SATIF-10 Summary

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SATIF-10
CERN
June 2-4, 2010

Sessions

There have been impressive presentations, productive discussions and constructive dialogue in all 6 sessions:

1. Source term and related topics (1 + 8)
2. Induced radioactivity (1 + 10)
3. Benchmarking (1 + 7)
4. Dosimetry (1 + 2)
5. Medical and industrial accelerators (1 + 5)
6. Present status of data and code libraries (1 + 4)

+ RP Network discussion

Six invited and 38 contributed talks, 68 participants

1. Source term and related topics

T. Nakamura. Excellent overview of experimental data (<2008) on neutron distributions and spallation products from thick and thin targets for p, d, He and HI beams (MeV to GeV). Invaluable asset for the community, include in SINBAD if/when digitized.

First time at this meeting, we have started discussion on what level of agreement between data and simulations is satisfactory.

A very interesting set of results on radiation fields induced by 243 and 390 MeV quasi-monoenergetic neutrons. Another good candidate for inclusion into SINBAD.

Source term and related topics (2)

Systematic studies of TTY, radiation fields in thick shielding, activation, muon-induced spallation reactions and radiation effects, all induced by proton beams with E up to 120 GeV within JASMIN collaboration. Certainly include in SINBAD when analysis is finished.

Consideration of dark current induced radiation in SC RF and shielding around. Interesting sensitivity analysis of effects of cryogenic moderator, reflector, decoupler and temperature on radiation field at CSNS.

Shielding and activation study for a high-intensity laser facility with a target area design (E_e up to 50 GeV). Neutron yield and nuclear transmutation at a photo-neutron source.

Dealing with MegaWatt Beams

- At new generation of accelerators, extremely high peak specific energy (up to ~0.1 MJ/g) and specific power (up to ~1 TW/g) in beam interactions with matter make design of such critical systems as targets, absorbers and collimators very challenging, requiring novel approach.

- This also puts unprecedented requirements on the accuracy, capability and reliability of the simulation codes used in the designs. Particle production, DPA, nuclide inventory, energy deposition and hydrodynamics coupling are the modules of special importance.

- Benchmarking is absolutely crucial. Justified emulation of extreme conditions at existing lower energy and beam power facilities is the way to go. JASMIN (Fermilab/Japan), BLIP (BNL) and HiRadMat (CERN) activities are the excellent examples. Joint efforts with material experts are needed.

2. Induced Radioactivity

All-in-one vs. Modular approaches

	All-in-one-code	Modular
Pros	•Decay emissions at reaction-site or position of tracked decaying ion •Proper analysis of statistical errors •Conservation of correlations on per particle basis	•Deterministic analysis gives full inventories •Allows for material depletion •Decay source terms for subsequent analyses
Cons	•Large memory footprint	•No statistical errors •Lost correlations •Region averaged decay sources

Need realistic simulations to avoid unnecessary costs

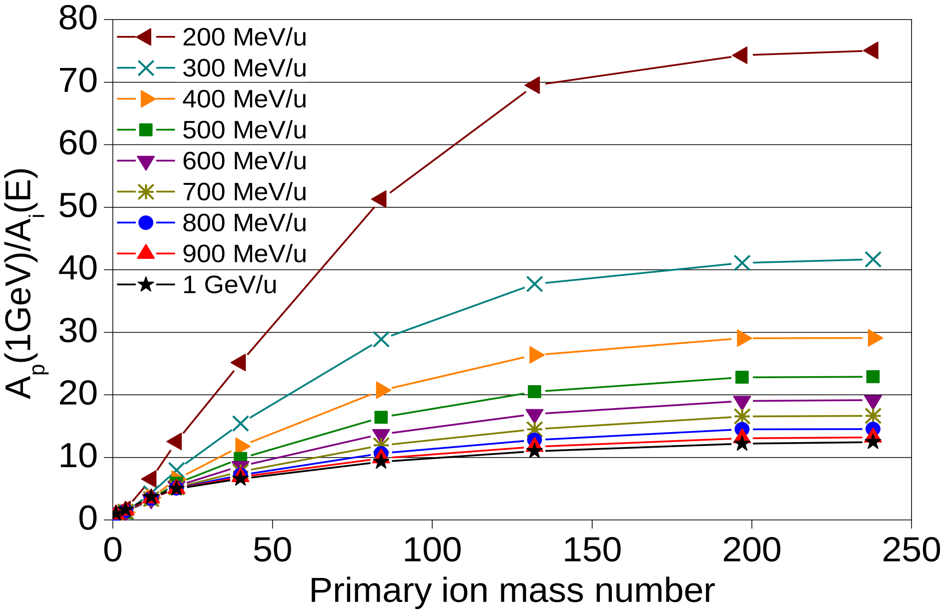
Use of Monte Carlo for generic activation studies – 1
Ivan Strasik for Heavy-Ion Accelerators (hands-on maitenance criterion)

1) Inventory of the isotopes does not depend on the projectile species.

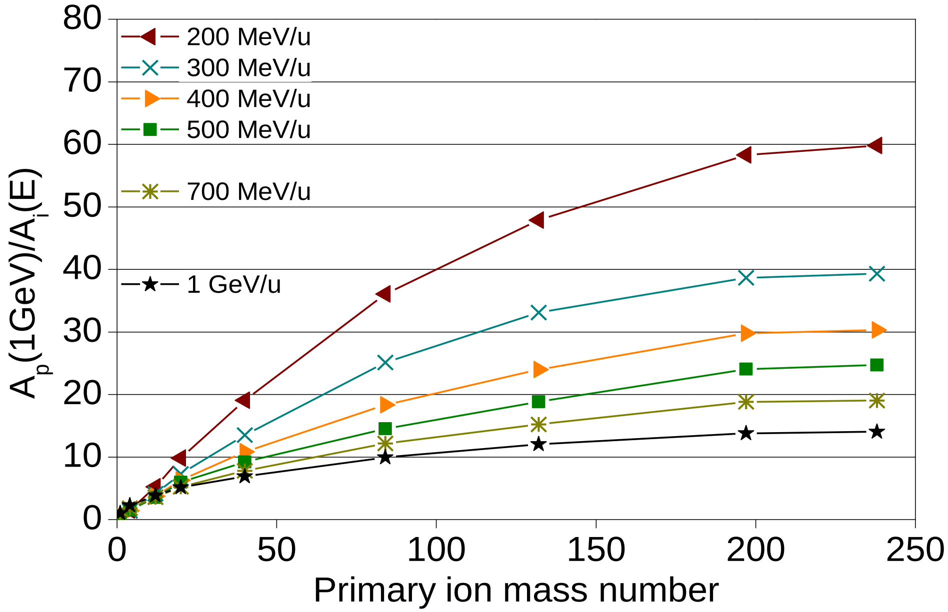
2) Time evolution of the activity correlates to the generic curve.

3) The activity induced by 1 W/m of beam losses is decreasing with increasing ion mass and with decreasing energy.

FLUKA



SHIELD



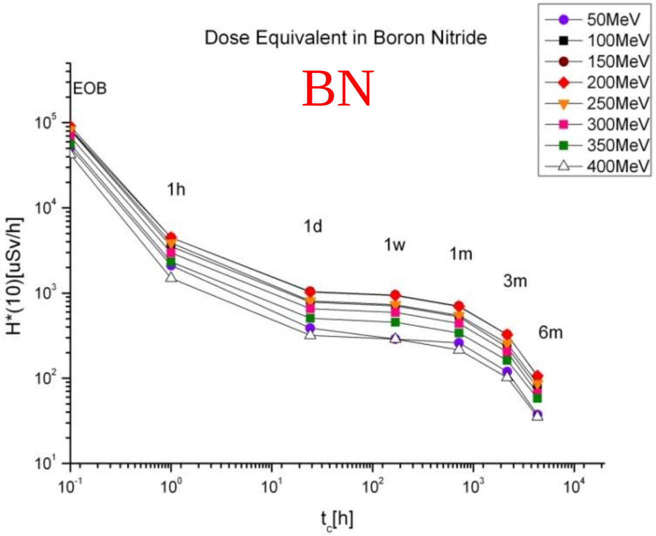
$A_p(1GeV)$ – normalized activity induced by 1 GeV proton beam (reference)
$A_i(E)$ – normalized activity induced by the beam of interest at given energy

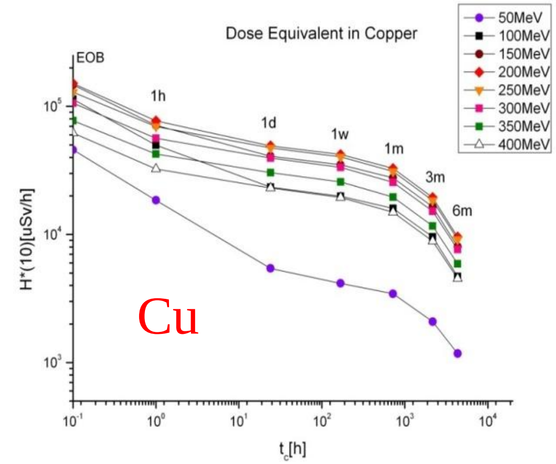
the normalized activity [Bq/W/m]

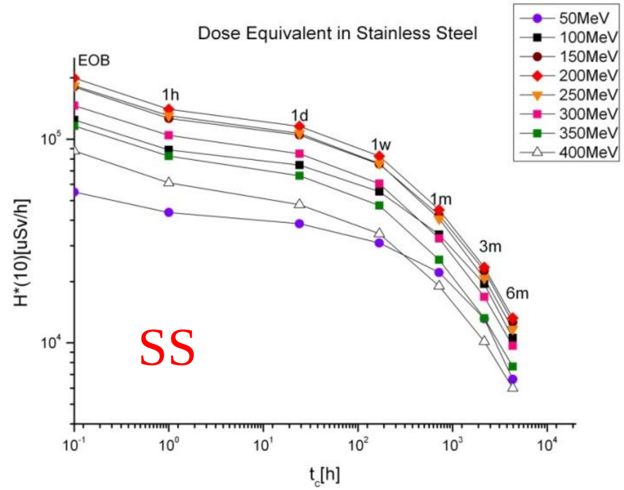
Use of Monte Carlo for generic activation studies -2

Nikolaos Charitonidis for 50-400 MeV medical accelerators

Ambient dose equivalent rate as a function of cooling time



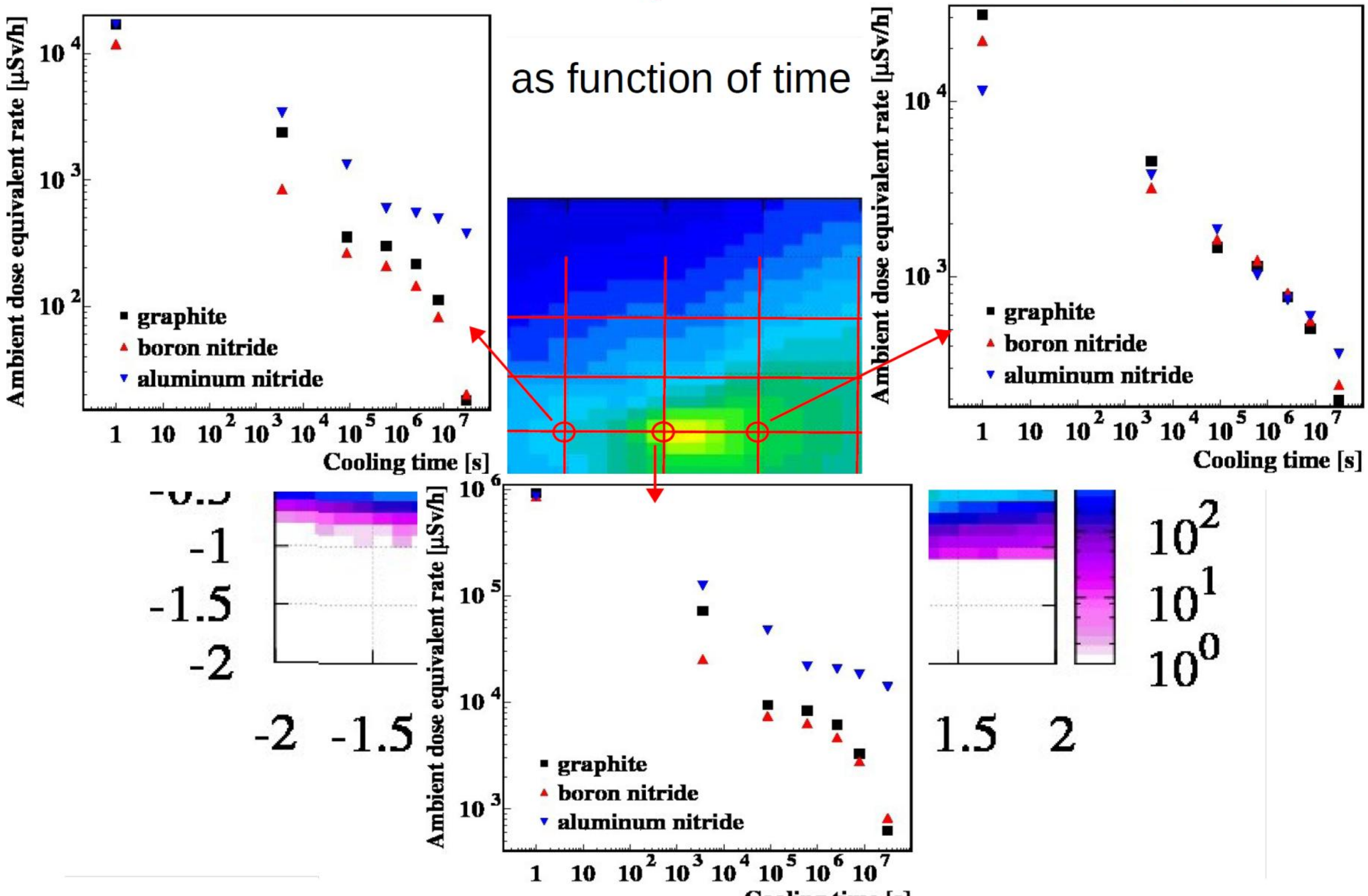




Activation properties-important factor for material choice

Roberto Versaci for 160-MeV H0/H- dump

Ambient dose equivalent rate H*(10)

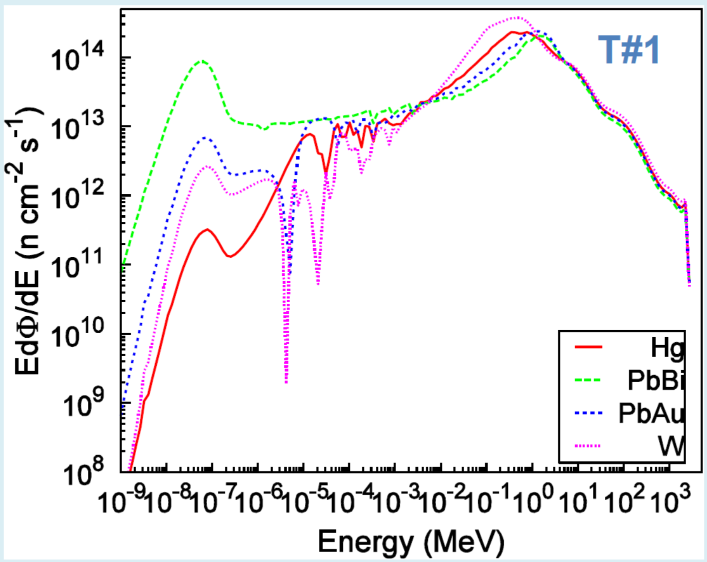


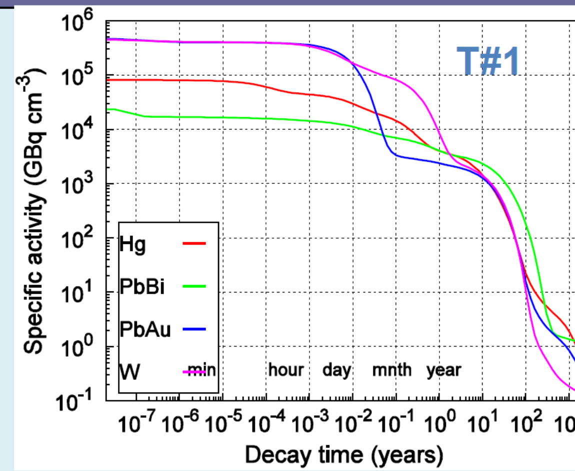
Activation - important factor for material choice

Daniela Ene for ESS

European Spallation Source

Target material





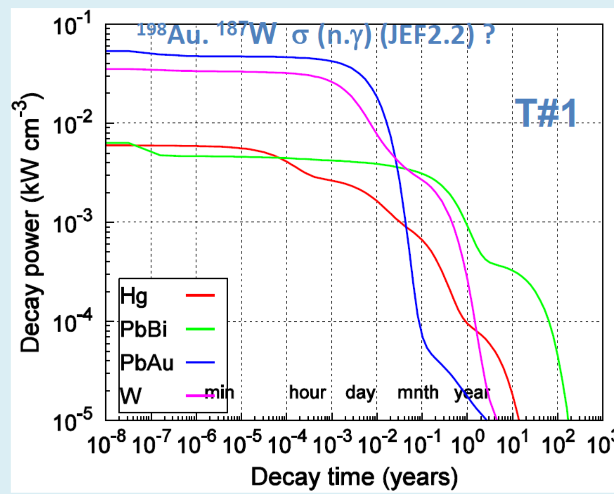
^{194}Hg-^{194}Au

^{208}Bi

^{202}Pb

^{163}Ho. ^{191}Nb.

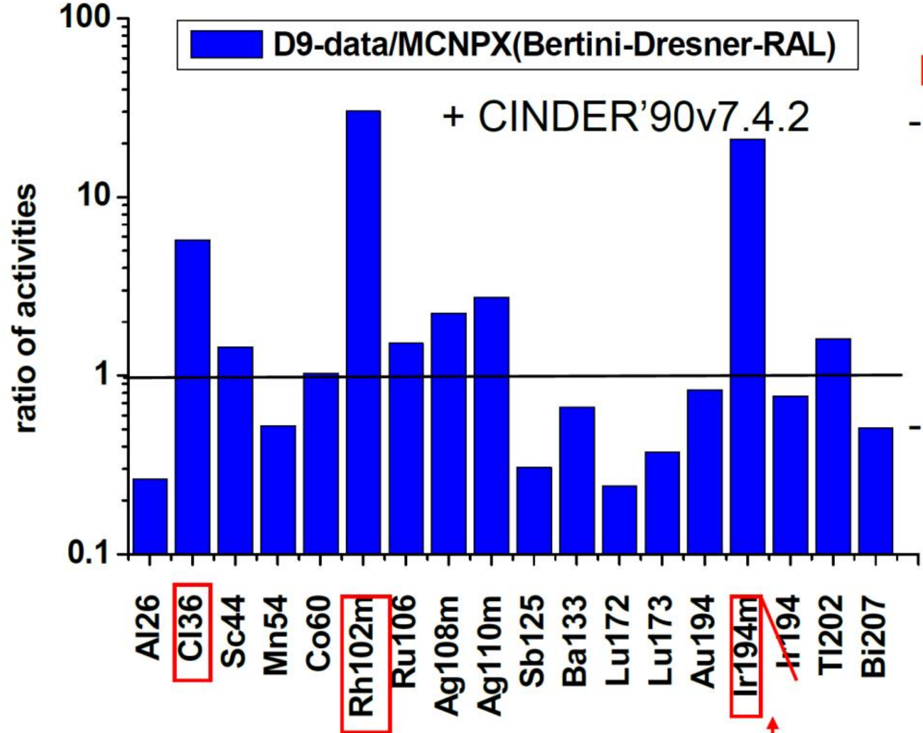
^{93}Mo



Activation: Benchmarks, benchmarks, benchmarks
Daniela Kiselev for PSI beams

PAUL SCHERRER INSTITUT PSI

Results for D9-sample: BERTINI-Dresner-RAL



Ir194 was not measured

Prominent Deviations:

- Ir194m:
  Ir below 2ppm detection limit
  → only 30% more production
  Ir194 would match
  exp. data: checked, no mix-up
  simulation?
- Rh102m:
  see other models

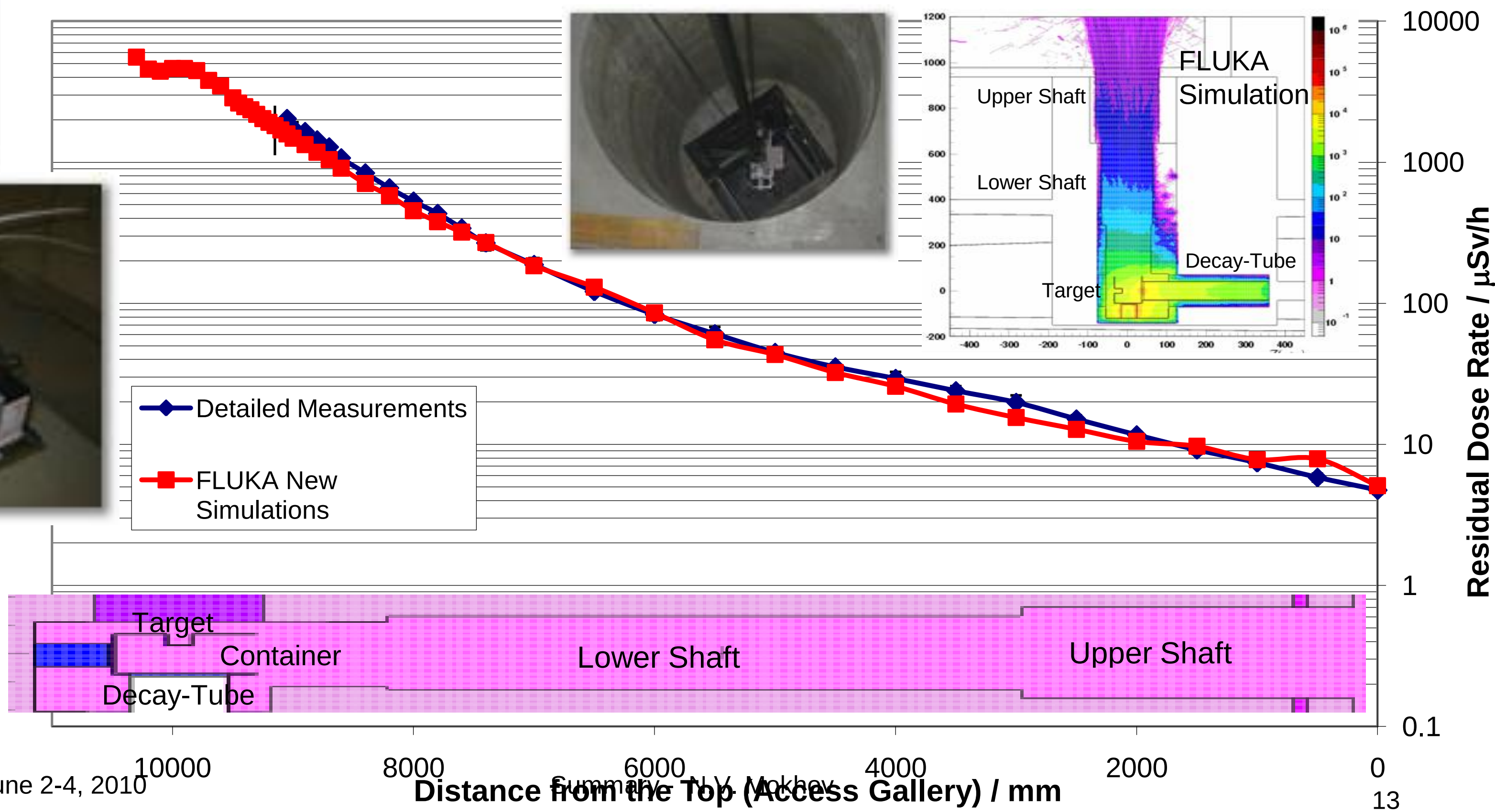
- Cl36: main production via Cl35(n,γ)Cl36 but missing in material definition
  reason: cannot be detected by applied method (ICP-OES via dissolved probe)

Activation: Benchmarks, benchmarks, benchmarks

Elias Lebbos for CERN nToF

Inside the pit: using a laser attached to the crane to contr
the position of the remote detector (attached to the hook)

Measurement/FLUKA Comparison
after Detailed Pit Survey Measurements 01.11.2007



3. Benchmarking

Scope: Monte Carlo and others. Physics Models. Parameterizations. Data. Nuclear data.

Intercomparison between codes when no data: DPA, role of Λ, etc.

Microscopic Benchmarking

IAEA activity : www-nds.iaea.org/spallations

Advanced Workshop on Model Codes for Spallation Reactions
Double Differential Cross section: CEA-Saclay
Isotopic Distribution Cross section: GSI
Light Charged Particle Production: NSC, LANL, COSY
etc.

GSI activity

Isotopic Distribution Cross section: GSI

CERN experiment: Secondary particle production

Macroscopic Benchmarking

Proton accelerator experiments:

- RCNP: Deep penetration (forward)
- FNAL: JASMIN, deep penetration, TTY, muon-induced nuclide production
- BNL: Deep penetration (lateral)

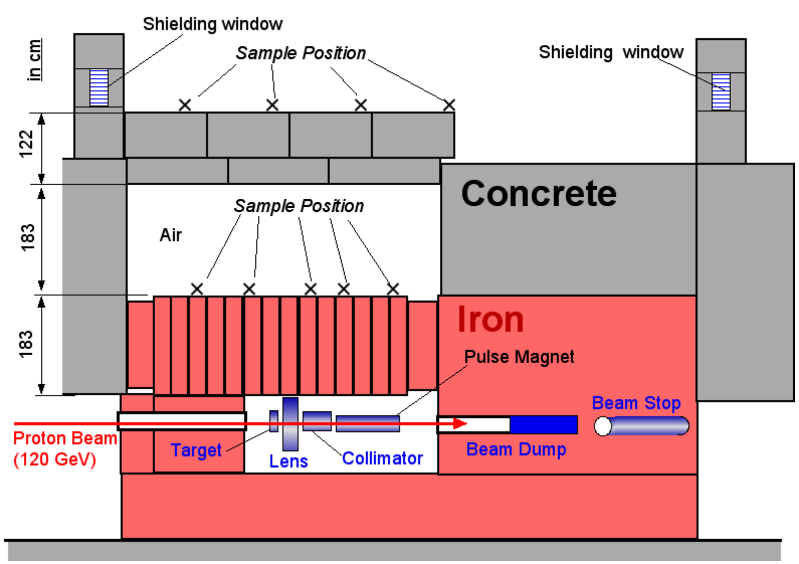
Heavy ion accelerator experiments:

- RIKEN: Secondary neutron production

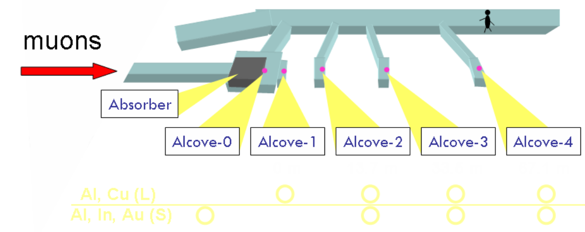
SHIELDING AND RADIATION EFFECT EXPERIMENT

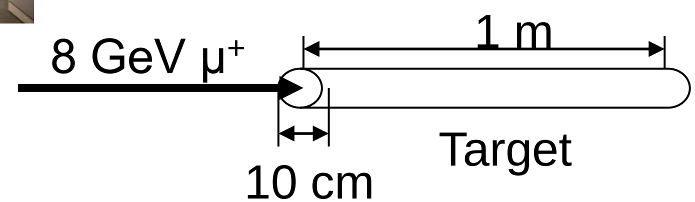
JASMIN Japan-FNAL Collaboration:
Shielding and Radiation Effect Experiments at FNAL
T-972 (2007-2009)
T-993 and T-994 (2009-2012)

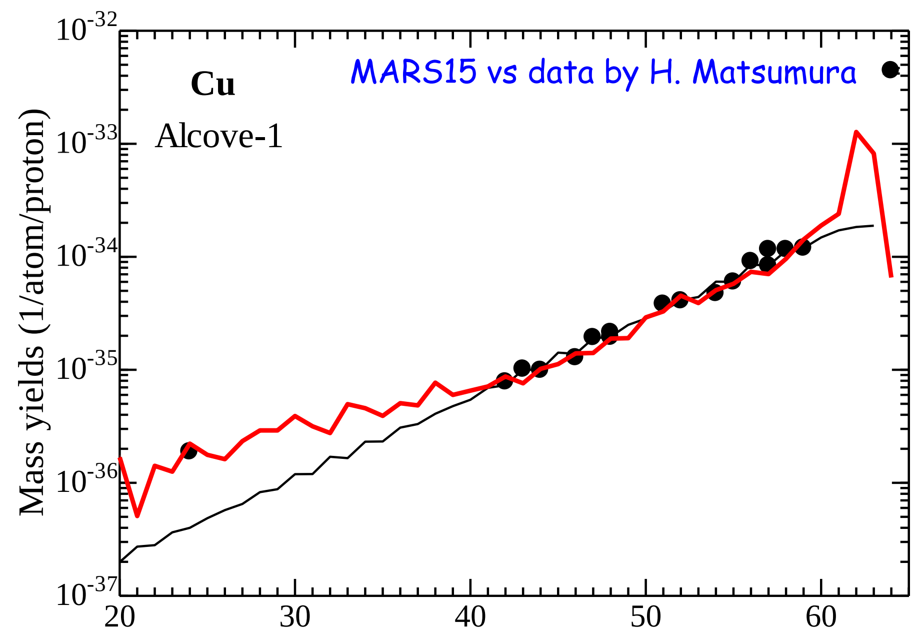
Shielding data and code benchmarking; targets, collimators and thick shields; radiation effects on instruments and materials



Example: Muon-induced nuclide production







Code benchmarking: hadrons

Neutron production and propagation: reasonably well understood by most codes (with some caveats), see also Dr. David presentation (IAEA benchmark)

Deep penetration: surprisingly well predicted, further benchmarks welcome

Residual nuclei predictions: huge steps forward in the last 10+ years, still a lot of work… new data/comparisons welcome for both thin and thick targets. Special cases (eg production of rare isotopes through (α,x) reactions by secondary α's) sometimes interesting/critical $\rightarrow$ data welcome

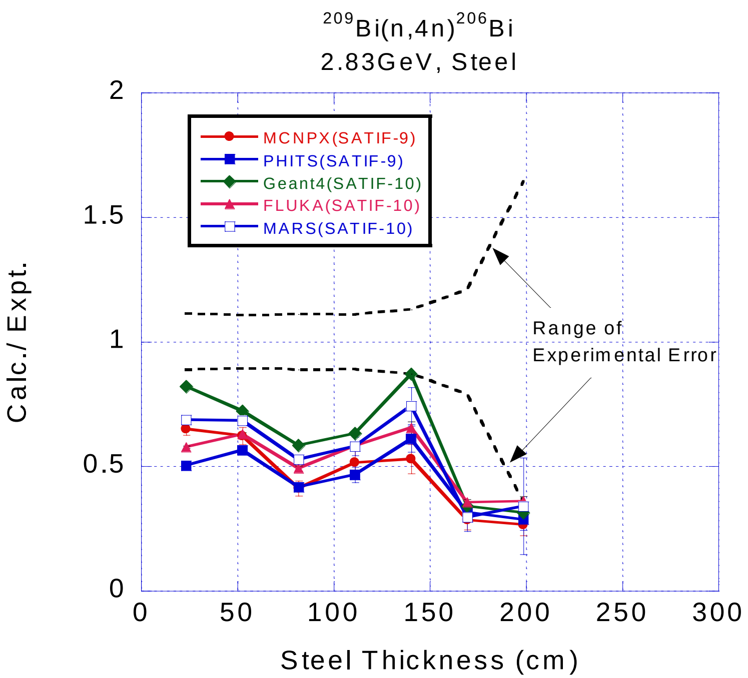
Light (composite) charged particle production: a big challenge, it could be relevant also for radioprotection purposes

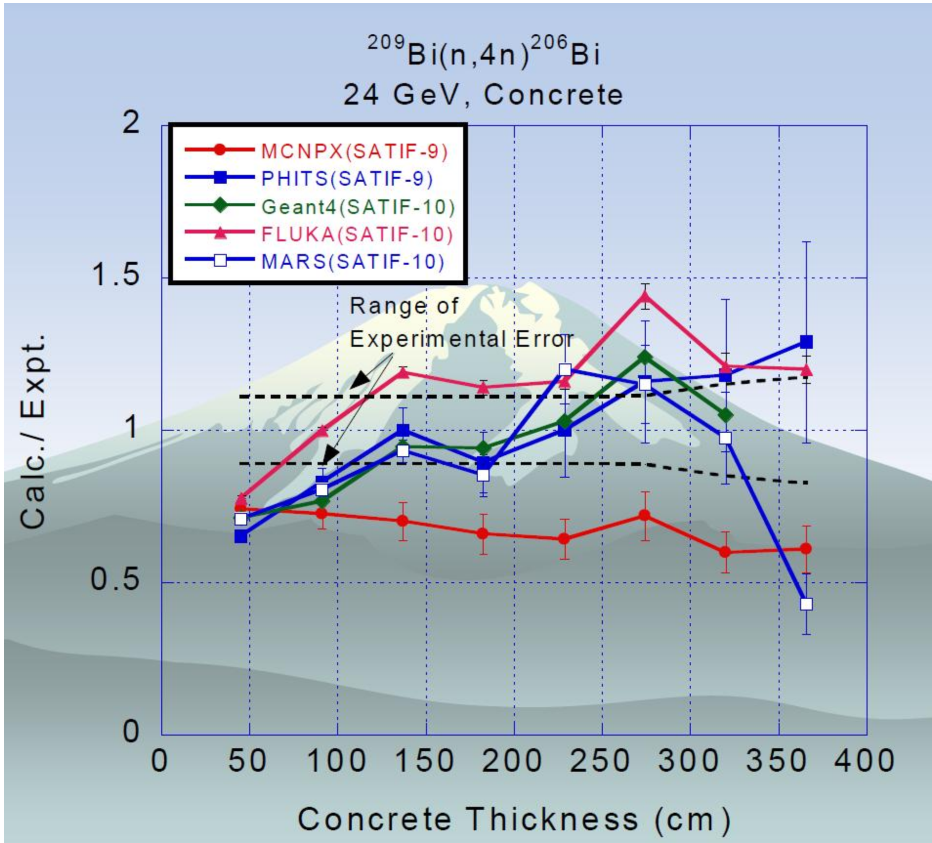
Photonuclear reactions/data: Not too much data available at medium/high energies… new data welcome

Summary of contributors for Neutron attenuation calculation

Name of participants and organization	Name of computer code	Particles treated
T. Koi and D. Wright (SLAC National Accelerator Laboratory)	Geant4 v9.3 (2009 Dec. released)	All particles (Including recoil nucleus)
Y. Uwamino (Riken)	HETC-3STEP	neutron, proton, π^-
N. Matsuda (JAEA) and K. Niita (RIST)	PHITS 2.24	all established hadoronic states
S. Roesler (CERN)	FLUKA 2008.3c.	All hadrons which FLUKA can transport
N.V. Mokhov and I.L. Rakhno (Fermilab)	MARS15(2010)	All elementary particles and heavy ions

Deep penetration



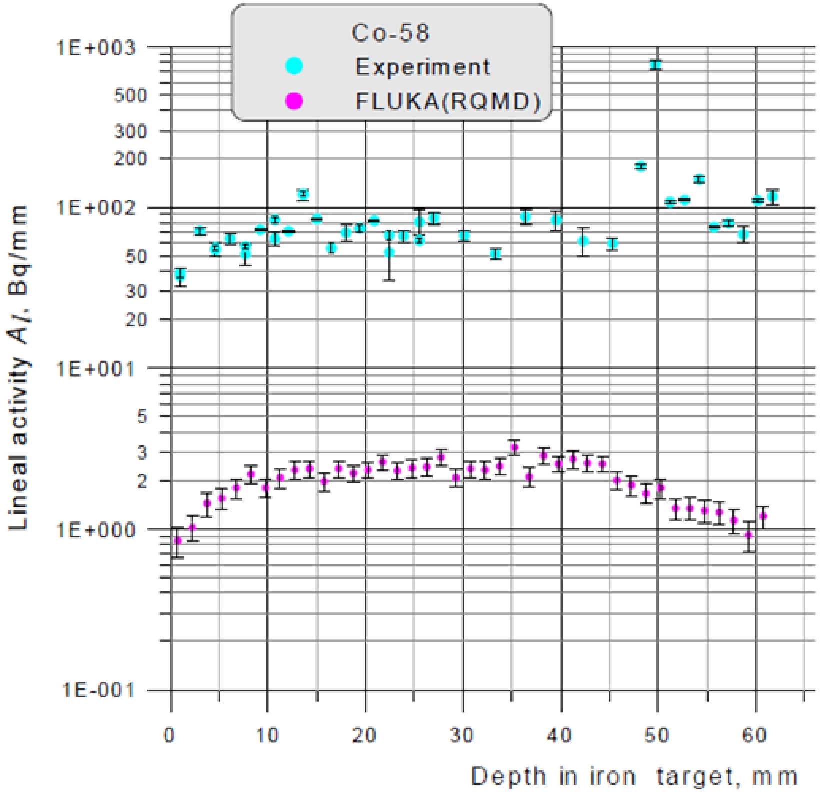


Agreement within a factor of 2,
but systematic deviation to be resolved

Code benchmarking: (α/d/t,x) reactions

400 MeV/u carbon ions on iron at HIMAC by T. Ogawa

- Low E light ion (α, t, etc) induced reactions?



The answer is (very likely) yes!!

Code benchmarking: heavy ions

Neutron production: many experiments (mostly by Japanese groups), significant room for improvements in codes (eg forward angles), almost no data available above 1 GeV/n

Projectile fragmentation: very important for therapy and not only. All data/benchmarking welcome (the FIRST experiment at GSI should provide data in the next future)

A lot of interesting data from GSI/FAIR, with also some unexpected challenges (ranges…). Radionuclide production distributions of great interest

In general all sort of data for heavy ions are welcome

Priorities??

DPA "a la carte":

Very important for future projects (and not only)

Unfortunately very complex physics together with the impossibility of direct measurements generate a lot of different results (=confusion)

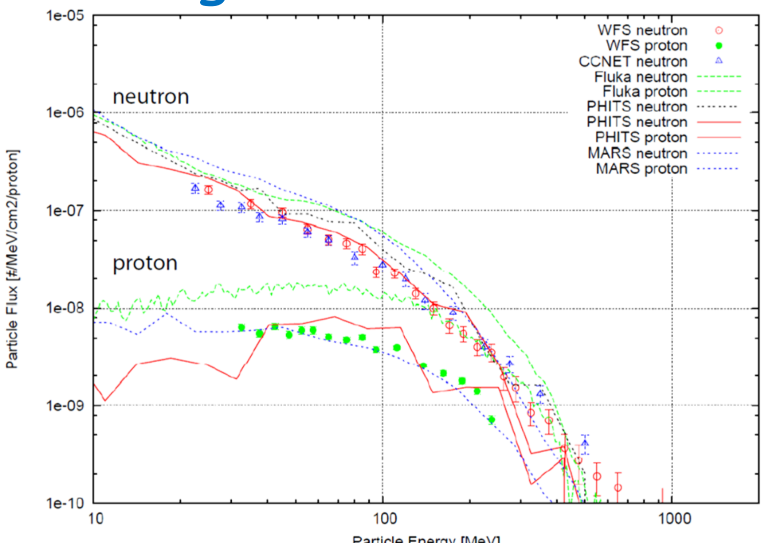
The practical implementation, as well as the calculational methods can vary from very naïve to extremely complex

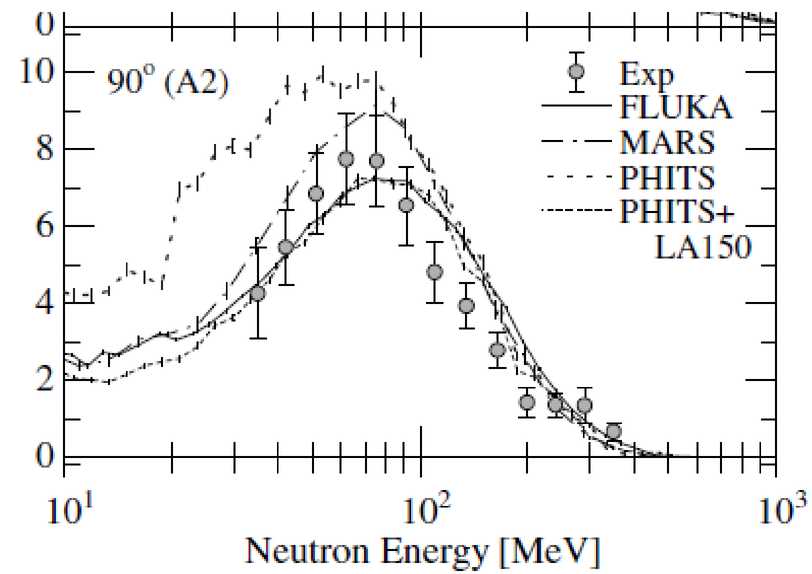
More in general, predictions relevant for material properties are becoming more and more essential for future projects

Why not plan a future SATIF session (or a dedicated workshop) where every code should present how its "DPA's" are computed and where to compare results on simple cases?

Questions/Issues

- Are Λ's very special? The ***cτ=7.89 cm*** and the cross section comparable with p's and π's give the answer: No.
- Clarify different trends in 120 GeV benchmarking at CERN and FNAL
- Scintillators: do we really control well enough their efficiency?
- Biasing: it is not voodoo!!





Scintillator efficiencies:

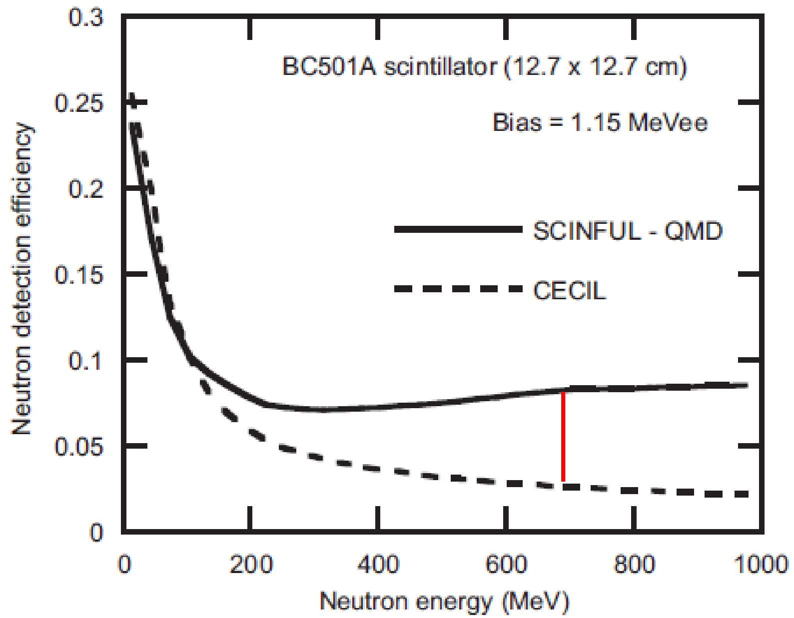
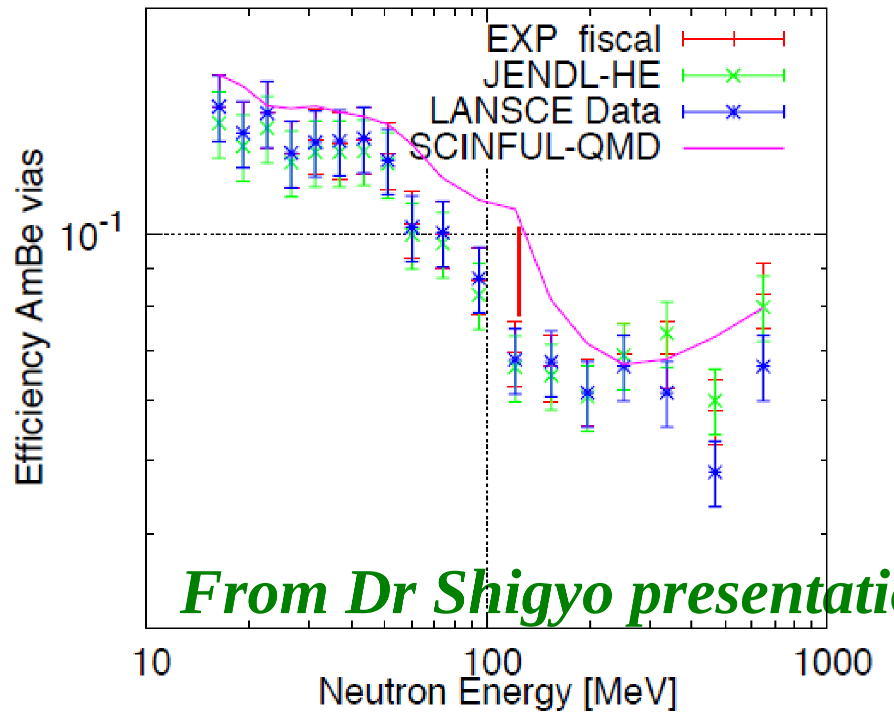


Fig. 1. Neutron-detection efficiency of a BC501A-type liquid organic scintillator with bias of 1.15 MeVee. Solid and dashed lines indicate the calculation results of SCINFUL-QMD and CECIL, respectively. The escaping proton events were eliminated in both calculations.

From NIMA583, 507 (2007), renormalization of many (thick target) AA neutron production data

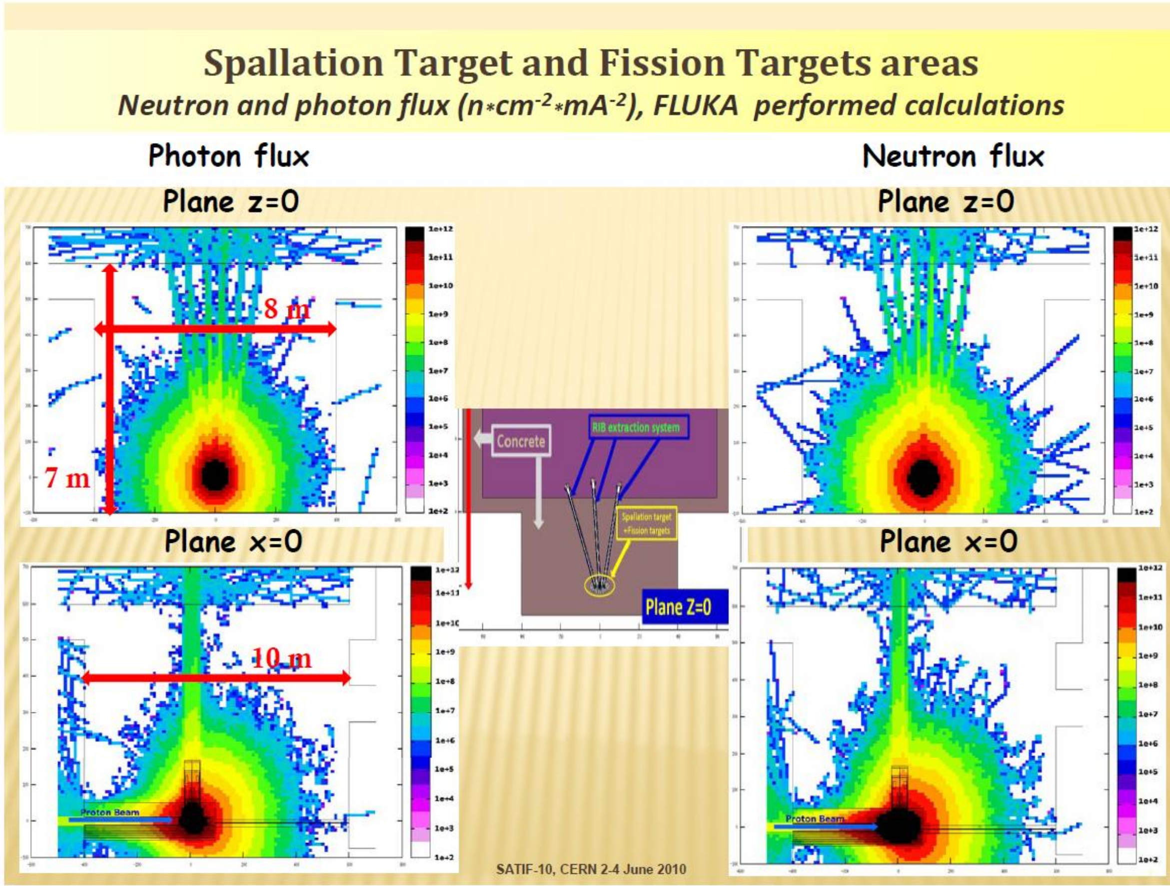
NE213 neutron efficiency



From Dr Shigyo presentatio

Do we really know sufficiently well scintillator efficiencies for high energy neutrons?

Biasing: why not?? MC was born with biasing!



<u>No chance to make meaningful calculations for intense accelerators without biasing (variance reduction techniques), it is not black magic, it is sound (and smart) mathematics!!</u>

4. Dosimetry

Review of recent dosimetric studies by T. Sato: computational dosimetry (ICRP103 FTDCC: updated w_R & w_T and authorized voxel phantom) and experimental dosimetry (JASMIN and KEK experiments)

Radiation levels at IP1 of LHC by Z. Zajacova: comprehensive FLUKA calculations of prompt dose rate in service caverns and on the surface

Entrance surface dose for medical X-ray diagnostic by S. Esmaili

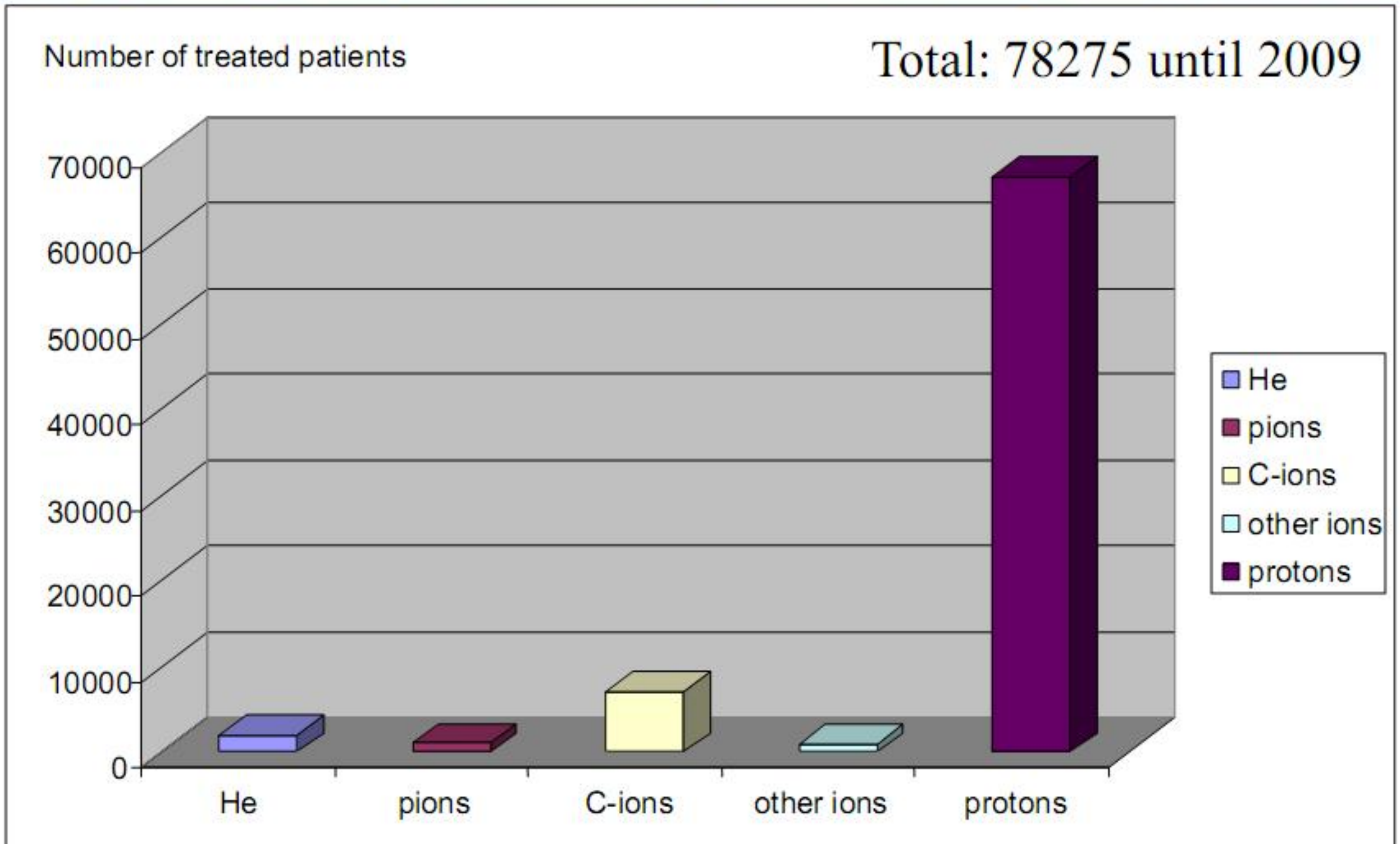
Discussion of dose - definitions, ingredients, phantoms and their description correlated with computer power, and detectors by V. Mares

5. Medical and Industrial Accelerators

- Growing number of proton and C-12 ion medical accelerators
- Synchrotrons and cyclotrons, with some novel accelerator technologies
- Passive and active beam shaping systems
- Fixed beams and isocentric gantries

Growing Number of Patients Treated

Number of Patients treated with Hadrons (PTCOG, 03/2010)



Hadron Therapy Accelerators

- Main radiation source is neutrons: source term, neutron spectra (exp and MC)
- Many radiation sources in the accelerator and treatment rooms (patient included)
- Various approaches to radiation shielding: Monte Carlo and analytical, attenuation curves
- Shielding materials: concrete, combined low-Z + high-Z, sandwich technology
- Ducts and labyrinths: Monte Carlo and analytical
- Activation issues: accelerator, energy degrader, beam transport, passive beam shaping system

Conventional Electron Linacs

- Seismic base-isolation structure
- Additional shielding for basement very expensive, need alternative solution
- Monte Carlo model validated by measurements to predict dose rates due to radiation scattered and streaming underneath the treatment room, multiple beams due to rotating gantry
- MC versus simple analytical method

Example 3/3 Particle Therapy Facility: HIT Heidelberg Ion Therapy Center

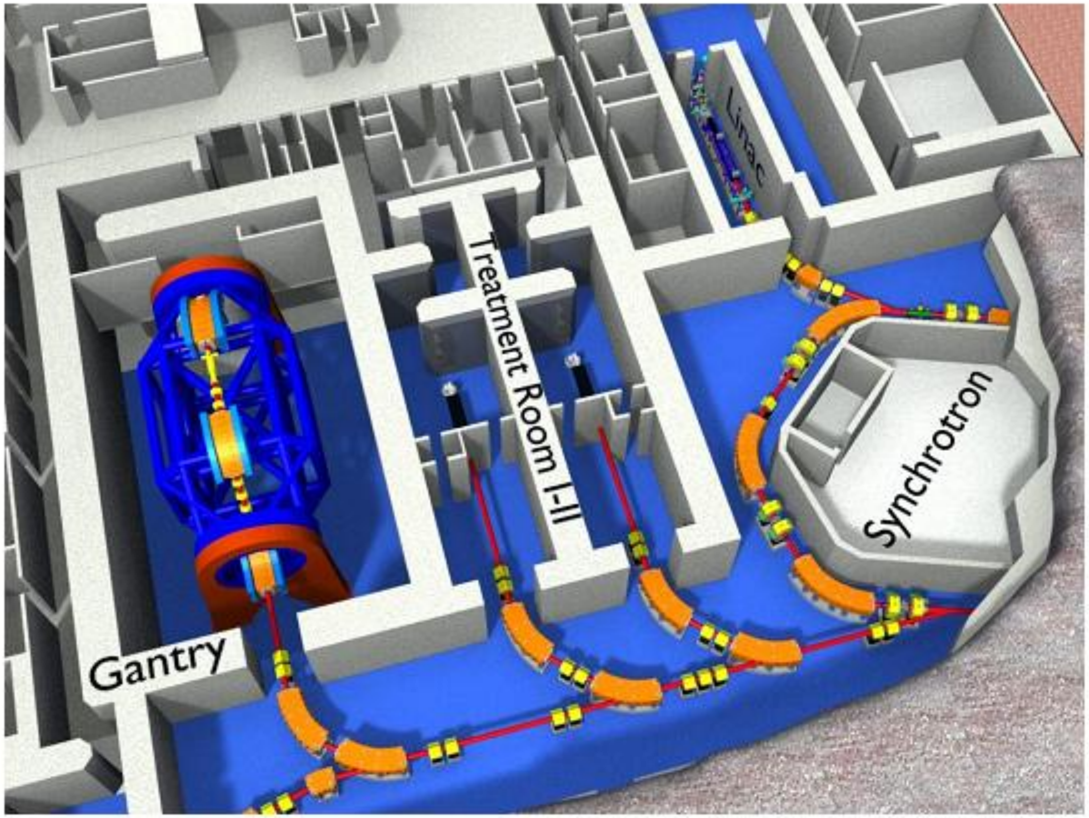
- Proposal for a dedicated ion beam facility for cancer therapy by GSI, University Clinic Heidelberg, Research Center Dresden (1998)
- Characteristics:

Synchrotron for particle accel.:
p, He, C, O, 3 treatment rooms:
2 H, 1 Gantry
Beam: (particles per pulse)
50-220 MeV/u for p, He ($4 \cdot 10^{10}$, $1 \cdot 10^{10}$)
85-430 MeV/u for C, O ($1 \cdot 10^{9}$, $5 \cdot 10^{8}$)

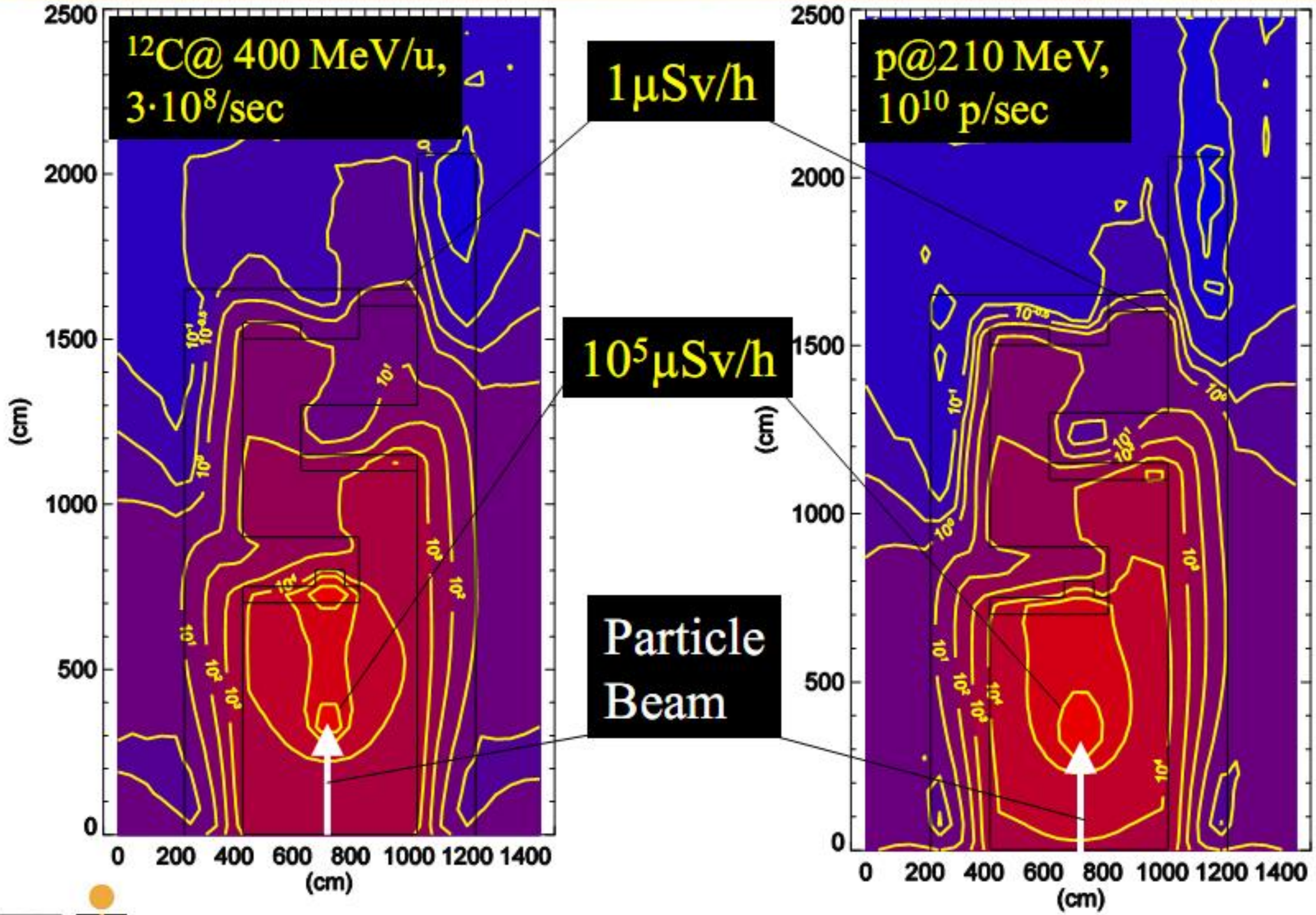
- Shielding (Concrete/Steel):

Line-of-Sight model on the basis of neutron spectra of Kurosawa (C@400 MeV/u), FLUKA calculations using Kurosawa data

- Patient treatments since November 2009



Proton and Carbon Ion Beams@HIT: Spatial Neutron Dose Distribution



Medical Accelerators Summary

- Increasing number of proton and light ion therapy facilities are under construction or already in operation (according to PTCOG ~44 facilities)
- Particularly in Japan and Europe there are some combined proton/light ion (carbon) facilities (HIMAC, Hyogo, Gunma, HIT, CNAO, Marburg, Kiel)
- Neutron source data are sufficient for shielding calculations for the whole angular range; improvements are desireable particular for the lowest angles (0° - 15°)
- There are appropriate calculational tools for the development of the architectural shielding layout (MC, line-of-sight), need for more shielding data for light ion facilities; improvements desireable for low angle for the line-of-sight approaches
- Comparable shielding requirements for proton and carbon ion beams (demonstrated for HIT facility)
- Use of active scanning techniques instead of passive scattering techniques provides advantages with regard to RP for both the patient and the planner of the building
- Cyclotron systems using ESS and passive scattering techniques implicate higher activation and radiation exposure of personnel working at activated components in contrast to synchrotron based facilities

Medical Accelerators: Needs

- Need for improvement of models for shielding of ^{12}C ion facilities
- More data needed for light ion facilities, so far data are essentially for measurements at HIMAC

Industrial Accelerators

- High current, low energy accelerators for novel applications like material testing in strong neutron field
- Dump must withstand high particle current and it becomes a very intense neutron source
- Novel shielding solutions required
- Challenges posed by high-intensity laser facility and photo-neutron source

6. Present status of data and code libraries

Excellent review of nuclear computational information by B. Kirk

Modern activation-transmutation systems by J.C. Sublet: European Activation System (EASY) =European Activation File (EAF) nuclear data libraries, FISPACT inventory code, EASY User Interface and SAFEPAQ-II library production application

GEANT4 for shielding calculations by T. Koi: "Physics List is where user define all the particles, physics processes and cut-off parameters for his/her application. Preparing a physics list is not a simple job even for non-novice user. Currently offered 26 different physics lists and many builder classes helping implementation of user specific physics list." **OK for HEP, but is it acceptable for RP ?**

Improved INCL4 and ABLA models by J.C. David: impressive performance (light fragments etc.)

Radioprotection and safety issues in IFMIF by J. Sanz: Limitations of MCNPX and PHITS; MCUNED for light ions

Updated Software and Data Since SATIF-9

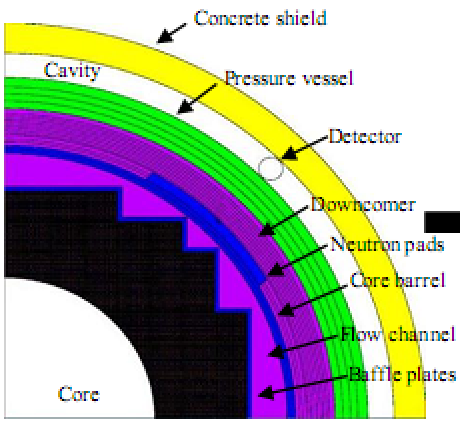
C00657	Code System to Calculate Multigroup Beta-Ray Spectra.	BETA-S 6
C00684	Code System for Evaluating Routine Radioactive Effluents from Nuclear Power Plants with a Windows Interface.	NRCDOSE 2.3.15
C00726	One, Two- and Three-Dimensional Coupled Neutral and Charged Particle SN Code System.	CNCSN
C00728	GENII-LIN Multipurpose Health Physics Code System with a New Object-Oriented Interface, Release 2.0.	GENII-LIN 2.1
C00735	Inventory Code System for Neutron Activation Analysis.	EASY-2005.1
C00737	Environmental Radiation Dosimetry Software System.	GENII 2.09
C00740	Monte Carlo N-Particle Transport Code System Including MCNP5 1.51 and MCNPX 2.6.0 and Data Libraries (Source & Executables).	MCNP5/MCNPX
C00740	Monte Carlo N-Particle Transport Code System Including MCNP5 1.51 and MCNPX 2.6.0 and Data Libraries (Executables - No Source).	MCNP5/MCNPX-EXE
C00742	Gamma-electron Efficiency Simulator, Version 3.1	GES_MC
C00744	Visualization Code System for Gamma and Neutron Shielding Calculations.	EASY-QAD 1.0
C00745	Modular Code and Data System for Fast Reactor Neutronics Analyses	ERANOS 2.0
C00750	Modular Code System for Performing Criticality and Shielding Analyses for Licensing Evaluation with ORIGEN-ARP (Source & Executables).	SCALE 6
C00750	Modular Code System for Performing Criticality and Shielding Analyses for Licensing Evaluation with ORIGEN-ARP (Executables - No Source).	SCALE 6-EXE
C00753	Analytical Benchmarks; Case Studies in Neutron Transport Theory.	GANAPOL-ABNTT
C00755	Code System for Actinide Transmutation Calculations	CINDER 1.05
C00756	Code System to Perform Monte Carlo Simulation of Electron Photon Showers in Arbitrary Marerials.	PENELOPE2008.1
C00758	ACtivation ABacus Inventory Code System for Nuclear Applications.	ACAB-2008
C00761	Radiological Safety Analysis Code System.	RSAC7
C00764	MCNP Utility for Reactor Evolution.	MURE
C00766	Fine-flux Cross Section Condensation, 2D Few Group Diffusion and Transport Burnup Calculations	BOXER

P00158	Code System for Multilevel R-Matrix Fits to Neutron and Charged-Particle Cross-Section Data Using Bayes' Equations.	SAMMY-8
P00338	Code System for Inelastic and Elastic Scattering with Nucleon-Nucleon Potential	DWBA07/DWBB07
P00352	SCAMPI: Collection of Codes for Manipulating Multigroup Cross Section Libraries in AMPX Format.	SCAMPI
P00542	Code System to Determine Pu Isotope Abundances from Multichannel Analyzer Gamma Spectra.	MGA8
P00544	Covariance Matrix Interpolation and Mathematical Verification.	ANGELO-LAMBDA
P00545	Nuclear Properties and Decay Data Chart of Nuclides.	NUCHART
P00546	Nuclear Model Code System for Distorted Wave Born Approximation and Coupled Channel Calculations.	DWUCK-CHUCK
P00548	Nuclear Model Code System for Analysis and Prediction of Nuclear Reactions and Generation of Nuclear Data.	TALYS 1.0
P00550	Statistical Model Code System to Calculate Particle Spectra from HMS Precompound Nucleus Decay.	ALICE-2008
P00552	Plotting Program with Special Features for Windows Environment.	PLOT-S
P00553	Computer Code for the Analysis of Small-Break Loss-of-Coolant Accident of Boiling Water Reactors.	THYDE-B1/MOD2
P00554	Computer Code for PWR LOCA Thermohydraulic Transient Analysis.	THYDE-P2
P00555	Dynamic Analysis of Nuclear Energy System Strategies.	DANESS V1.0

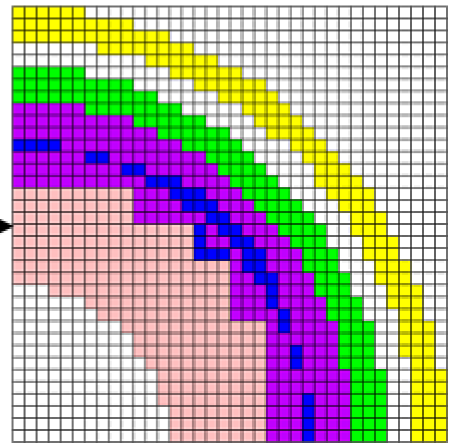
D00196	Power Reactor Embrittlement Data Base, Version 3.	PR-EDB
D00239	A Temperature-Dependent Linearly Interpolable, Tabulated Cross Section Library Based on ENDF/B-VII.0	POINT2009
D00242	Fine-Group Cross Section Library Based on JEFF3.1 for Nuclear Fission Applications.	MATJEFF31.BOLIB
D00243	TALYS-Based Cross Section Library for Use with MCNP(X).	TENDL-2008-ACE

CADIS Methodology for Automated Variance Reduction

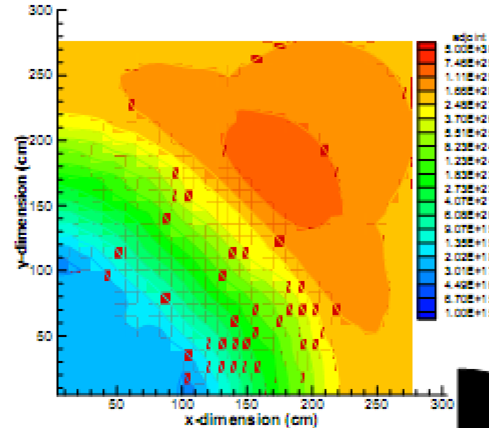
Example: PWR Ex-Vessel Thermal (^{10}B) Detector Response



Monte Carlo model

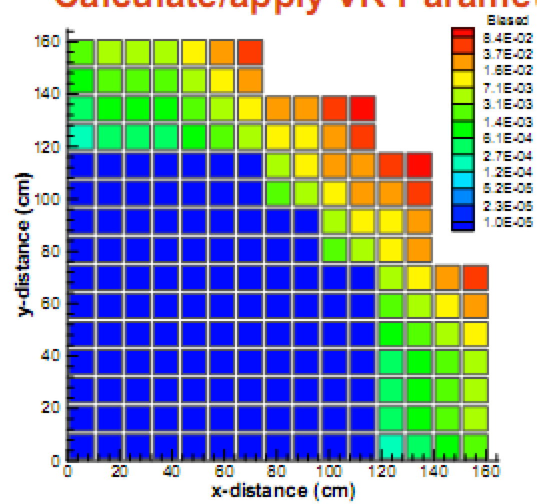


Deterministic model



Adjoint data

Calculate/apply VR Parameters



Faster Results

CASE	CPU TIME TO ACHIEVE RE=1% (h)	SPEEDUP
No VR	8.86E+4 (10.1 yrs)	1
Manual VR	13.6	6500*
CADIS VR	**1.02**	**87000**

* Required ~3 weeks by an experienced MC practitioner using all applicable MCNP4C VR capabilities

Induced Radioactivity: Proposal to SATIF

Create a database of reaction x-sections:

- thermal to TeV (at least to 1 GeV)
- hadron, photon and heavy-ion projectiles
- accelerator-relevant target materials

Focus on:

- Calculation of radioactive inventory
  transport, handling, waste
- Ground and sump water activation
- Air activation
- Cooling water activation

Questions Raised

- **What calculations are we not happy with?**

  DPA, heavy-ions at low energies, light fragment yields, nuclide yields (in some cases), consistency in deep penetration benchmarking, model performance at intermediate energies, DCC at > 1 GeV

- **What level of agreement between data and simulations is satisfactory?**

  Depending on a quantity or/and application it can be from a few % to a rather big factor.

- **What data is needed?**

  See first bullet. Material damage tests in nuclear and electromagnetic dominated cases at room and cryo temperatures. (Low-energy) pion spectra. Light-, heavy-ion and photon induced particle production, radiation effects and radiation fields. Continue with JASMIN and HIMAC experiments.

- **Organization of RP network? Dedicated DPA SATIF session?**