Recent Improvement of PHITS for Space Application

Tatsuhiko Sato (JAERI) and Koji Niita (RIST)

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•Calculation of Neutron Spectra inside Spacecrafts

•Estimation of Dose for Astronauts

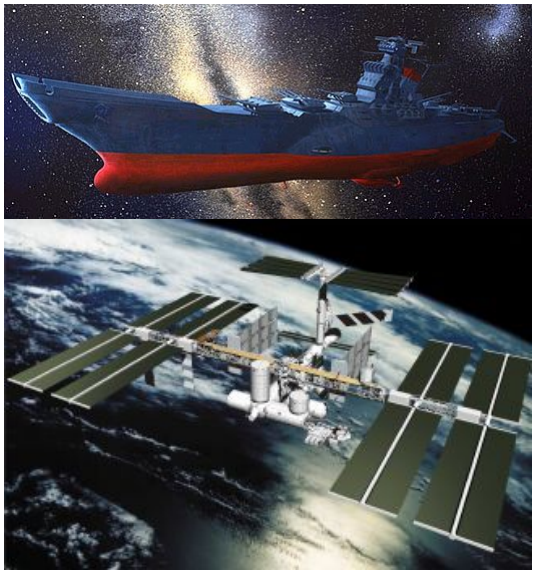
•Recent Improvement of PHITS

•Summary

JAERI 日本原子力研究所
Japan Atomic Energy Research Institute

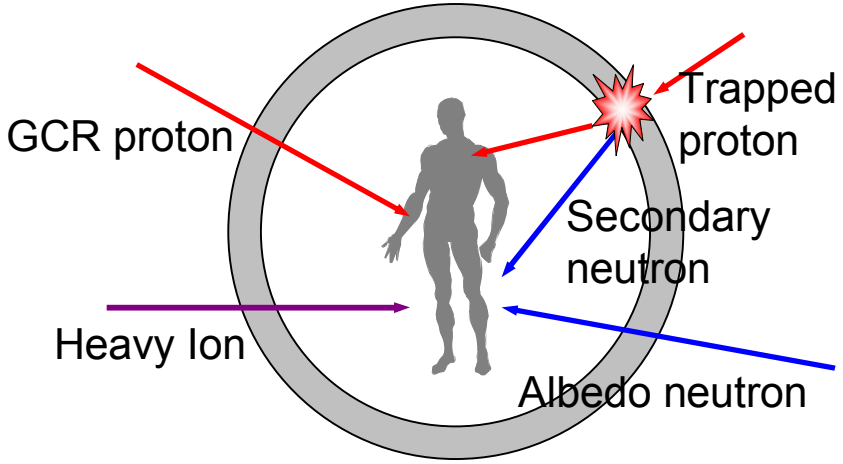
Background (I)

Long-term space mission



Evaluation of Dose for Astronauts are very important

Particle fluence inside spacecrafts is indispensable



Background (II)

Particle fluence outside spacecrafts

- Proton & HZE particle (Z < 28, E < 100 GeV/nucleon)
- Calculated by NASA's model, CREME96, OMERE etc.

HZE particle transport simulation

	1-D Deterministic Code	3-D Monte Carlo Code
Code	HZETRN (NASA)	**PHITS**, FLUKA, GEANT4, SHEILD-HIT
Computational Time	Reasonable	Time-consumptive
Charged Particle Spectra	Precise	Precise
Neutron Spectra	Not precise	**Precise**

particle fluence inside spacecrafts

Neutron, Proton & HZE particles

Introduction of PHITS

Particle and Heavy Ion Transport code System

History

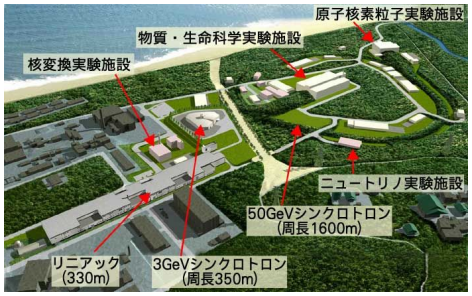
1951	1983	1997	2001	2003
NMTC	NMTC/JAERI	NMTC/JAERI97	NMTC/JAM	PHITS
(ORNL)	High Energy Fission		All hadron < 200 GeV	Heavy Ion low energy neutron

Capability

Transport and collision of all particles with wide energy range

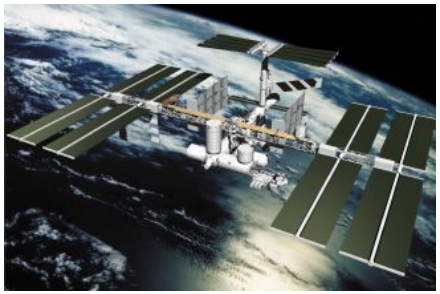
- in 3D phase space with magnetic field & gravity
- neutron, proton, meson, baryon electron, photon, nucleus
- up to 200 GeV

Application Fields



Accelerator Design

Radiation Therapy

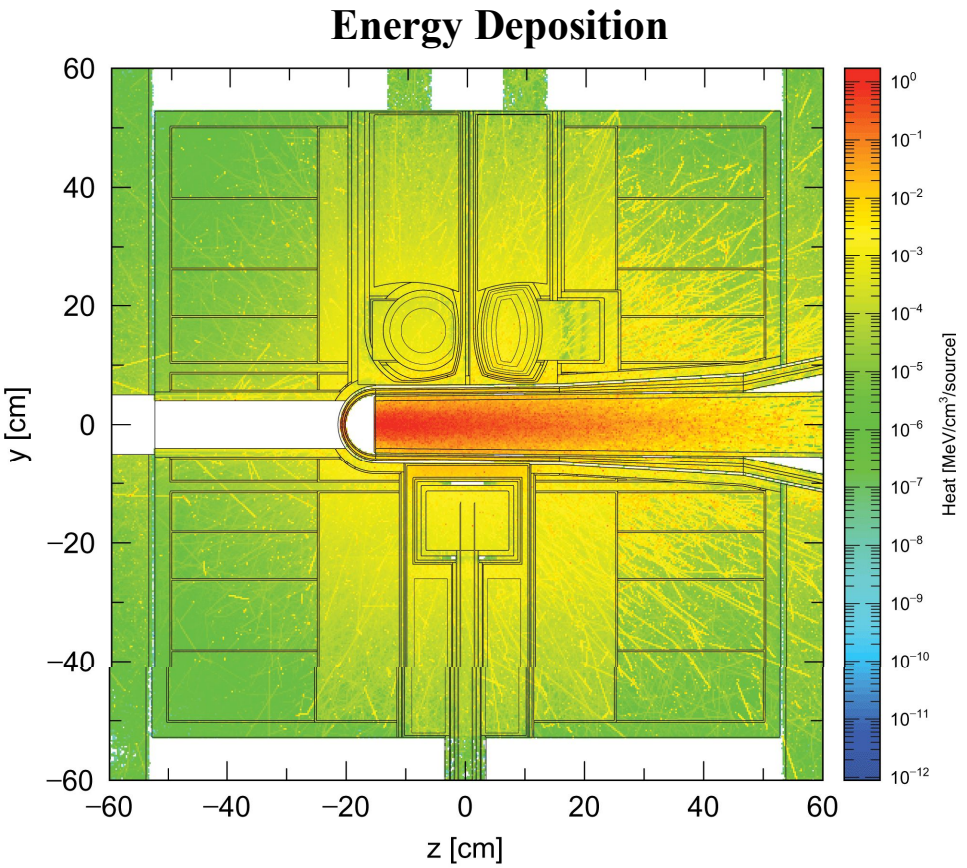


Space Application

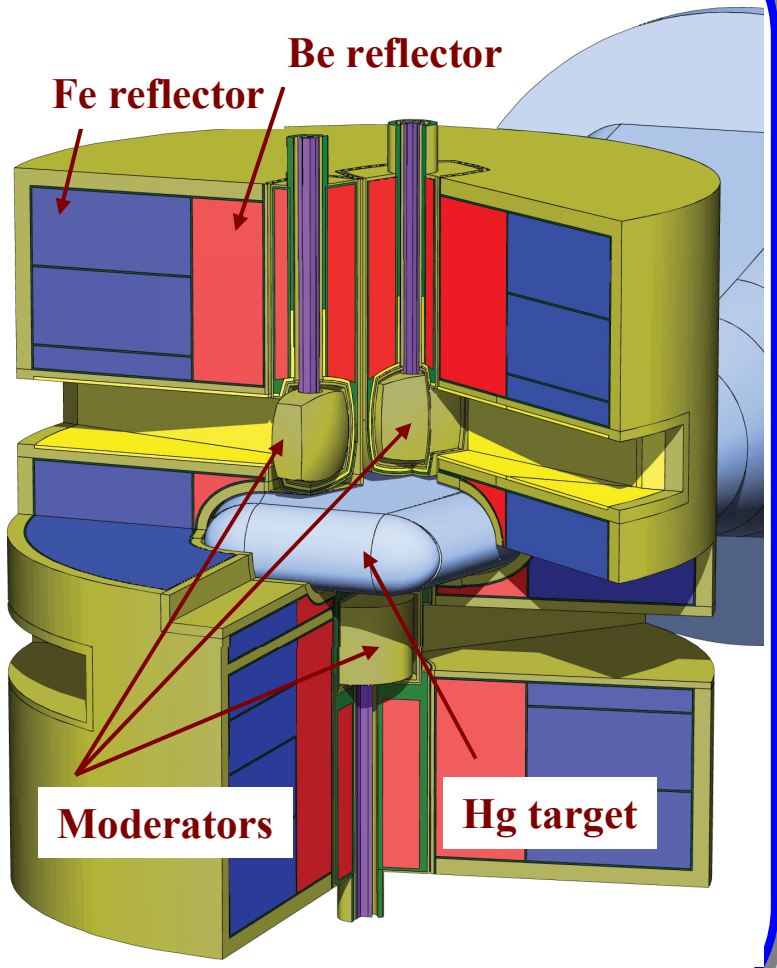
Example of PHITS Calculation

Particle and Heavy Ion Transport code System

Example Result



Accelerator Shielding Design



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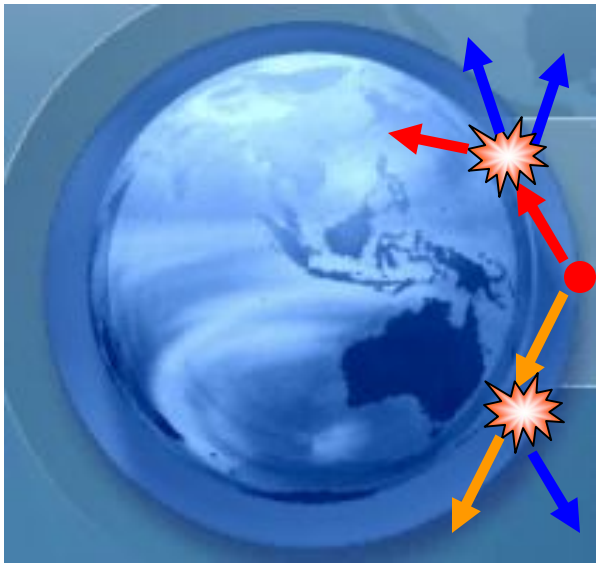
Spectra outside Spacecrafts

Charged Particle

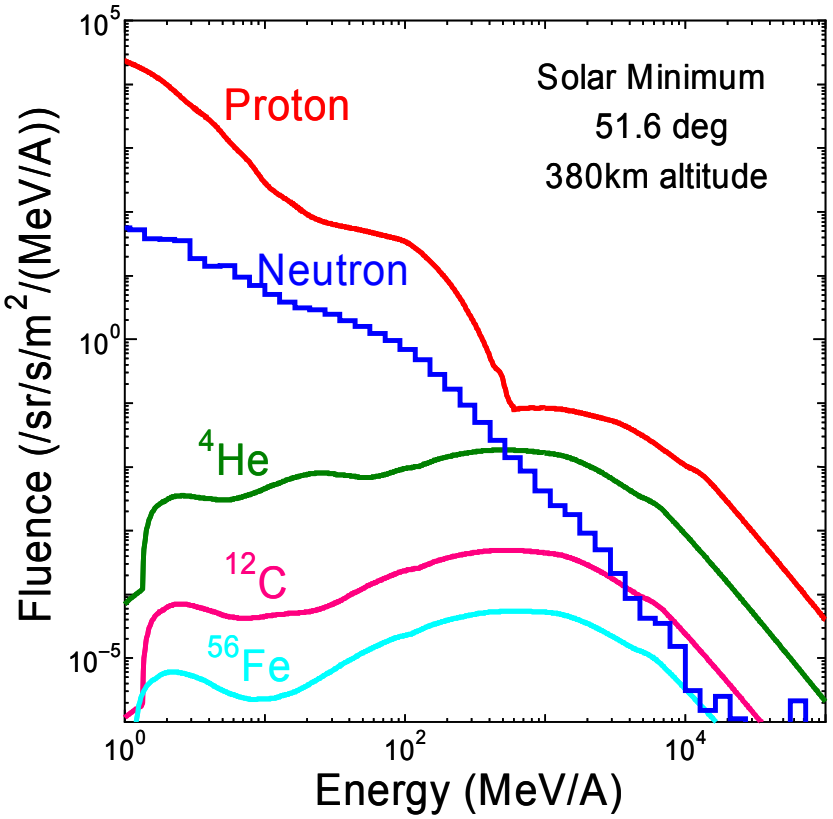
Calculated by CREME96

Neutron



Simulation by PHITS

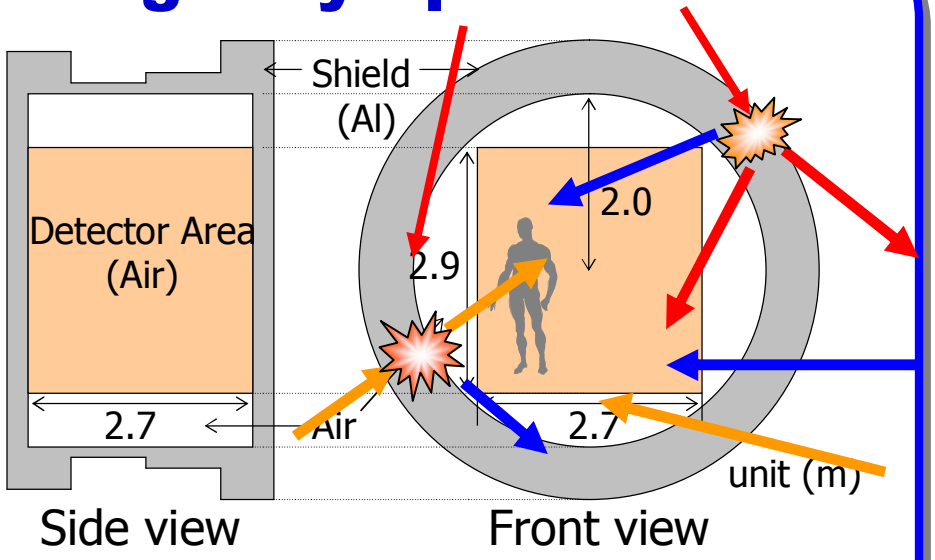
based on charged particle spectra at the altitude of 86 km

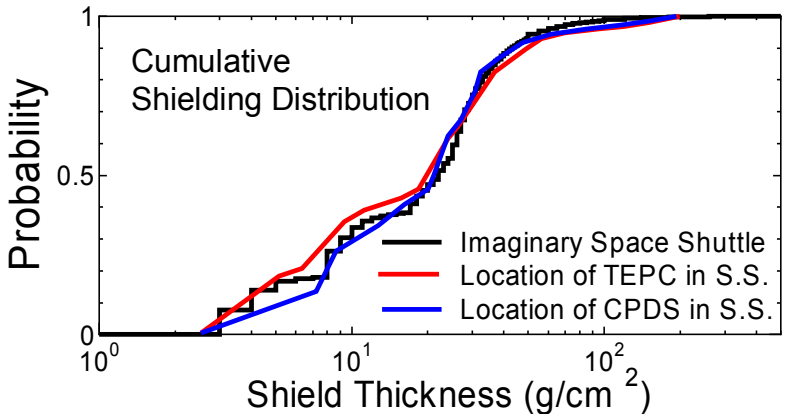


Spectra outside spacecrafts

Substitution of Spacecrafts

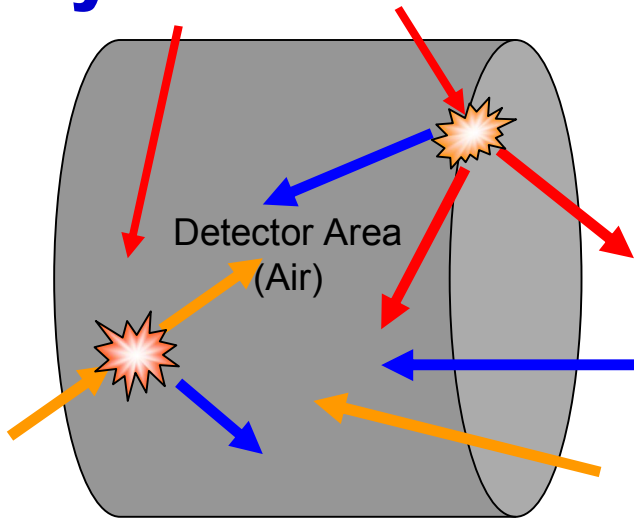
Imaginary Space Shuttle





Reproduce Experimental Data

Cylindrical Shell

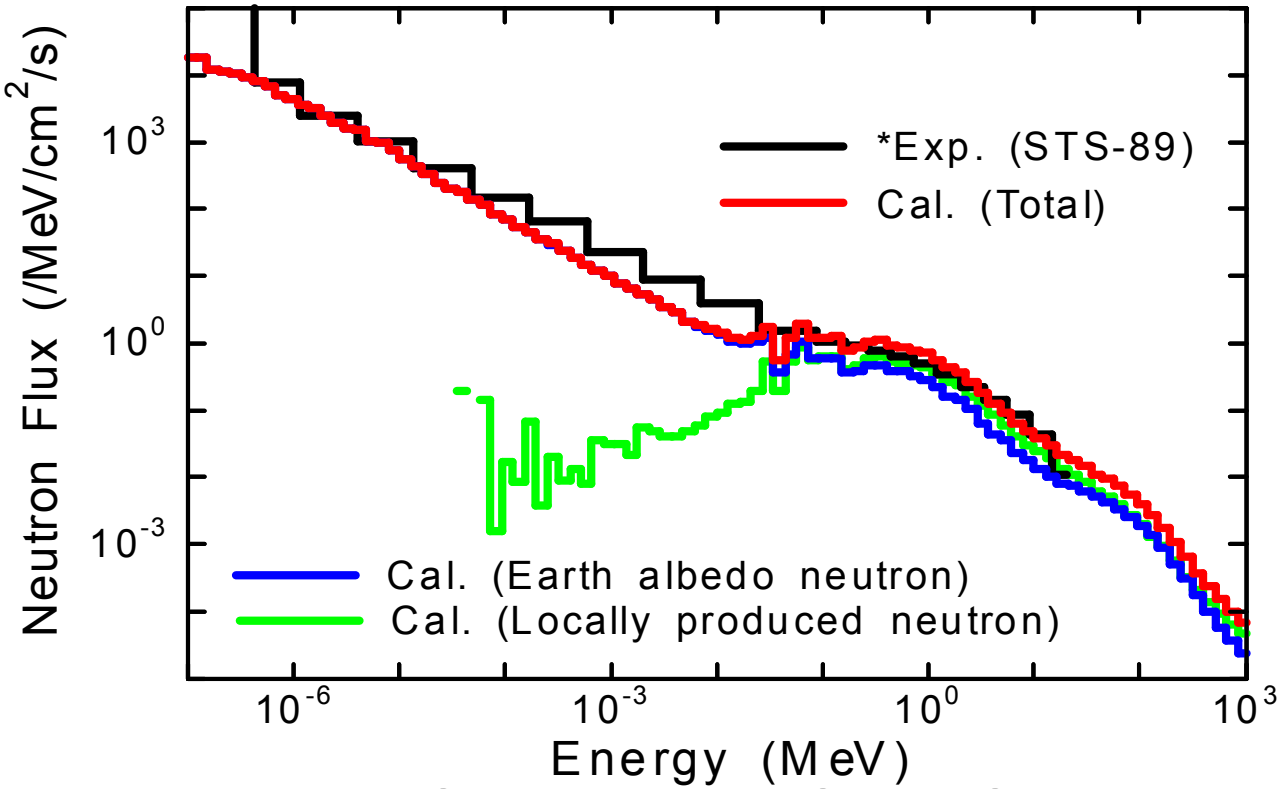


Aluminum

0, 5, 10, 20, 30, 40, 80 g/cm^2

Analyze Shield Thickness Dependence

Comparison with Measured Data



Neutron Spectra inside Space Shuttle

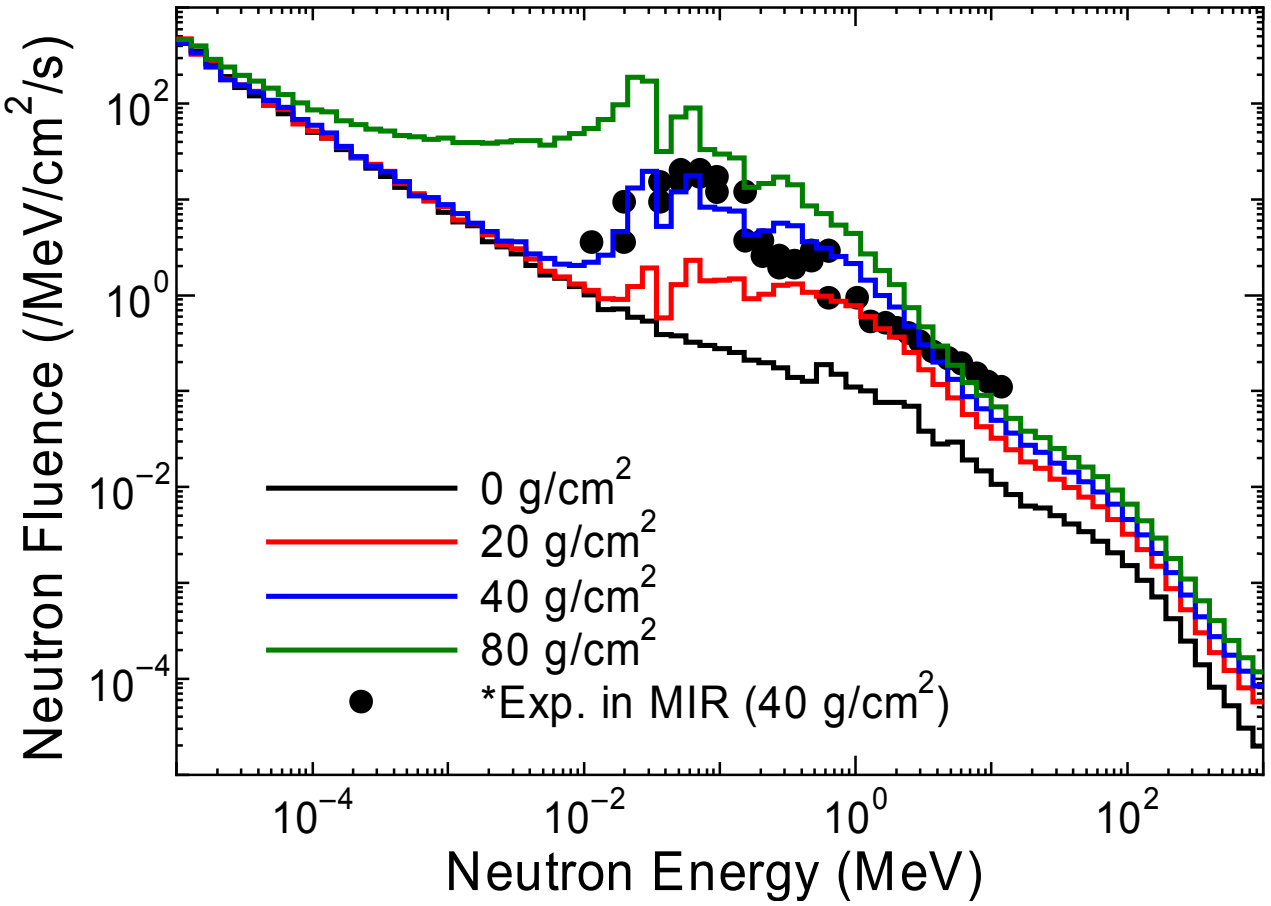
Calculated neutron spectra inside the Imaginary Space Shuttle

Excellent Agreement !!

Experimental data measured by BBND mounted on Space Shuttle

*H. Matsumoto *et. al. Radiat. Meas.* **33**, 321 (2001)

Thickness Dependence



Neutron Spectra inside Cylindrical Shell

*V. E. Dudkin et.al. Radiat. Meas. **26**(3), 535 (1996)

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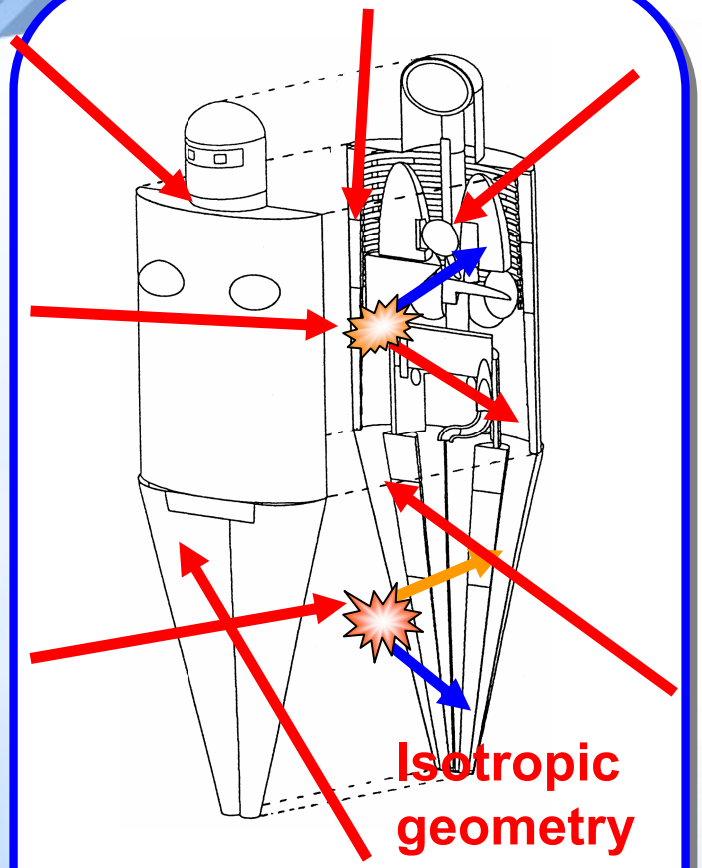
Fluence to Dose Conversion Coefficient



Mathematical Phantom

Proton, Neutron and Heavy Ion (～200GeV)

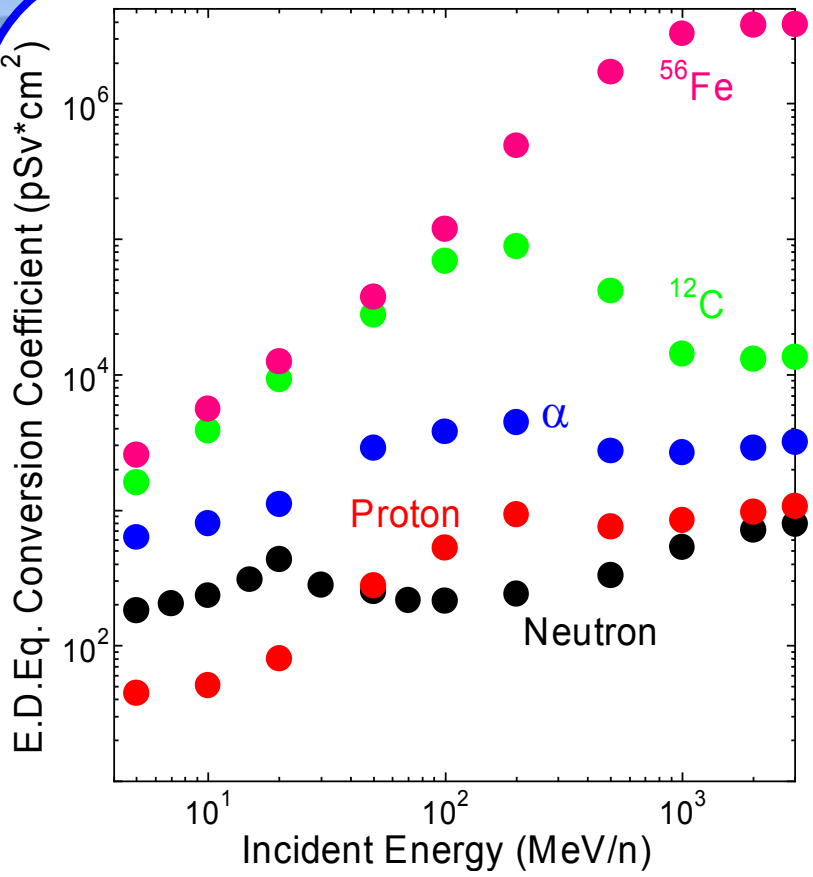
- Dose in Organ or Tissue
- LET Distribution

Defined in ICRP60

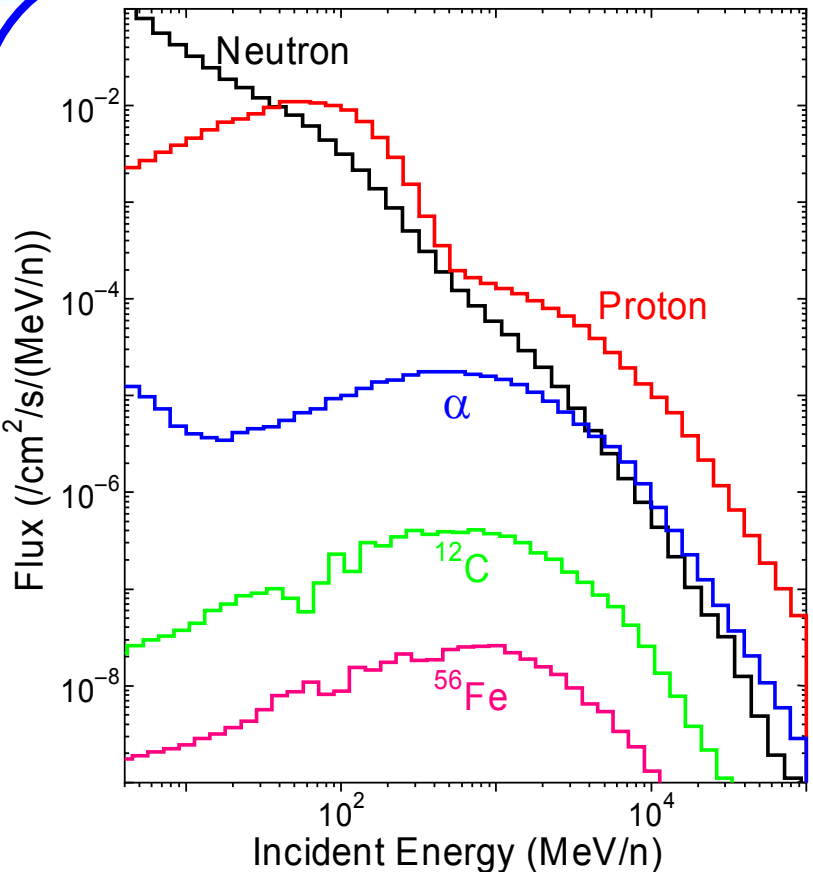
- Tissue weighting factor: w_T
- Radiation quality factor: Q(L)

- Effective dose equivalent
- Dose equivalent for some important organs

Estimation of Dose for Astronauts



Dose Conversion Coefficient

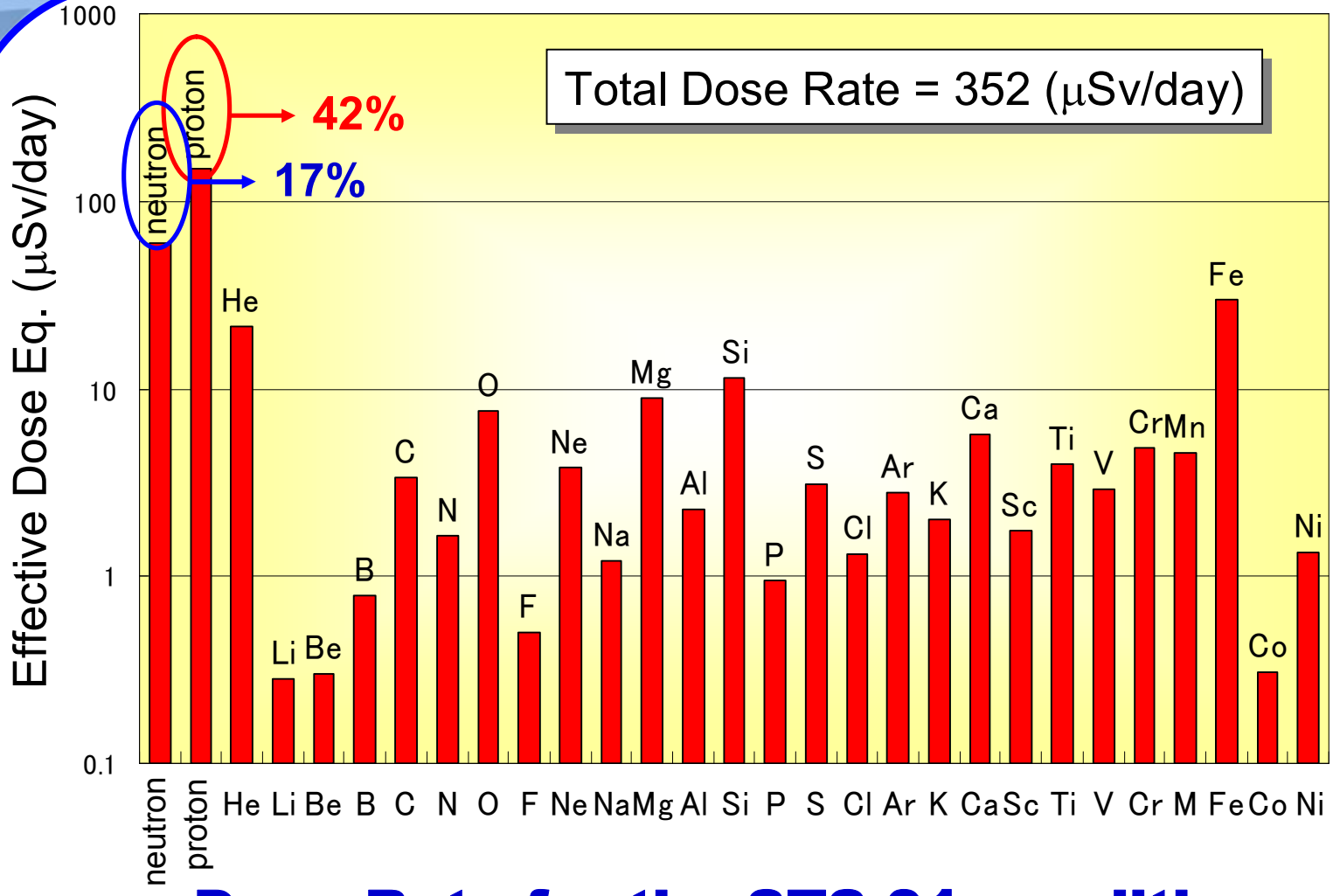


Particle Spectra inside spacecraft

Integrate

Dose for Astronauts

E.D.Eq. Rate from Each Particle



Dose Rate for the STS-91 condition

Comparison with Experiments
~ Organ Dose ~

Dose Rate for the STS-91 condition

	Absorbed Dose (μGy/day)		Dose Equivalent (μSv/day)	
	PHITS	*Exp. (STS-91)	PHITS	*Exp. (STS-91)
Bone marrow	150	179 +– 13	342	347 +– 41
Stomach	144	209 +– 23	343	439 +– 51
Skin	213	245 +– 6.7	446	459 +– 7.2

- Dose in bone marrow & skin : **Calculation ≒ Experiment**
- Dose in stomach : **Calculation < Experiment**

Due to ignorance of an-isotropic effect

*G.D.Badhwar *et. al. Radiat. Res.* **157**, 76 (2002)

Comparison with Experiments
~ Neutron Dose ~

Experimental Value

24.2 (μSv/day)

Effective Dose Eq.
from neutron below 15 MeV

Spectrum Measured by BBND
×
Dose Conversion Coefficient

Excellent agreement !

Calculated Value

22.8 (μSv/day)
(from neutron below 15 MeV)

Total Neutron Dose is …
59.3 (μSv/day)

Measurement of higher energy neutron spectrum is indispensable for radiation safety for astronauts

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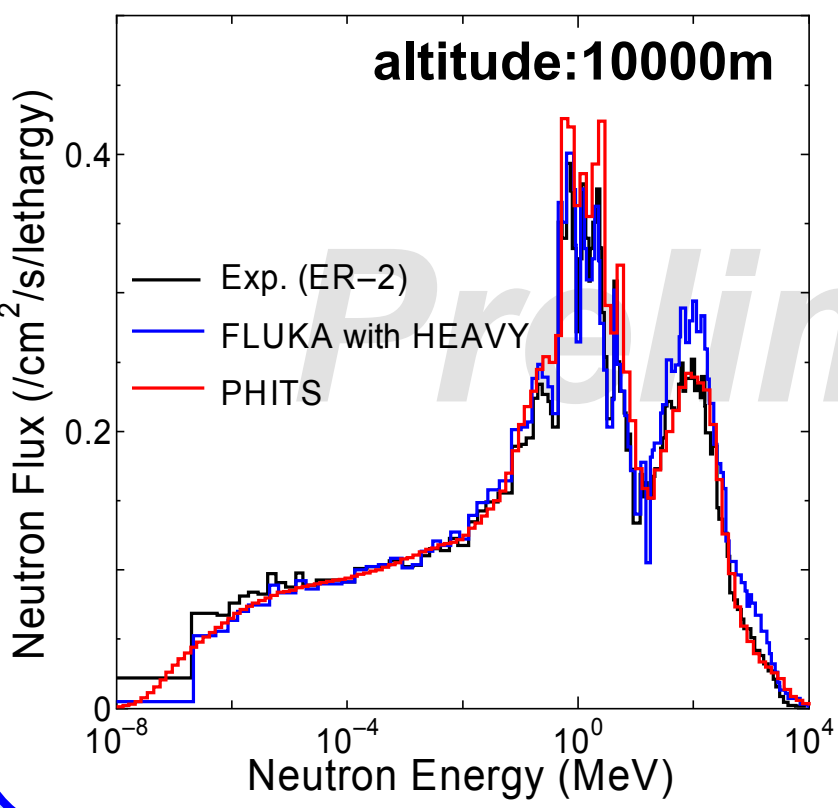
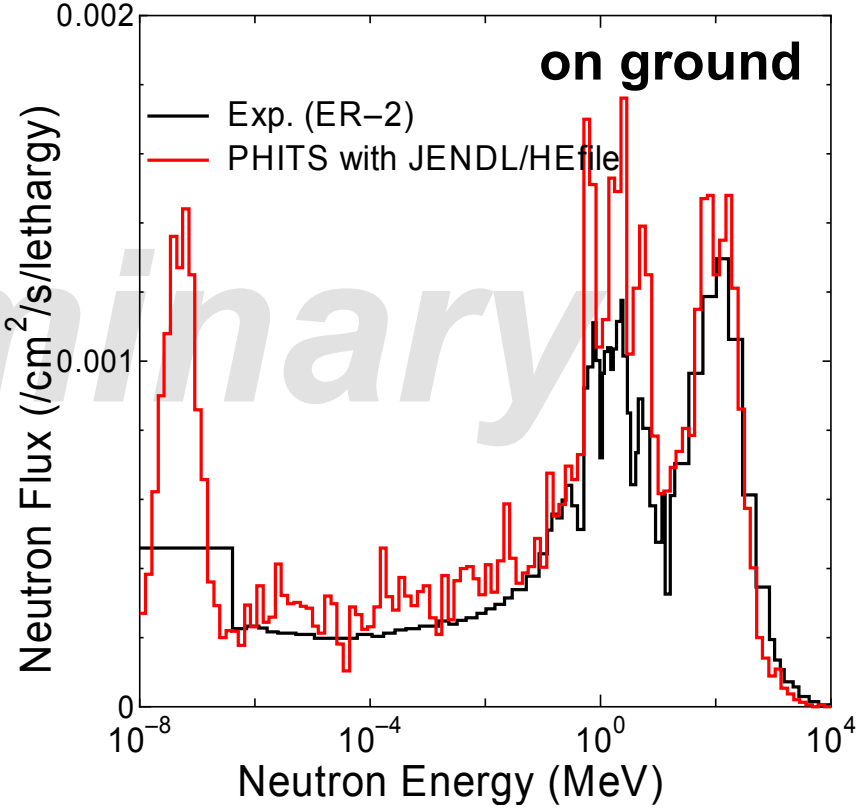
High Energy Nuclear Data File

Neutron Spectra in the Atmosphere



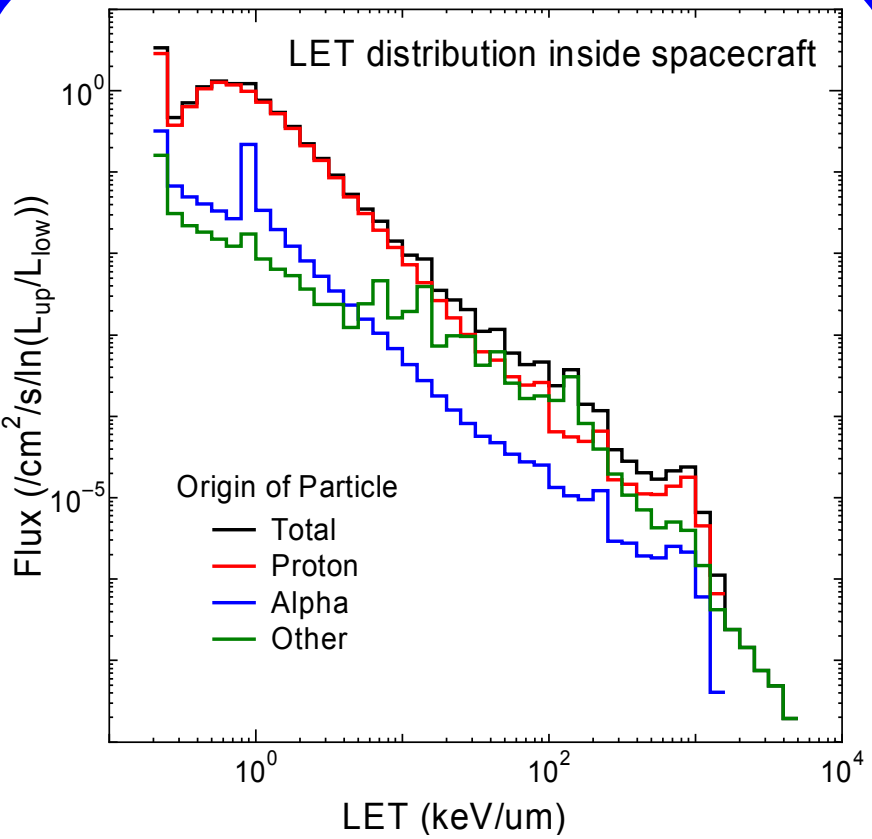


LET Tally into PHITS

Track & Dose distribution in terms of LET

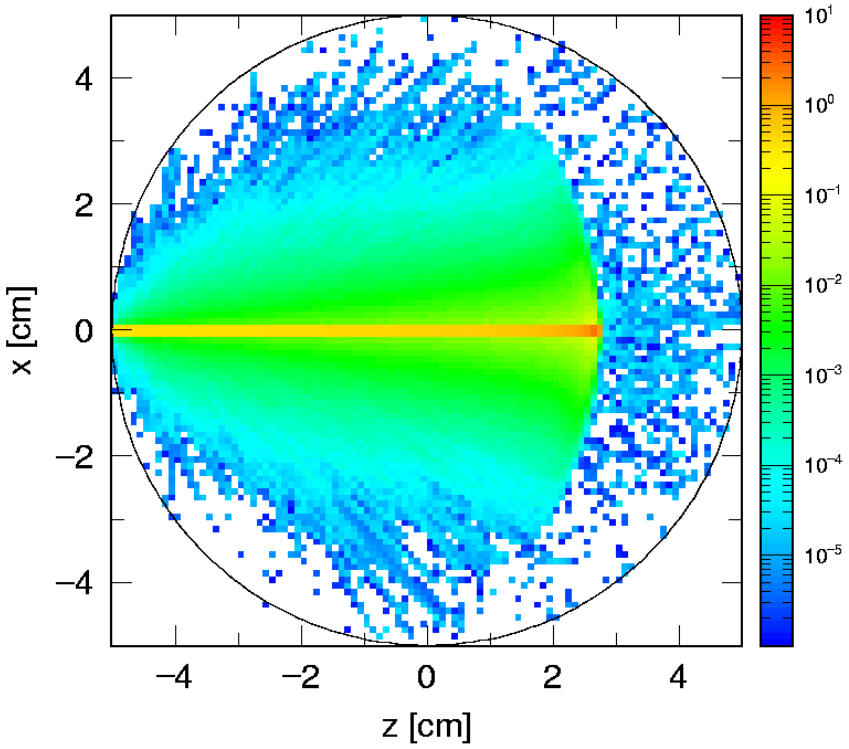
Dose Equivalent

Response of Detector



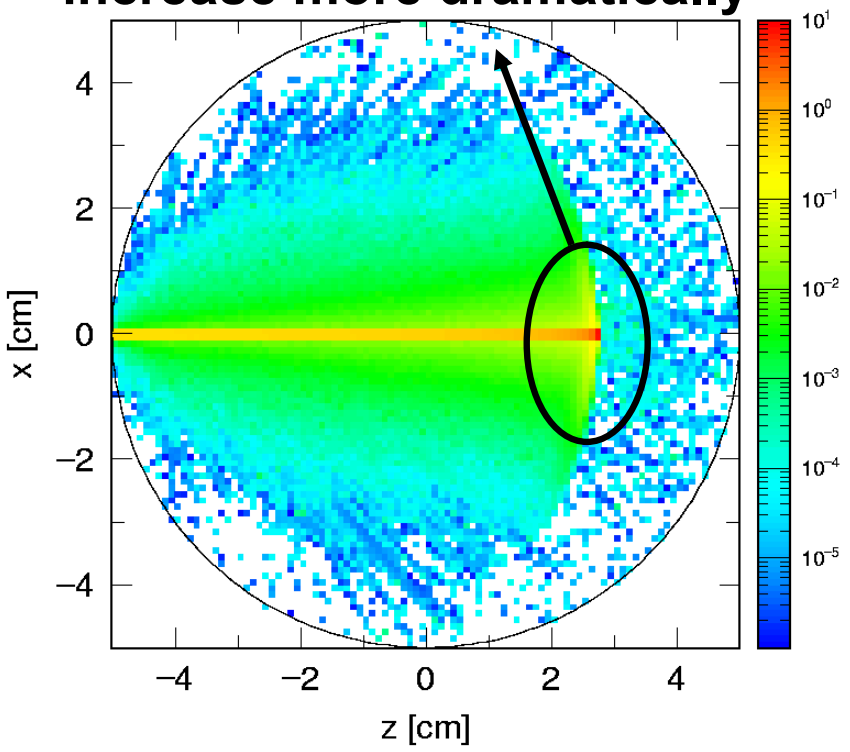
Charged-Particle Spectrum inside Spacecraft in terms of LET in Water

Calculation of Dose Equivalent



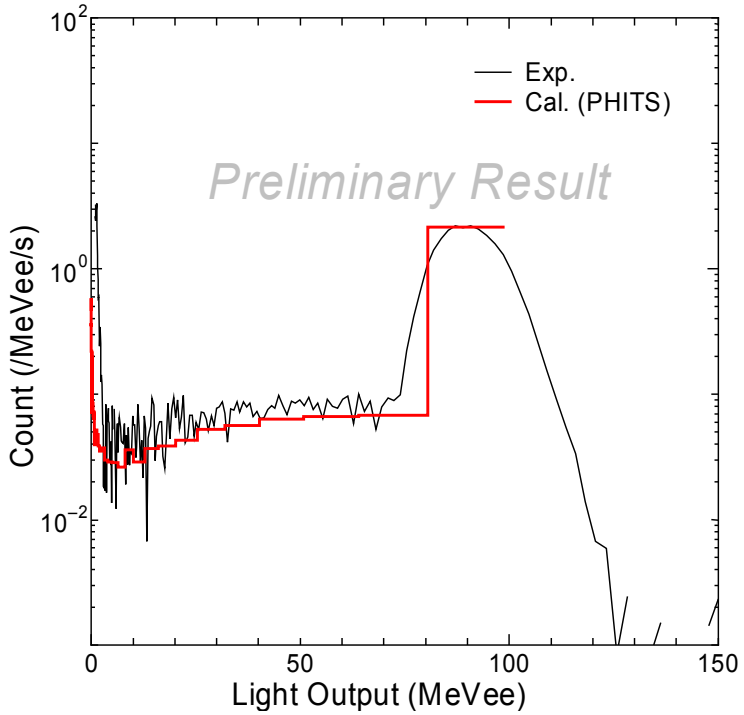
Dose Distribution in Tissue Equivalent Material Irradiated by 100 MeV Proton

increase more dramatically



Dose Equivalent Distribution in Tissue Equivalent Material Irradiated by 100 MeV Proton

Calculation of Detector Response



Response of CsI for 100 MeV Proton

$$\text{Light Output} = \frac{\text{S x Deposition Energy}}{1 + kB \times \text{LET} + C \times \text{LET}^2}$$

Quenching Effect

LET tally function is indispensable in the precise estimation of response

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Summary

PHITS can reproduce ...

- Neutron spectrum inside Space Shuttle
- Absorbed dose and dose equivalent for astronauts

Recent improvement of PHITS enables us ...

- reproduce particle spectra in the atmosphere by employing high energy nuclear data file
- calculate dose equivalent and detector response by means of the LET tally function.

PHITS has a great possibility of playing an important role in space exploration