# Calculation of Radiation Exposure on the Moon Surface by using PHITS

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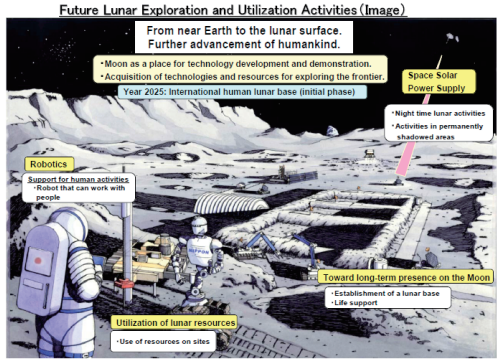
# JAXA Vision

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# Method to Calculate Radiation Spectra on the Moon Surface

- GCR model
  - CREME86
    - Using spectra out of magnetosphere
    - Solar minimum
    - Proton - Ni
    - Solid angle: 2π
    - >10MeV/n
- SPE model
  - CREME96 WORST DAY
- Radiation transportation
  - To calculate secondary neutrons and secondary photons from interactions between the moon surface and GCR/SPE by using radiation transportation code “PHITS”. (considering gamma rays from activated nuclei)
- Geometry for calculation
  - Next slide

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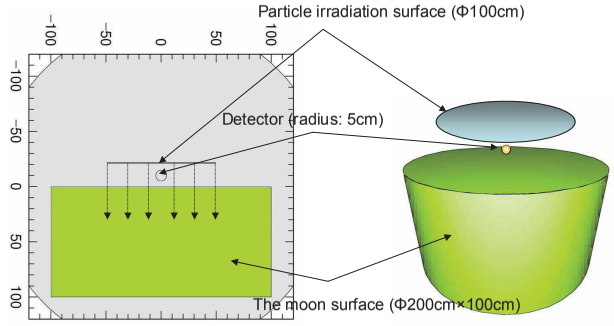
# Geometry to calculate secondary neutrons and photons

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# Chemical Composition of the Moon Surface

- Fraction by number of atoms
  - O 60%
  - Si 17%
  - Al 4.5%
  - Ca 4.5%
  - Mg 5%
  - Fe 6%
  - Ti 1.5%
- Reference: Haskin, L., and P. Warren, Lunar chemistry, in Lunar Sourcebook, 357-474, Cambridge Univ. Press, New York, 1998.

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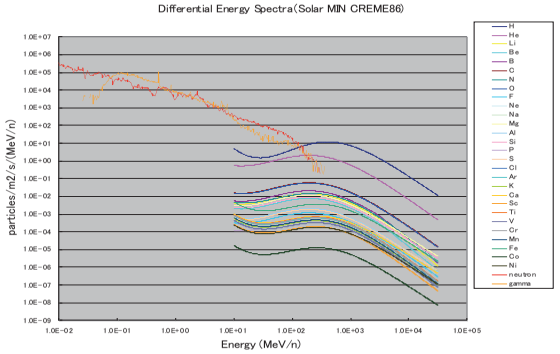
# Calculation Result
## GCR + secondary neutrons and photons

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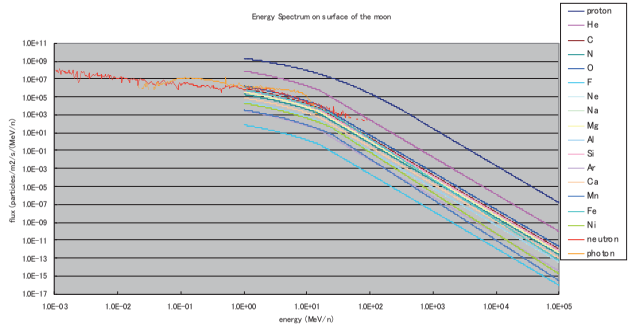
# Calculation Result
## SPE + secondary neutrons and photons

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# Method to Calculate Radiation Spectra under 10g/cm$^2$ (Al) shielding

- Input: spectra of the previous slides
  - GCR
  - SPE
  - Secondary neutrons and photons
- Radiation transportation
  - To calculate spectra of radiation transported through 10g/cm$^2$ (Al) shielding by using PHITS
- Geometry
  - Next slide

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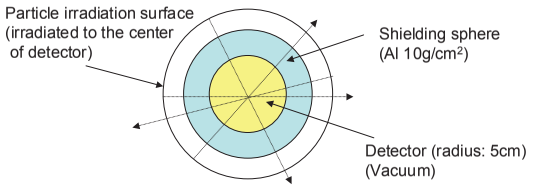
## Geometry to Calculate Radiation Spectra under 10g/cm$^2$ (Al) shielding

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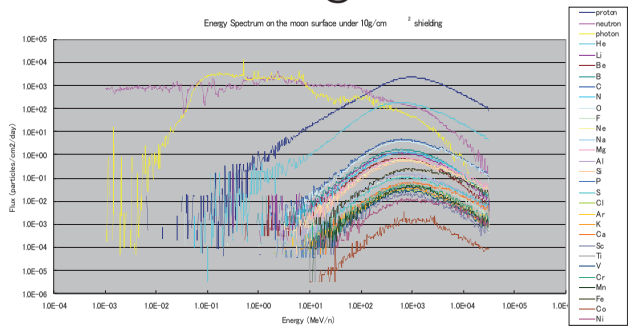
## Calculation Result
## Energy spectra under 10g/cm$^2$ (Al) shielding in Solar MIN@CREME86

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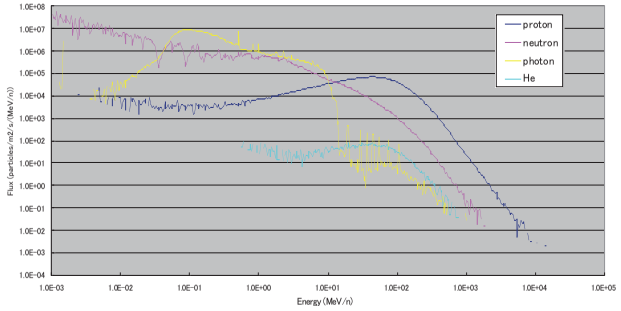
## Calculation Result
## Energy spectra under 10g/cm$^2$ (Al) shielding in SPE Worst Day@CREME96

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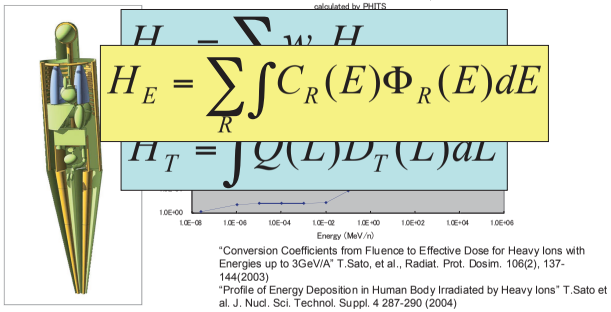
## Method to Calculate dose exposed on the Moon surface

- Using conversion coefficients from fluence to effective dose equivalent calculated by PHITS.




$$H_E = \sum_R \int C_R(E)\Phi_R(E)dE$$

$$H_T = \int Q(L)D_T(L)dL$$

"Conversion Coefficients from Fluence to Effective Dose for Heavy Ions with Energies up to 3GeV/A" T.Sato, et al., Radiat. Prot. Dosim. 106(2), 137-144(2003)
"Profile of Energy Deposition in Human Body Irradiated by Heavy Ions" T.Sato et al. J. Nucl. Sci. Technol. Suppl. 4 287-290 (2004)

## Calculation Result
## Exposed Dose on the Moon Surface

Effective Dose Equivalent

| | No shielding | | 10g/cm$^2$ (Al) shielding | |
|---|---|---|---|---|
| | GCR CREME86 MIN | SPE Worst day | GCR CREME86 MIN | SPE Worst day |
| PHITS | 0.71 mSv/day | 4100 mSv/day | 0.55 mSv/day | 36 mSv/day |

**In long term manned mission on the moon, shielding design and space weather forecast are expected to be very important.**

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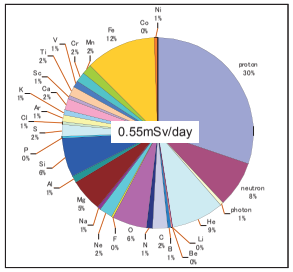
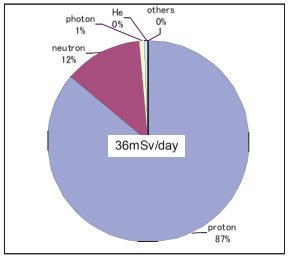
## Calculation Result
## Contribution to dose

- under 10g/cm$^2$ (Al) shielding




GCR: CREME86




SPE Worst Day

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## Future Works

- To calculate energy spectra and dose in various shielding thicknesses
- To calculate energy spectra and dose in various shielding materials

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## Summary

- Radiation environment and exposed dose has been calculated by PHITS.
- It is suggested that shielding design and space weather forecast are to be very important in the long term manned space mission on the moon.
- Calculation of energy spectra and dose under various shieldings will be needed for conceptual design of the manned mission on the moon.

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