Surface
(not representative of deep space)



11 year Solar Cycle

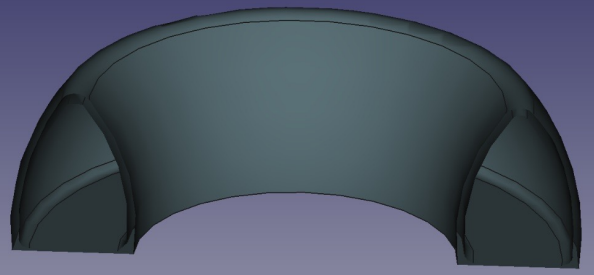


SpaceWeatherLive.Com

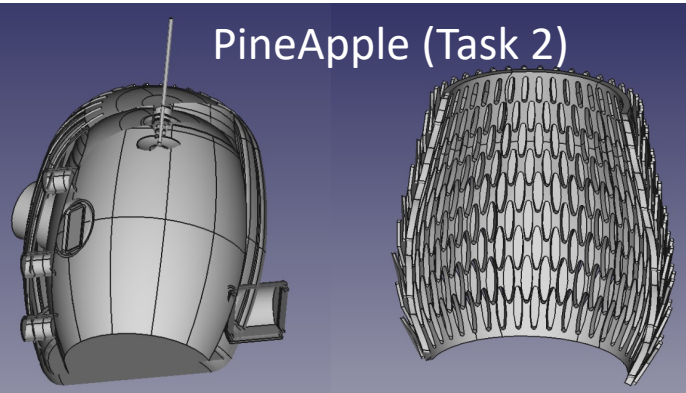
Note: Cosmic ray flux is at a minimum at the maximum Solar activity, when Solar outbursts are most likely

Habitat Structures

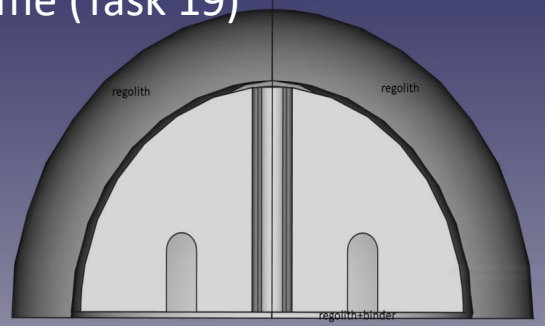
Bundt Cake (Task 1)



PineApple (Task 2)



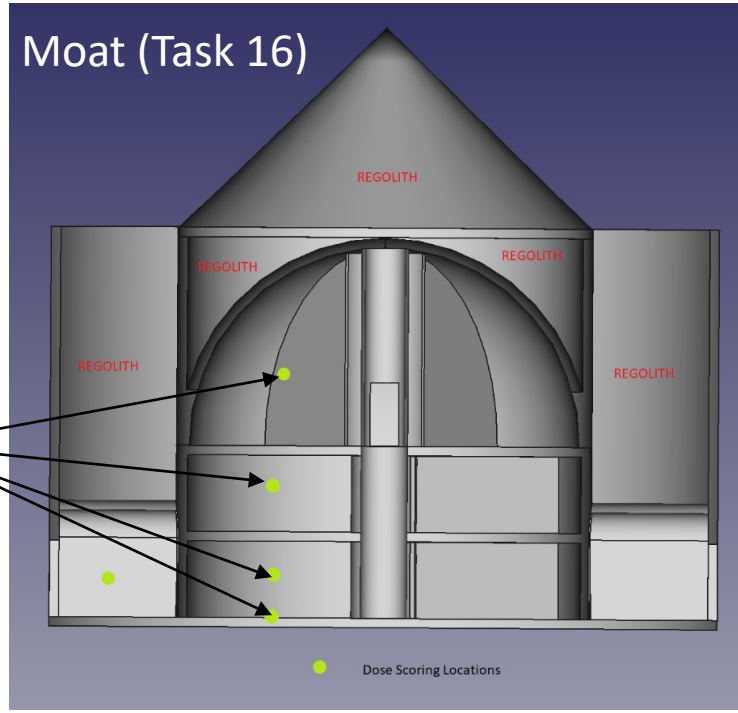
Dome (Task 19)



	Materials	Simulations
Regolith	highlands for south pole	
Binders	calcium sulfo-aluminate	Completed
	magnesium oxysulfate	Completed
	sodium silicate	
	sulfur nickel	
Others	aluminum with graphene	
Sintered Regolith	Same composition, higher densities	

Locations selected for analysis (green)

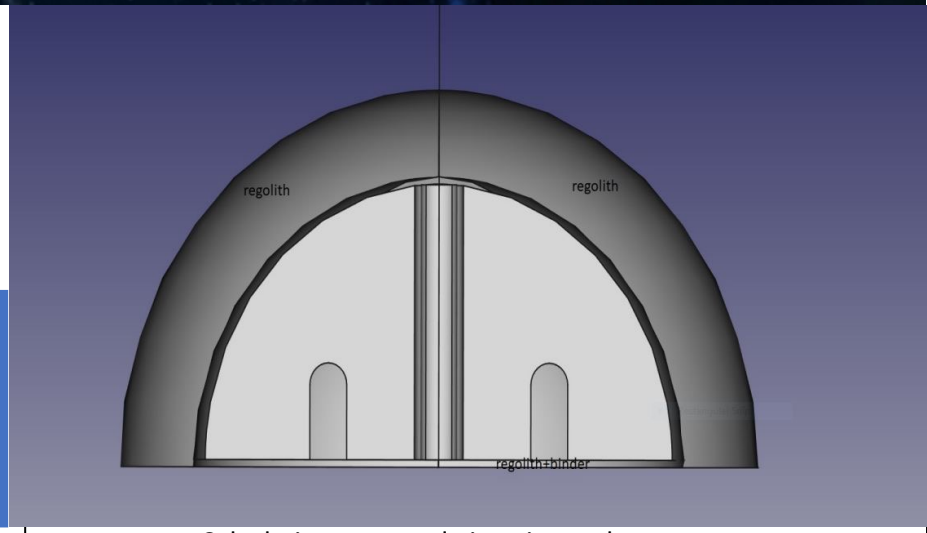
Moat (Task 16)



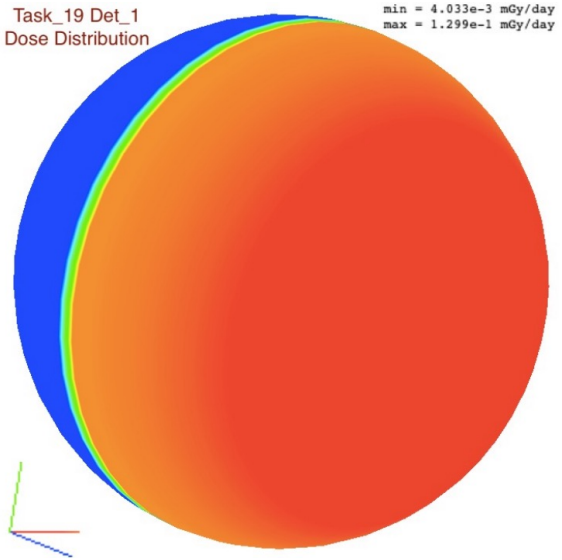
Sample of Radiation Analysis Results

Simulation Result for Dome Habitat

Sample 1 year exposure	GEANT4 Dose (mGy)	GEANT4 Dose-Equiv (mSv)	OLTARIS Dose (mGy)	OLTARIS Dose-Equiv (mSv)
External: Above	76	428	68.8	455.7
Internal: Half height	29.3	77.1	24.6	119.8
Internal: Floor	26.5	74.9	22.4	111.1



Calculations are made interior to the structure



3D representation of the radiation pattern

OLTARIS uses a point for these calculations

GEANT4 uses a disk for these calculations

Summary of Results Completed

OLTARIS results for all four structures (floor)

Binder $MgO/MgSO_4$: 30% binder, 70% regolith

Binder $(CaO)_4(Al2O_3)_3SO_3$: 30% binder, 70% regolith

OLATARIS Results Annual Exposure	Lunar Surface	Moat Floor	Bundt Cake Floor	DOME Floor	PineApple Floor
Dose (mGy)	68.8	6.8	13.3	24.6	30.0
Dose-Equivalent (mSv)	455.7	35.7	68.0	119.8	130.5
Dose (mGy)	68.8	7.1	14.7	25.2	31.6
Dose-Equivalent (mSv)	455.7	39.6	78.6	129.5	143.8

Status

- Calculations for each structure with first binder (Magnesium Oxysulphate) completed using both simulation codes
- Calculations with two binders (Magnesium Oxysulphate & Calcium Sulphoaluminate) completed using OLTARIS for each structure
- Will complete the remaining candidate materials using OLTARIS
- Additional analyses can be performed as needed
- Dose within materials is low, probably better to study material physical properties through testing of samples (EM41)