Dose Assessments During Interplanetary Journeys with SPENVIS: Approach to the Issue and Comparison of Results with DREADCode

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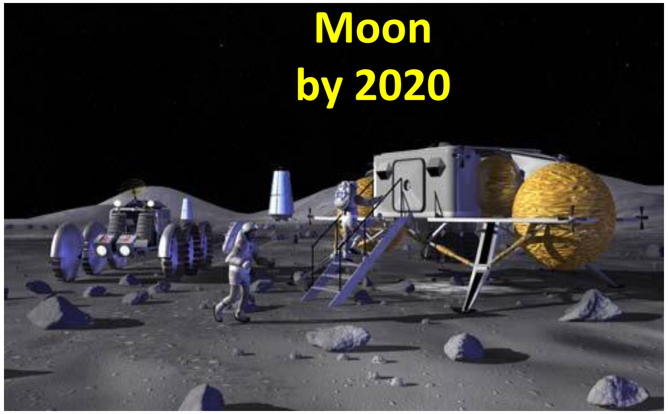
Outline

- Why studying the radiation doses for interplanetary travels?
- Missions on the Moon and Mars Schedule
- Missons Analysis with SPENVIS
- DREADCode: Main Features, Inputs and Outputs
- Comparison between SPENVIS and DREADCode Results

Interplanetary travels colonization



- ✓ tecnical and scientific purposes
- ✓ logistic and resource exlpoitation
- ✓ *know-how* development

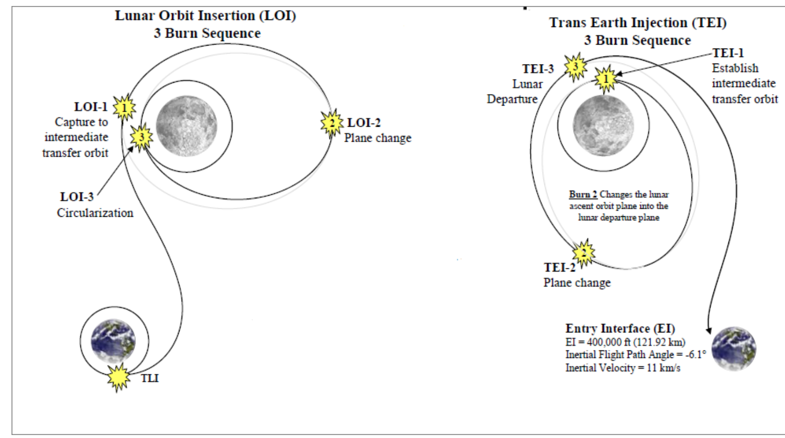
- ✓ tecnical and scientific purposes
- ✓ *know-how* utilization

- ✓ resources exploitation
- ✓ *know-how* development

Missions to the Moon and Mars - Schedules and Generic Trajectories

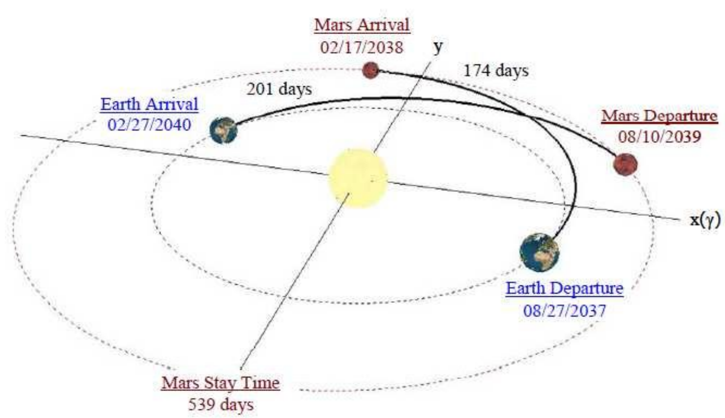
Mission phase	Earth-Moon transfer	Stay on the Moon	Moon-Earth transfer*	Total mission
Duration (days)	8*	180	8	196
Crew size	4	4	4	4
EVA number**	0	60	0	60

* including three days in LEO;
** each EVA includes two astronauts for eight hours maximum.



Earth Departure				Mars Arrival			Mars Departure			Earth Return	
Earth Departure Date (GMT)	LEO Incl. (deg)	TMI V_∞ (km/s)	TMI ΔV** (km/s)	Outbound TOF (days)	MOI V_∞ (km/s)	MOI ΔV** (km/s)	Mars Stay Time (days)	TEI V_∞ (km/s)	TEI ΔV** (km/s)	Return TOF (days)	Earth Return V_∞ (km/s)
2/23/2031	28.5	3.940	3.955	190	4.176	1.789	572	3.847	1.573	134	6.813
5/21/2033*	34.6	4.290	4.090	191	3.756	1.517	553	3.847	1.573	133	5.762
7/3/2035	28.5	3.327	3.740	180	2.792	0.971	560	3.847	1.573	183	4.438
8/27/2037	32.6	4.290	4.090	174	4.101	1.739	539	3.847	1.573	201	5.598
10/01/2039	50.2	4.318	4.100	213	4.085	1.675	502	3.847	1.573	199	6.813
11/14/2041	36.3	4.301	4.094	225	3.733	1.502	486	3.847	1.573	197	6.797
12/24/2043	28.5	4.290	4.090	215	4.067	1.716	507	3.847	1.573	180	6.813
2/6/2046	28.5	4.290	4.090	200	4.077	1.723	547	3.847	1.573	148	6.813

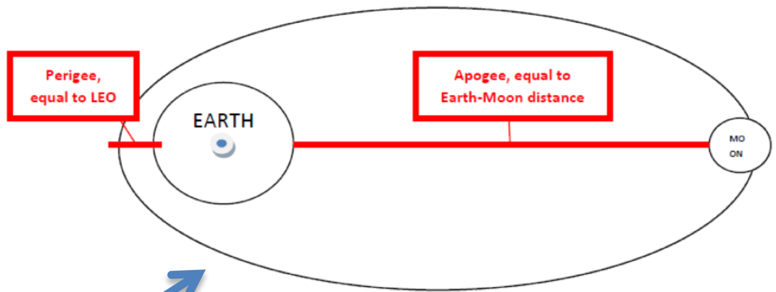
*Other potential trajectories exist with a shorter outbound time of flight (TOF) but higher LEO inclinations.
**All delta-Vs include gravity losses but no plane changes.



Coordinates Generator

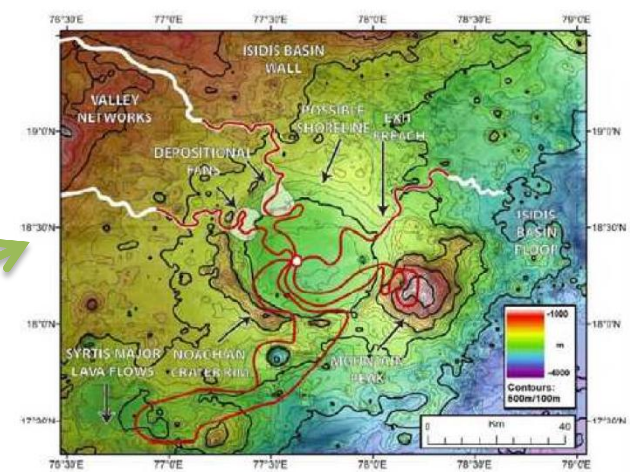
In both cases we can split the overall journey in segments:

- maneveurs in LEO
- interplanetary travel
- permanence on the surface



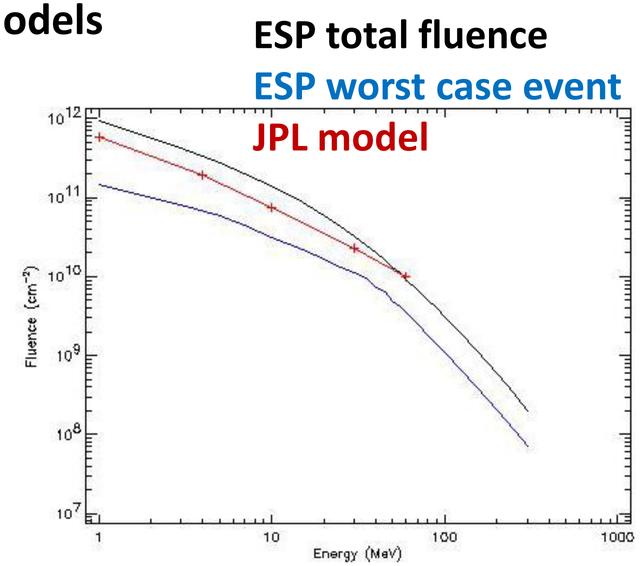
How to set it on SPENVIS?

- ➢ circolar orbit in LEO (407 km altitude)
- ➢ eliptical orbit approx or near Earth interplanetary orbit option
- ➢ approx the Moon as satellite orbiting around Earth (Moon case)
- ➢ MEREM tool-package (outpost) and near Earth interplanetary orbit option (mother-ship)



Radiation Sources

- **LEO orbit** ⟶ **Trapped Belts, AP-8 and AE-8 models**
- **SEP events** ⟶ **ESP model, more conservative**
- **GCR + ACR** ⟶ **Nymmik model, at solar minimum**



Radiation Effects

Two tools used:

- SHIELDOSE-2 (only dose)
- MULASSIS (Effective Dose and Ambient Dose Equivalent)

Total Mission on the Moon – Slab Geometry

SHIELDOSE-2 total absorbed dose (trapped particles + solar protons) [Gy]	
no offset	4-years offset
1.40E-02	1.64E+00
MULASSIS with 10000 particles (SPENVIS source particles)	
Effective Dose [Sv]	3.2362E-01
error on effective dose [Sv]	2.2440E-02
ambient dose equivalent [Sv]	4.7316E+00
error on ambient dose equivalent [Sv]	6.5068E-01

Mission on Mars - Phase 2 - Outpost

Total Dose Assessment – 539 days	
Centre of Sphere Configuration	
Thickness [g/cm^2]	Total Absorbed Dose [Gy]
10	1.370
Finite Slab Configuration	
Thickness [g/cm^2]	Total Absorbed Dose [Gy]
10	0.259
Dose Assessment with MULASSIS	
Effective Dose [Sv]	0.290
Ambient Dose Equivalent [Sv]	0.502

How to evaluate the radiation risks?

We need to define a physical quantities to represent radiation effects

$$D = \frac{dE}{dM} \quad \left[\frac{\text{J}}{\text{kg}}\right] = [\text{Gy}]$$

Dose = energy released into the unit mass

in order to consider different particles damages

$$H = \sum_R D_R \cdot w_R \quad [\text{Sv}]$$

Dose Equivalent

Radiation type	Radiation weighting factor, w_R
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy

in order to consider different tissues radio-sensitivity

$$E = \sum_T H_T \cdot w_T \quad [\text{Sv}]$$

$$\sum_T w_T = 1$$

Effective Dose

Tissue	Tissue weighting factor, w_T	Sum of w_T values
Bone-marrow (red), colon, lung, stomach, breast, remainder tissues[a]	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
Total		1.00

[a] Remainder tissues: Adrenals, extrathoracic (ET) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/cervix (♀).

DREADCode - Dose and Radiation Effects Assessment Distribution Code

Main features:

- particles data from satellites (+ Nymmik model for GCRs and ACRs)
- (almost) real-time input particles data
- based on the Bethe-Bloch's equation for the stopping power, fast computation

$$-\frac{dE}{dx} = K \cdot z^2 \cdot \frac{Z}{A} \cdot \frac{1}{\beta}\left[\frac{1}{2} \cdot \ln \frac{2 \cdot m_e \cdot c^2 \cdot \beta^2 \cdot \gamma^2 \cdot T_{max}}{I^2} - \beta^2 - \frac{C}{Z} - \frac{\delta}{2}\right]$$

- only HZE particles

http://www.spaceweather.eu/biological_effects

Main DREADCode's output

Effective Dose [mSv]

fluence-to-effective-dose coefficients

- *Sato et al.* coefficients (ICRP publication 103)
- ICRP publication 116

Ambient Dose Equivalent [mSv]

Computation run according to the definition in ICRP publication 103

*The dose equivalent at a point in a radiation field that would be produced by the corresponding expanded and aligned field in the **ICRU sphere** at a depth of 10 mm on the radius vector opposing the direction of the aligned field*

ICRU sphere = 30 cm diameter sphere with 1 g/cc density composed by 76.2% O, 11.1% C, 10.1% H and 2.6% N, in order to simulate the human tissue's behavior

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eHeroes

SPENVIS Workshop – Brussels, May 23th 2013

SEVENTH FRAMEWORK PROGRAMME

Main input parameters

Start date: *
Feb 1 2012

Insert the ending date: *
Feb 8 2012

Number of shielding layers: *
1

Area of exposed surface: *
300
in cm^2

Spatial discretization step: *
10^-4
in cm

Type of flux: *
4*pi

Distance to the Sun: *
1
in AU

Flux scaling factor beta: *
1
such that F=F(1AU)*R^beta

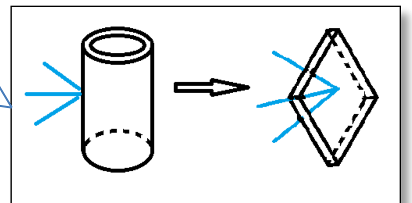
Layer 1

Layer composition [Z]:
13

Layer weight fraction [%]:
100

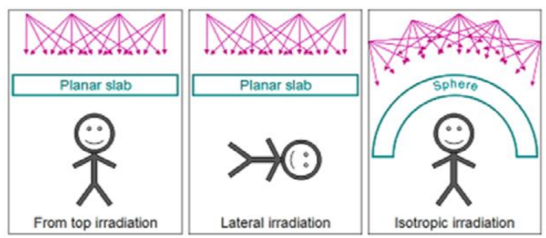
Layer thickness [cm]:
0.7

Submit



$$F = F(1\,\mathrm{AU}) \cdot R^{-\beta}$$

$$\beta = 2 \div 4$$



SPENVIS website, www.spenvis.oma.be

ISO turns out to be the most conservative option

D.F. Smart and M.A. Shea, Comment on Estimating the Solar Proton Environmen that May Affect Mars Missions, Adv. Space Res., 31, 45-50, 2003, doi: [10.1016/S0273-1177(02)00655-5](10.1016/S0273-1177(02)00655-5)

Radiation environment: *

- ACE (values since 1997-08-30)
- GOES-13 (values since 2010-04-14)
- GOES-15 (values since 2011-10-01)
- Nymmik model (GCR + ACR)

Type of dose assessment: *

- Effective dose with fluence-to-effective dose coefficients
- Ambient dose equivalent with ICRU sphere

Fluence-to-Effective-Dose coefficients for protons: *

- Sato et al. (2009,2010) from ICRP 103
- ICRP Publication 116 values

See references for further explanations

Fluence-to-Effective-Dose coefficients for alpha particles: *

- Sato et al. (2009,2010) from ICRP 103
- ICRP Publication 116 values

See references for further explanations

Exposure type for protons: *

- AP - Anterior-to-Posterior
- ISO - Isotropic
- PA - Posterior-to-Anterior
- LLAT - Left Lateral
- RLAT - Right Lateral
- ROT - Rotational

See references for further explanations

Exposure type for alpha particles: *

- AP - Anterior-to-Posterior
- ISO - Isotropic
- PA - Posterior-to-Anterior

See references for further explanations

Next

Comparison with results obtained from SPENVIS and conclusions

SPENVIS

	Effective Dose [mSv]	Ambient Dose Equivalent [mSv]
Moon mission	323.6	4731
Mars mission (surface)	1459	1170
Mars mission (orbiting)	1049	1145

DREADCode

	Effective Dose [mSv]	Ambient Dose Equivalent [mSv]
Moon mission	294.91	2250.425
Mars mission	1066.09	3691.542

- mission to Mars without considering the atmosphere, high computational costs
  - similar values in similar conditions
- *Ambient Dose Equivalent* is computed running the code inside the ICRU-sphere
  - slightly different results compare to SPENVIS (fluence-to-dose coeff.)
  - strongly dependent on conditions and how is computed (i.g., wR for protons recently from 5 to 2)
- Higher value for the mission to Mars
  - longer permanence, despite greater shields thicknesses

Thank You for Your Attention