External MC code : PHITS

Particle and Heavy Ion Transport code System

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Yosuke Iwamoto[2], Norihiro Matsuda[2], Yukio Sakamoto[2], Hiroshi Nakashima[2],
Davide Mancusi[4], Lembit Sihver[4,5]

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Contents

PHITS : Particle and Heavy Ion Transport code System

- All particles transport code system,
  Geant4, MCNPX, FLUKA, MARS, ...
- All source files and Windows binary are distributed.
- All in one package including graphic utility, not a tool kit,
  its physical models are fully integrated.

5 major codes for all particle transport in a world

	MCNPX	GEANT4	FLUKA	MARS	PHITS
Lab. Affiliation	LANL	CERN,IN2P3 INFN,KEK,ESA, SLAC,TRIUMF	CERN INFN	FNAL	JAEA,RIST GSI,KEK Chalmers Univ.
Language	Fortran 90/C	C++	Fortran 77	Fortran 95/C	Fortran 77
Release Format	Source & binary	Source & binary	Source & binary	Binary	Source & binary
Users	~2000	~1000	~1000	220	220
Parallel Exec.	Yes	Yes	No	Yes	Yes

By G. W. McKinney in FNDA (Fast Neutron Detectors and Applications Conference) April 2006
Revised by L. Waters in HSS06 (Hadronic Shower Simulation Workshop) Sep. 2006

Overview of PHITS (Particle and Heavy Ion Transport code System)

1951 NMTC (ORNL) → 1983 NMTC/JAERI High Energy Fission → 1997 NMTC/JAERI97 CG geometry → 2001 NMTC/JAM JAM, GG Magnetic Field → 2003 PHITS JQMD, MCNP Gravity

PHITS = MCNP + JAM + JQMD

MCNP	Neutron, Photon, Electron Transport by Nuclear Data
JAM	Hadron-Nucleus Collisions up to 200 GeV
JQMD	Nucleus-Nucleus Collisions by Molecular Dynamics

External Field: Magnetic Field, Gravity Optical and Mechanical devices

Language and Parallelism

FORTRAN 77
MPI

Transport Particle and Energy

Proton	0 ~ 200 GeV
Neutron	10^{-5} eV ~ 200 GeV
Meson	0 ~ 200 GeV
Barion	0 ~ 200 GeV
Nucleus	0 ~ 100 GeV/u
Photon	1 keV ~ 1 GeV
Electron	1 keV ~ 1 GeV

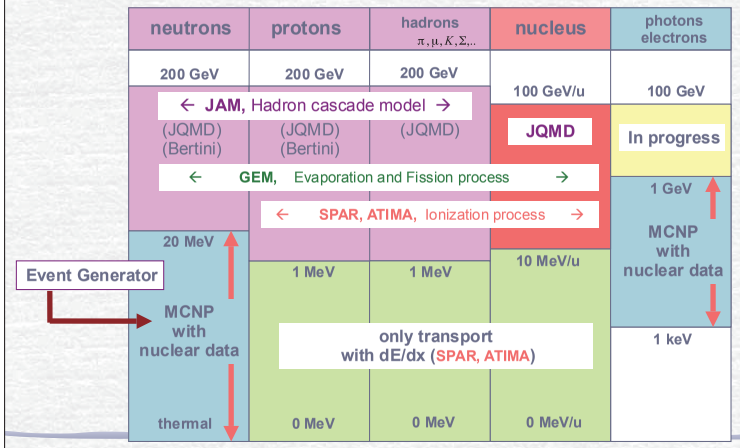
Geometry: CG and GG

Tally, Mesh and Graphic

Tally: Track, Cross, Heat, Star, Time, DPA, Product, LET
Mesh: cell, r-z, xyz
Counter:
Graphic: ANGEL (PS generator)

PHITS : H. Iwase et.al. J. Nucl. Sci.Technol. **39** (2002) 1142

Map of Models, transport particles and energies in PHITS



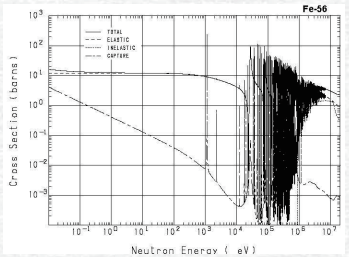
MCNP code *for Neutron Transport below 20 MeV with Nuclear Data*

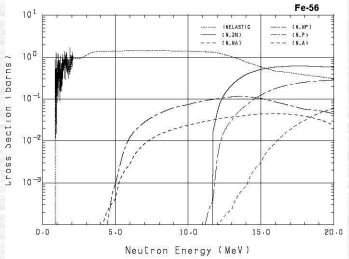
Monte Carlo N-Particle Transport Code System *developed by Los Alamos National Lab.*

for Neutrons, Photons, Electrons
by using Evaluated Nuclear Data, such as **ENDF, JENDL, …**

Applications:
Nuclear Criticality Safety, Radiation Shielding, Fission Reactor Design, …

n-56Fe Reaction Cross Sections





Event Generator Mode for low energy neutrons in PHITS

How to estimate the deposit energy of charged particles and nuclei for neutron transport below 20 MeV

MCNP type	⟺	PHITS
Transport based on Boltzmann equation with nuclear data		Event Generator Mode with nucleus transport
Local Approximation (Kerma factor)		Energy Deposition in event by event
Average Values		Deposit energy distribution

This assumption is not valid for :

- Size of system is smaller than Range of charged particles
- Distribution is necessary instead of average value

Energy is conserved in average
No correlation

⇩

Only one-body observables

Treat all ejectiles of collisions.
Energy and Momentum are conserved in each collision.

⇩

Any observables
Beyond one-body observables

Event Generator Mode for low energy neutrons in PHITS

Neutron data + Special Evaporation Model

We use the channel cross sections and neutron energy spectrum of the first neutron and assume the binary decay of recoiled nucleus.

Neutron channels

- **capture** $\Gamma_n = 0$ — charged particle and photon decay
- **elastic** — final state is uniquely determined
- **(n,n')** $\Gamma_n = 0$ — charged particle and photon decay after the first neutron emission
- **(n,Nn')** $\Gamma_n \neq 0$ — all particle and photon decay after the first neutron emission

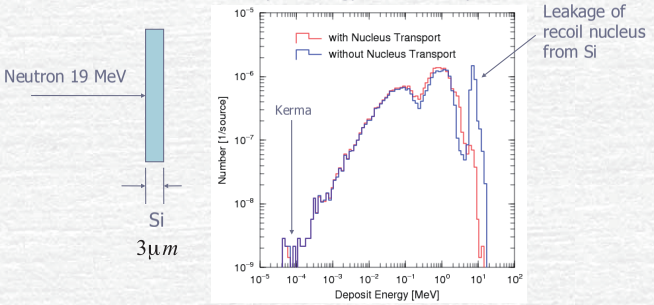
By this model, we can determine all ejectiles (neutrons, charged particles, nucleus and photons) with keeping energy and momentum conservation.

PHITS can transport all charged particle and nucleus down to zero energy and estimate deposit energy without local approximation (kerma factor).

An example of Event Generator Mode

Neutron-induced semiconductor soft error
SEU: single event upset

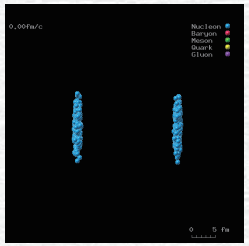
Deposit Energy Distribution by PHITS



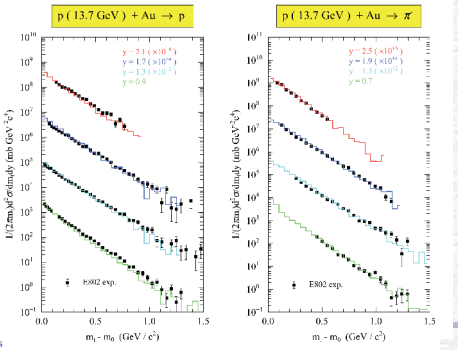
JAM code for Hadron Nucleus Collisions up to 200 GeV

Introducing JAM *(Jet AA Microscopic Transport Model)* Y. Nara et.al. *Phys. Rev.* **C61** (2000) 024901
JAM is a ***Hadronic Cascade Model***, which explicitly treats all established hadronic states including resonances with explicit spin and isospin as well as their anti-particles.
We have parameterized all ***Hadron-Hadron Cross Sections***, based on ***Resonance Model*** and ***String Model*** by fitting the available experimental data.

Au+Au 200GeV/u in cm



119 kinds of Mesons
170 kinds of Baryons

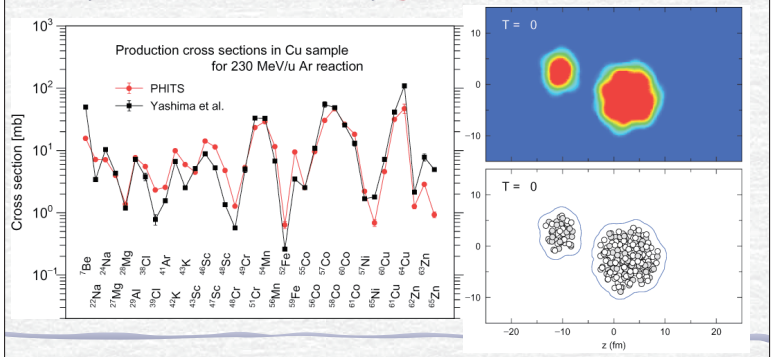


JQMD code for Nucleus-Nucleus Collisions up to 100 GeV/u

JQMD *(Jaeri Quantum Molecular Dynamics) for Simulation of Nucleus-Nucleus Collisions*
K. Niita et.al. *Phys. Rev.* **C52** (1995) 2620 *http://hadron31.tokai.jaeri.go.jp/jqmd/*

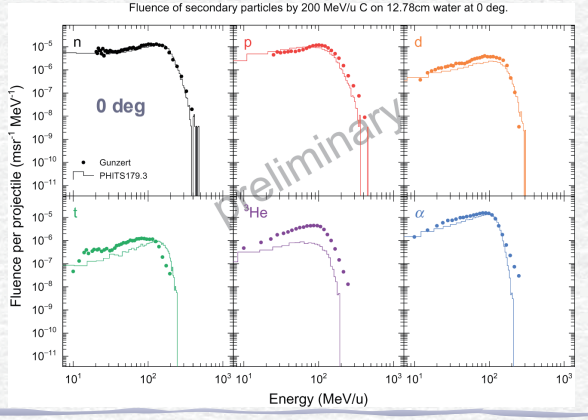
Analysis of Nucleus-Nucleus Collisions by ***JQMD***

^{56}Fe 800 MeV/u on ^{208}Pb

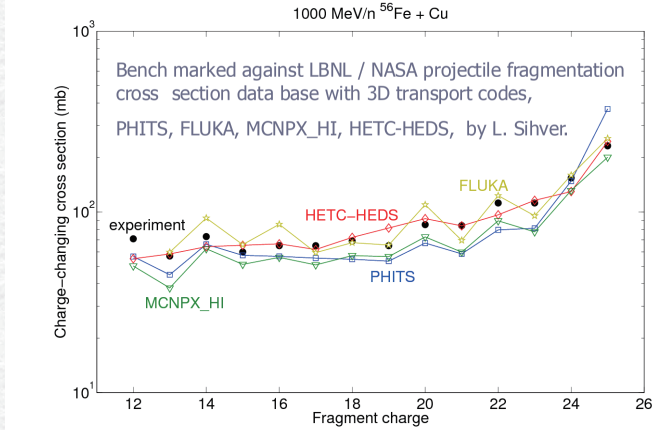


Secondary Particle Production Cross Sections

From 200 MeV/u Carbon beam on 12.78 cm depth Water by K. Gunzert-Marx at GSI

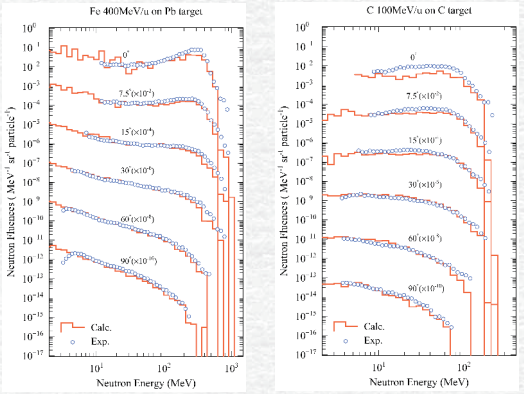


Charge Changing Cross Section



Neutron Spectra from Thick Target

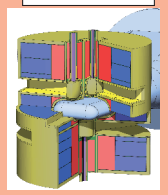
Introducing JQMD in PHITS : H. Iwase et.al. *J. Nucl. Sci.Technol.* **39** (2002) 1142



JQMD-2

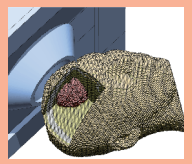
Application Fields of PHITS

Accelerator



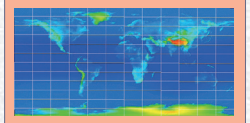
J-PARC
Spallation Neutron Source
Neutron Optics
Heavy Ion Facilities

Cancer Therapy



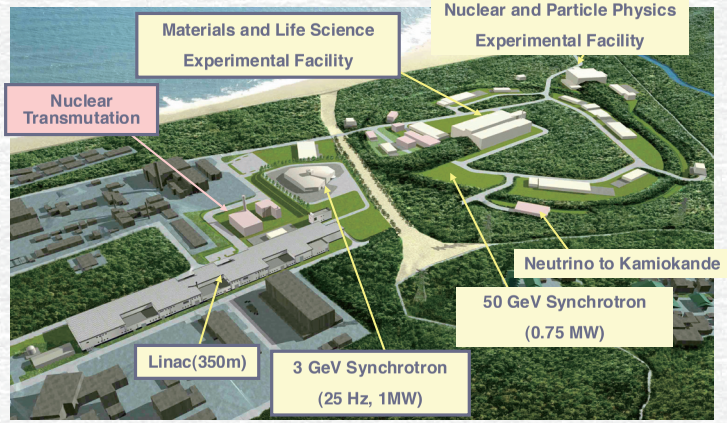
BNCT
Proton and
Heavy Ion Therapy

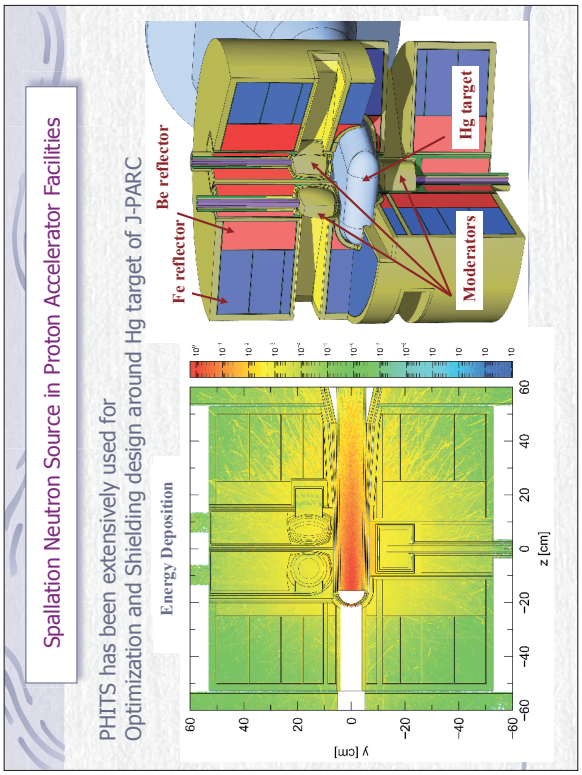
Space Technology

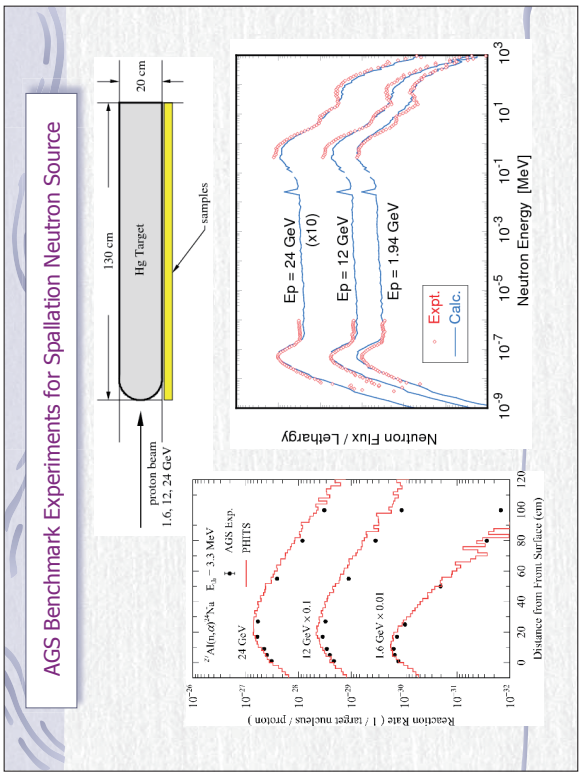


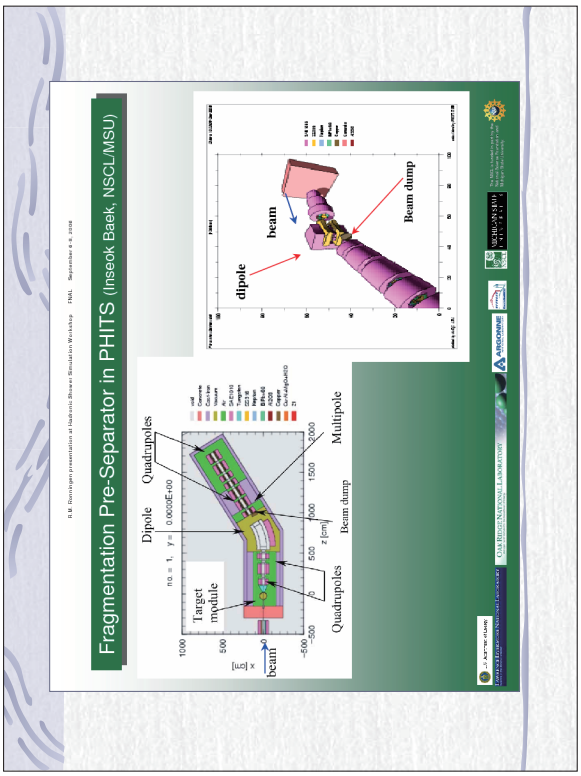
Dose in Space Shuttle
Atmospheric Cosmic-Ray

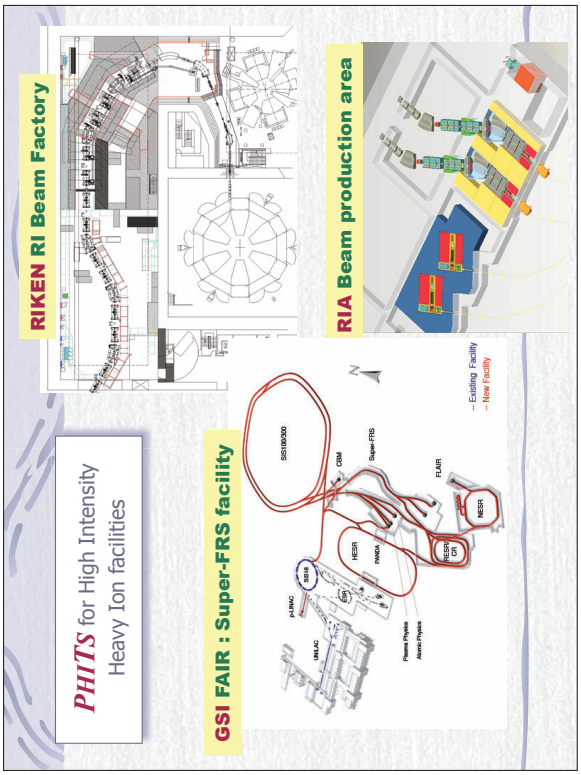
J-PARC = Japan Proton Accelerator Research Complex

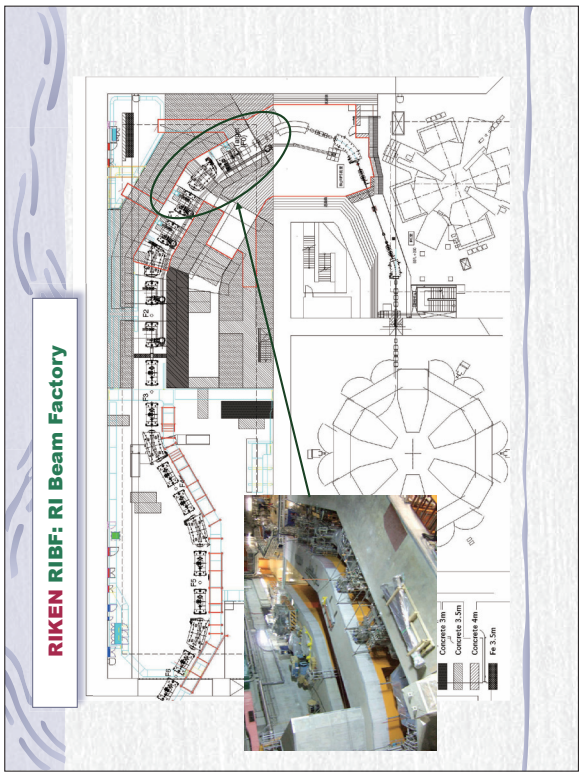


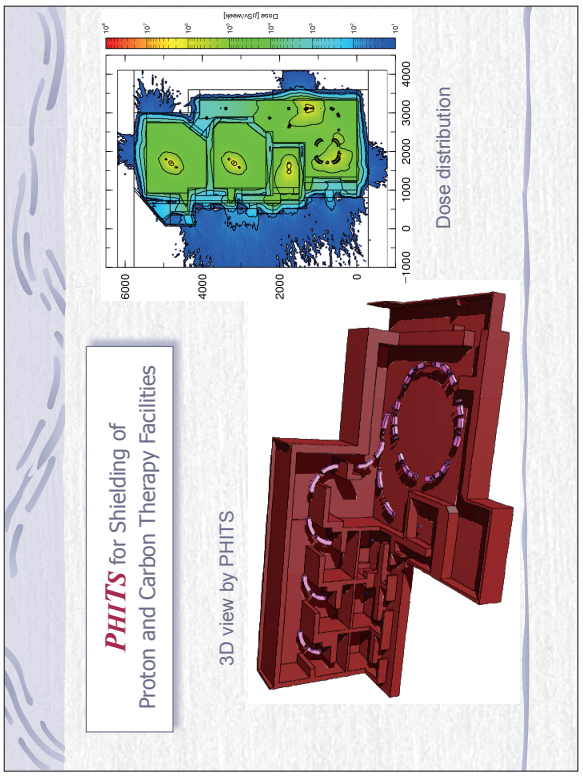


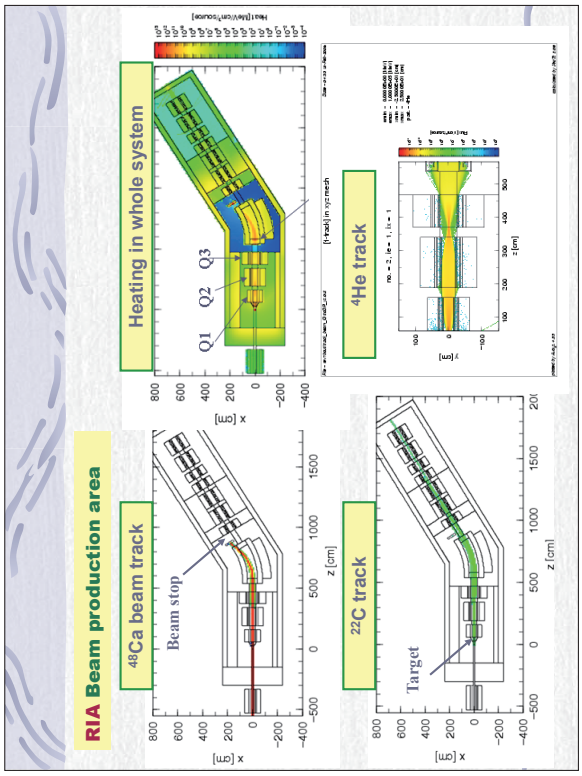


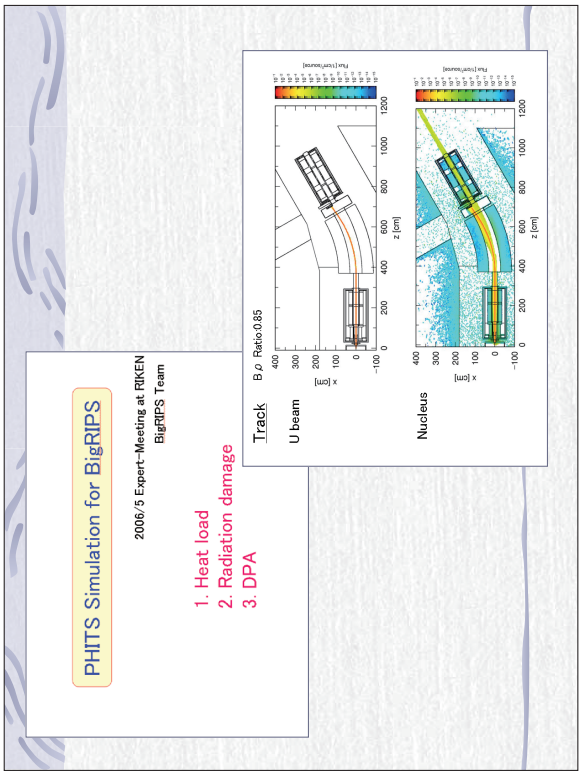










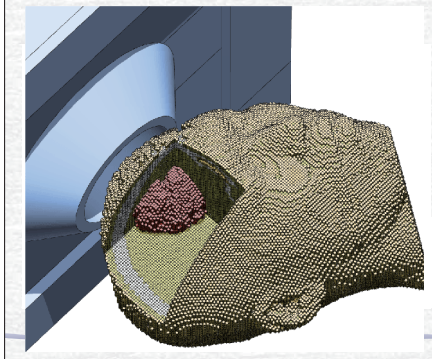


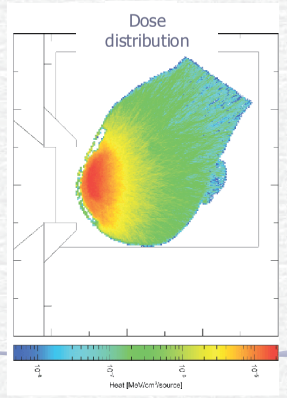
PHITS for planning system for radiotherapy

Boron Neutron Capture Therapy at Dept. Research Reactor, JAERI

3D view by PHITS

JCDS (Jaeri Computational Dosimetry System) **creates the Voxel data from CT and MRI data for MCNP (PHITS) calculation.**





PHITS for Single Event Upset

Investigation of Thermal Neutron Induced Single Event Upset using PHITS

●Yutaka Arita (Renesas Technology Corp.)

Koji Niita (Research Organization for Information Science & Technology)

Mikio Takai (Osaka University)

Tsutomu Yoshihara (Waseda University)

Yuji Kihara (Renesas Technology Corp.)

Junichi Mitsuhashi (Renesas Technology Corp.)

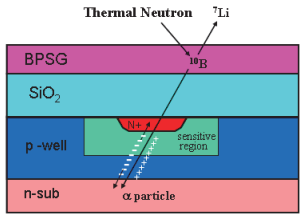
7th International Workshop on Radiation Effects on Semiconductor Devices for Space Application

2006/10/17

1

Background

- Thermal neutron induced Single Event Upset (SEU)

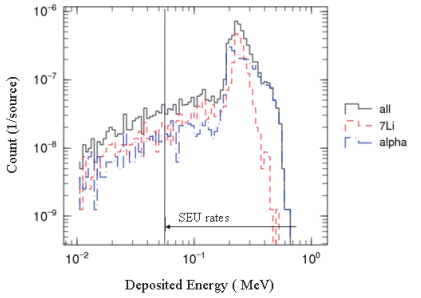


- Process technology < 0.25 μm
- Thermal Neutron + $^{10}B \rightarrow$ α (1.48 MeV) + ^{7}Li (840 KeV)
- Electrons are collected to N+ region by drift current and/or by diffuion current

3

Result of simulation

- Deposit energy of α particle and ^{7}Li in sensitive region



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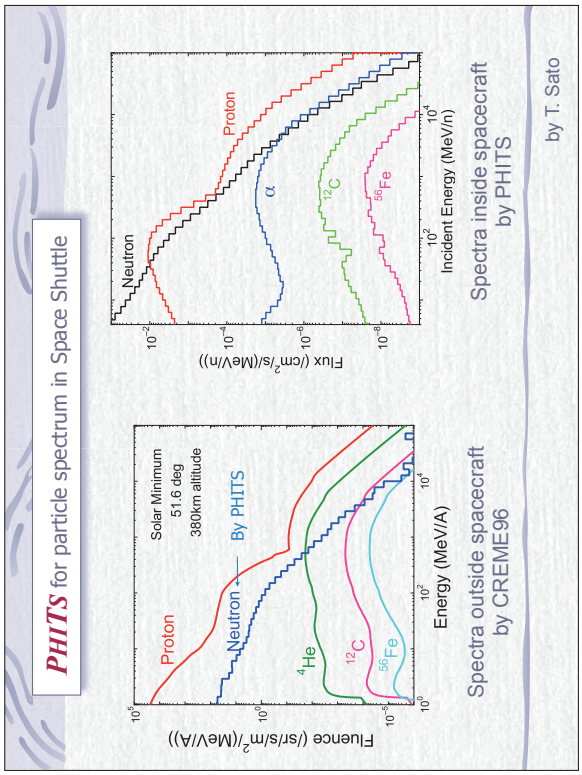
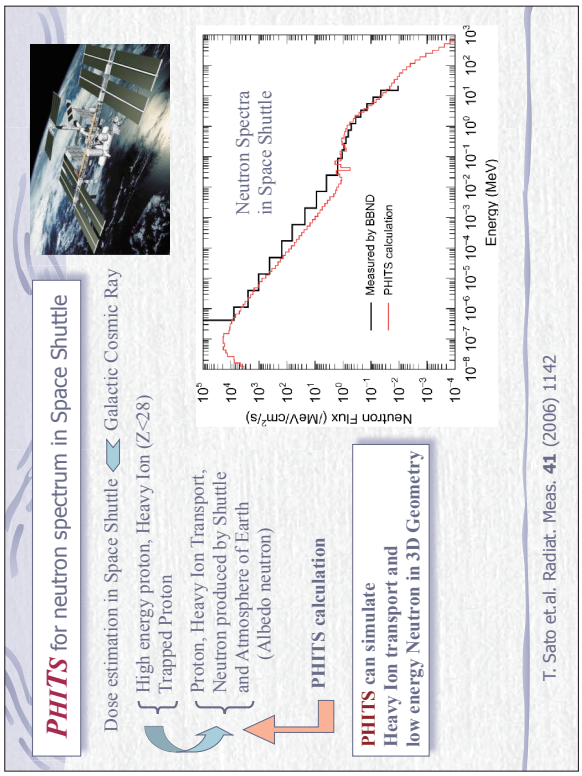
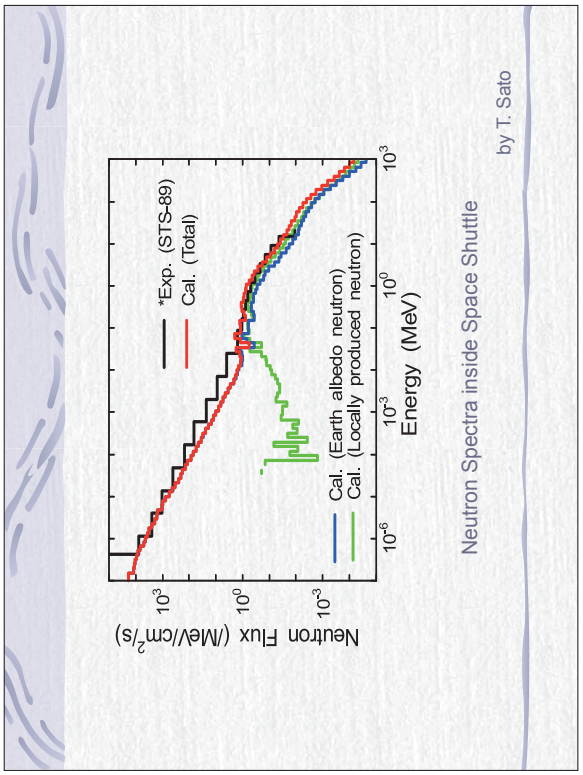




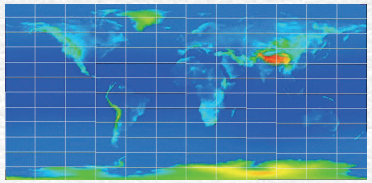


PHITS for neutron spectrum in atmosphere

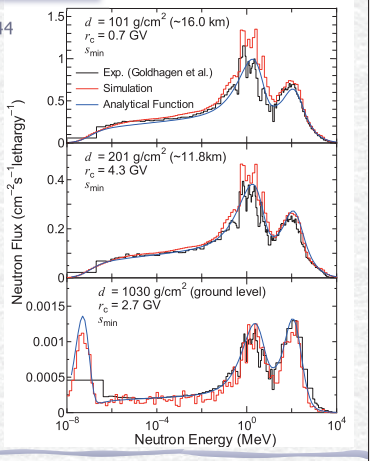
T. Sato and K. Niita, Radiat. Res., **166** (2006) 544

Galactic Cosmic Ray (CREME96)
+
PHITS with JENDL-HEfile

Neutron spectrum in any height of atmosphere even at ground level

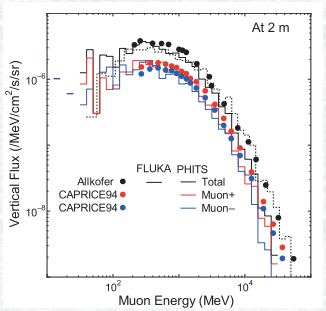


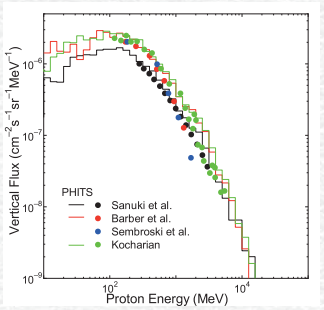
dose map on ground level



http//www3.tokai-sc.jaea.go.jp/rphpwww/radiation-protection/expacs/expacs.html

Muon and Proton Spectra on the earth





by T. Sato

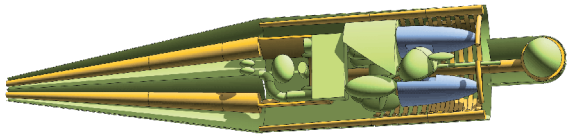
Conclusions

- Particle and heavy ion transport code (PHITS) is an essential implement in design study of accelerator facilities for various purpose, in planning system for radiotherapy, and in space radiation.
- Description of nuclear reactions in the code is one of the key quantity to determine the accuracy of the transport code.
- Tow reaction models: JAM and JQMD and Nuclear data are employed in PHITS to describe the nuclear reactions.
- Event generator combined with the nuclear reaction model and the nuclear data is necessary to describe new quantities which are related to the higher order correlations beyond one-body observables.

Conclusions

Distribution of PHITS

PHITS *ver.2.13* and **ANGEL** *ver.4.35*
have been released from JAEA.



niita@tokai.rist.or.jp
RIST. Code Center: *http://www.rist.or.jp*

distribution