SATIF 10

Wednesday, 2 June 2010 - Friday, 4 June 2010

CERN

Book of Abstracts

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Induced radioactivity and energy deposition studies for a H0/H- dump at 160 MeV

Author: Roberto Versaci[1]

Co-authors: Alessio Mereghetti [1]; Marco Silari [1]; Rocio Chamizo [1]

[1] *CERN*

Corresponding Author: roberto.versaci@cern.ch

A new injector linac (Linac4) for the Proton Synchrotron Booster (PSB) is under construction at CERN.
H- ions will be accelerated to 160 MeV and stripped to protons at injection into the PSB.
A dump will be installed in the injection region to stop unstripped or partially stripped ions.
In order to select the best material for the core and optimize the design of the dump, Monte Carlo simulations with the FLUKA code have been performed to investigate energy depositions, total activities and residual dose rates in the various materials of the dump.
This paper will compare the results for three materials chosen for the core.

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A Review of Nuclear Computational Information

Author: Bernadette Kirk[1]

[1] *Oak Ridge National Laboratory*

Corresponding Author: kirkbl@ornl.gov

The Radiation Safety Information Computational Center (RSICC) and the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency Data Bank (NEADB) work together to acquire sets of computer codes, nuclear data and integral experiments relevant to shielding and dosimetry applications for fission, fusion and accelerator applications. To keep up with advances in computing technology, nuclear software continue to be developed by international researchers. Collection centers like RSICC and NEADB serve the community and play a role in advancing nuclear science and technology research.

Session 4 - Dosimetry / 8

A review of the recent studies on the dosimetric issues

Author: Tatsuhiko Sato[1]

[1] *Japan Atomic Energy Agency*

Corresponding Author: sato.tatsuhiko@jaea.go.jp

Recent studies on the dosimetric issues will be reviewed at the meeting. The review will be given mainly on the following 3 topics:
(1) Calculation of the fluence to the dose conversion coefficients based on ICRP103
(2) Cosmic-ray dosimetry for aircrews and astronauts
(3) Development of dose monitors for high-energy neutron fields

Future requirements on dosimetric studies such as the extension of microscopic dosimetry to the macroscopic dosimetry will be also discussed at the presentation.

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Modern g,d,p,n-Induced Activation-Transmutation Systems

Author: Jean-Christophe Sublet[1]

Co-authors: Arjan Koning [2]; Dimitri Rochman [2]; Jura Kopecky [3]; Lee Packer [1]

[1] *Culham Centre for Fusion Energy*

[2] *Nuclear Research and Consultancy Group (NRG)*

[3] *JUKO Research*

Corresponding Author: jean-christophe.sublet@ccfe.ac.uk

The European Activation System (EASY) includes as the source of nuclear data the European Activation File (EAF) and as its engine the FISPACT activation-transmutation code. The latest version of the EAF, EAF-2010, contains cross section data for gamma-, deuteron- and proton-induced reactions in addition to the traditional neutron-induced data. The main reason for the addition of these data to EAF is to enable activation-transmutation calculations to be performed for even more nuclear facilities, including 'accelerator'driven devices with incident upper energy limit of 60 or 200 MeV. EAF-2010 has benefited from the generation and maintenance of comprehensive activation files in the past and the development of the processing code SAFEPAQ-II and model code TALYS. TALYS is the source for all gamma, proton and deuteron induced data and a fair share of the neutron-induced data. Cross section validation exercises against both experimental data and systematics, which were started in 1995, enable a comprehensive assessment of the data. Although EAF-2010 is certainly the most-validated activation neutron cross section library in the world, currently less than 3% of all the reactions can be compared with experimental information, and even then only for a very limited, and not always application-relevant, energy range. As with EAF-2001, -2003 2005 and 2007 results of integral experiments have been used to correct, adjust and validate data. This can be done using SAFEPAQ-II by inputting the measured effective cross sections. Validation using integral data has been performed by means of direct comparison with measurements of various materials under relevant particle spectra. A tool has recently been developed which is important now that the libraries contain so much TALYS-calculated data. Statistical Analysis of Cross Sections (SACS) is used to look for trends in the library data for a particular reaction type and this has proved efficient in identifying reactions with data that need correction or improvement. This method has been used with EAF-2005 and EAF-2007 and is a valuable additional validation method. However, the time has come to rethink the nuclear data generation processes alongside the transport-activation-transmutation code systems. A new approach is proposed that encompasses 25 years of research activities which can now be mobilised to fulfil the needs, using a much more systematic and automated approach. For the first time, all existing experimental data and nuclear models for all relevant materials can together be transferred to technology in a consistent manner. In this process, feedback of extensive validation and benchmark activities would automatically be taken into account.

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ACTIVATION AND "HANDS-ON" MAINTENANCE CRITERIA FOR HEAVY-ION ACCELERATORS

Author: Ivan Strasik[1]

Co-authors: Edil Mustafin [1]; Marius Pavlovic [2]; Nikolai Sobolevskiy [3]

[1] *GSI Darmstadt, Germany*

[2] *FEI STU Bratislava, Slovak Republic*

[3] *INR RAS Moscow, Russia*

Corresponding Author: i.strasik@gsi.de

In the frame of the FAIR project (Facility for Antiprotons and Ion Research) residual activity induced by heavy ions was studied both experimentally and numerically using Monte Carlo particle-transport codes. In the present work we report on the validation of the transport codes FLUKA and SHIELD based on the measurements of the residual activity of copper and stainless steel targets irradiated with uranium and argon beams at different energies. After the validation, the codes were used for simulations of the residual activity in two beam-loss scenarios representing: 1) losses in a beam pipe of an accelerator and 2) losses in a bulky accelerator structure like a magnet yoke or a coil. The main task of the study was establishing a scaling law that expands the existing '1 W/m' criterion for proton machines to heavy-ion accelerators. This scaling law enables specifying beam-loss criteria for all projectile species from proton up to uranium at energies from 200 MeV/u up to 1 GeV/u.

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Sandwich Technology in Radiation-Shielded Structures

Author: Reinhold G. Mueller[1]

Co-authors: Jan Forster [2]; Jürgen Karg [3]; Nils Achterberg [3]; Otto Pravida [4]

[1] *Univ. Erlangen DGMP; AAPM; DEGRO*

[2] *Forster Ingenieurgesellschaft*

[3] *Univ. Erlangen DGMP*

[4] *Pravida Bau GmbH*

Corresponding Author: reinhold.mueller@uk-erlangen.de

The construction company of Forster Ingenieurgesellschaft mbH has developed in cooperation with the University Erlangen-Nuremberg a process for the erection of radiation-shielded structures utilizing precast concrete components. About 50 bunkers were constructed using this sandwich technology during last three years. The core of the buildings is the filling material in-between the outer and inner double wall precast components.

Attenuation capability was calculated by Monte Carlo simulations and is validated for X-rays, protons and carbon ions by measurement, each with a variety of energies.

For high workload and intense neutron fluencies a waste layer can be prefixed at the wall in front to neutron sources. Depending on neutron fluence the waste layer may be replaced by a period of one year or less, protecting the remaining construction.

Dismantling of the complete construction is an easy going way because of small precasted walls (30-40 cm thickness) and loose gravel as filling material. Separation of the material can easily be done and rational decided after activity measurement. There is no need for diamond wire saw but an enormous reduction of accrued liabilities and radioactive waste.

Two German regulations are based on our data (PAS 1078, Jan. 2008 for proton therapy installations and DIN 6847-2 Sept. 2008 for Linacs in medical use).

Simulations, measurements, filling materials and examples of constructions will be presented.

Summary:

Sandwich technology in radiation protection buildings earns increasing interest and turns out to be a cost reduced alternative to conventional buildings made of reinforced concrete. Convincing is not only the cost reduction but also the reduction of erection time to less than a half of usual, no need for dry out time, and lack of shrinkage cracking. Using the physical data of new filling materials and compositions with higher densities and atomic numbers respectively high hydrogen content for neutron moderation

enables the constructor to reduce wall dimensions in relation to conventional buildings made of concrete only.

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Comparison of the German Rule PAS1078 with MCNPX Calculations

Author: Wolfgang Dittrich[1]

[1] *AREVA NP GmbH*

Corresponding Author: wolfgang.dittrich@areva.com

The German publicly available specification PAS1078 from Jan. 2008 provides rules for the construction of structural radiation protection in the case of medical accelerator facilities for proton therapy. The major points of PAS 1078 will be presented. Its methods for the estimation of shielding thicknesses will be compared with the results of Monte-Carlo calculations executed with MCNPX. Especially it is aimed to compare the shielding curves for various energies, their angular dependency, and the proposed approximation method for scattering through mazes. The results shall provide suitable knowledge concerning the precision of the PAS 1078.

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Radiation Protection for Particle Therapy Facilities

Author: Georg Fehrenbacher[1]

[1] *GSI*

Corresponding Author: g.fehrenbacher@gsi.de

During last years the construction of clinical proton and ion accelerators for applications in tumour therapy makes great strides. Based on encouraging results for tumour treatments in particle therapy in the past more and more facilities are presently installed worldwide.
Due an enumeration of particle therapy facilities given by the PTCOG (Particle Therapy Cooperative Group) 44 facilities are in operation or under construction and 8 facilities are planned in 16 countries (February 2010). The objective of this contribution is to give a summary of radiation protection related issues of particle therapy facilities. This comprises the discussion of radiation sources in different kind of facilities, cyclotron and synchrotron installations as well as the description of various types of beam forming systems (passive and active) and its shielding. Neutron radiation sources – the crucial radiation component - are described in terms of positions in the facility of intended and undesir-able, but unavoidable, beam depositions. Neutron energy distributions are quoted for various particle target combinations in the energy range of interest. Characteristics and differences of source distributions with impact on the architectural shielding design for diverse beam types (essentially for proton and carbon ion beams) are discussed.
Depending on the stage of the project different kinds of methods for the estimation of radiation levels outside the shielding are applied. An outline for the so called line-of-sight models, which are often used for the first architectural shielding layout (for instance) for cost estimates, will be given. Models for carbon ion beams are stressed. Examples for the more elaborated but more exact method of Monte Carlo radiation transport calculations are presented. Shielding layouts based on combined materials, high Z and low Z, are shown for cases when space for shielding is limited which is quite common for treatment facilities. Examples for particle treatment facilities including its shielding conception are presented for both, proton and carbon ion installations with an emphasis for the distinction of the architectural shielding layout of both installation types.
Furthermore radiation protection issues have to be considered as e.g. the exposure of per-sonal

working at and with activated components during maintenance and shut-down periods. Finally it will be reported on new accelerator developments which might play an important role in future particle therapy as e.g. laser driven particle accelerators.

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Shielding Design for the ETOILE Hadron Therapy Center

Author: Frederic Stichelbaut[1]

Co-author: Yves Jongen [1]

[1] *Ion Beam Applications*

Corresponding Author: frederic.stichelbaut@iba-group.com

The IBA Company is the industry leader in proton therapy (PT) technology with seven PT centers treating patients every day in the USA and Asia and nine additional centers in construction and installation in the USA and in Europe.

IBA now develops a hadron therapy system that is complementary to its proton therapy systems. It is based on a K=1600 superconducting cyclotron delivering 400 MeV/u 12C ion beams. Other ion species such as 4He, 6Li and 10B can also be produced.

That solution has been selected by the GCS (Groupement de Coopération Sanitaire) in Lyon, France to equip the ETOILE hadron therapy center. It will include two fixed beam irradiation rooms and two gantry rooms, one devoted to proton beams and the other one to ion beams.

The radiation sources are computed with the PHITS Monte Carlo code for 4He, 6Li, 10B and 12C beams with energies ranging between 100 MeV/u and 400 MeV/u and impinging on various thick targets. Besides the secondary neutrons representing the major radiation source, the production of secondary charged particles 1H, 2H and 4He is also taken into account. The secondary neutron fluxes predicted by PHITS for 4He and 12C primary ions are benchmarked against experimental data measured at the HIMAC facility.

Secondary particles transport through the shielding is achieved with the MCNPX 2.5.0 code. The passive shielding of the ETOILE center is modeled in details and the ambient dose equivalent is assessed at all locations outside and inside the center using various operating conditions. The use of PHITS to compute the neutron source and MCNPX to transport these neutrons is validated by reproducing the measurements obtained by the CONRAD benchmark exercise that took place in GSI cave A in 2006.

As the ion beams are extracted from the IBA cyclotron with a fixed energy of 400 MeV/u, an energy selection system (ESS) based upon a graphite degrader is needed to modulate the beam energy. The transmission efficiency of this ESS is computed with PHITS and MCNPX, these two codes giving rather similar results.

Session 1 - Source term and related topics / 15

Shielding Studies for Superconducting RF Cavities at Fermilab

Authors: Camille Ginsburg[1]; Igor Rakhno[1]

[1] *Fermilab*

Corresponding Author: rakhno@fnal.gov

Test facilities for high-gradient superconducting RF cavities usually are strong sources of radiation due to field emitted electrons inside the cavities. Design of shielding for such facilities involves significant uncertainties because of lack of a reliable model of the field emission. Present work describes a semi-empirical method that allows us to predict the intensity of the generated field emission. Spatial, angular and energy distributions of the generated radiation are calculated with the Fishpact code. The Monte Carlo code MARS15 is used for modeling the radiation transport in matter. Comparisons with measurements performed in the Fermilab Vertical Test Facility for ILC-type cavities with accelerating gradients up to 35 MV/m are presented as well.

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Neutron double differential distributions, dose rates and specific activities from accelerator components irradiated by 50 –400 MeV protons

Author: Nikolaos Charitonidis[1]

Co-authors: Francesco Cerutti [1]; Marco Silari [1]

[1] *CERN*

Corresponding Author: marco.silari@cern.ch

Systematic Monte Carlo simulations with the FLUKA code were performed to estimate induced radioactivity in five materials commonly found in particle accelerator structures: boron nitride and carbon (dumps and collimators), copper (RF cavities, coils and vacuum pipes), iron and stainless steel (magnets and vacuum pipes). Using a simplified geometry set-up, the five materials were bombarded with protons in the energy range from 50 MeV to 400 MeV. This energy range is typical of intermediate energy proton accelerators used as injector to higher energy machines, as research accelerators for nuclear physics, and in hadron therapy. Ambient dose equivalent rates were calculated at distances up to 1 metre around the target, for seven cooling times up to six months. A complete inventory of the radionuclides present in the target was calculated for all combinations of target, beam energy and cooling time. The influence of target size and of self-shielding was investigated. The energy and angular distributions of neutrons escaping from the target were also scored for all materials and beam energies. The influence on the neutron spectra of the presence of concrete walls (the accelerator tunnel) around the target was determined. The results of the present study provide a simple database to be used for a first, approximate estimate of the radiological risk to be expected when intervening on activated accelerator components.

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OPTIMUM SHIELDING DESIGN FOR ELECTRON LINAC ONCOLOGY FACILITIES INCORPORATING SEISMIC BASE-ISOLATION STRUCTURE

Author: Koji Oishi[1]

Co-authors: Kazuaki Kosako [1]; Takashi Nakamura [1]

[1] *Institute of Technology, Shimizu Corporation*

Corresponding Author: oishi@gakushikai.jp

Recently electric linac oncology facilities incorporating seismic base-isolation structure have become very popular in Japan to prevent strong impact to the equipments by the earthquakes. When the boundary of the registered area is set below the base-isolated foundations, additional shielding of iron plate is needed and the cost for shielding increases up to $100M. Since no one usually accesses

underneath the base-isolated foundation, except short maintenance period for base-isolation structure, it is reasonable to set the boundary around the downstairs room. However, it is very difficult to estimate the dose rate of new boundary by using the simple shielding calculation method because of effect of streaming and scattering radiation in the base-isolation floor. In this study detail calculations by using Monte-Carlo calculation code MCNP5 have been performed and found out the expensive iron plate free optimum shielding design for the electric linac facilities with seismic base-isolation structures. Measurements of the dose rate distribution in the practical facility have also been performed and very good agreements between measured and calculated results were obtained.

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Activation studies on benefit of the selection of the ESS target concept

Author: Dana ENE[1]

Co-authors: Cyril Kharoua [1]; Etam Noah [1]; Francois Plewinski [1]; Marry Chin [1]

[1] *ESS*

Corresponding Author: daniela.ene@esss.se

Presently, the ESS project is in the update phase of the conceptual design that has been preliminary defined in 2003 through the joint efforts of several European countries.
According with the baseline of the ESS update design, the linac will deliver 5 MW of 2.5 GeV protons to a single target, in 2 ms long pulses with a 20 Hz repetition rate.
The material activation in such facility is an important aspect that has to be taken into account since the early design phase. In particular the choice of the target material and the design of the target have to consider the following radiation protection issues: i) radiation level received by personnel during maintenance, ii) accident scenarios, iii) the production, handling and disposal of the radioactive wastes.
The aim of this work is to assess the radioactive inventory, decay heat and resulted gamma-ray spectra determining the radiation levels expected during maintenance work and to evaluate the amount of the residual radioactivity to be disposed of after the facility will shut-down for various target concepts under analysis.
In this respect a comparison of the two code systems: i) MCNPX2.6.0 (particle transport) and CINDER'90 (activation) and ii) PHITS (particle transport) and DCHAINSP 2001 (activation) was initially done in order to investigate their predictions and to decide the appropriate simulation tool for the problem.
Results of a sensitivity analysis accounting for various proton beam conditions (energy and profile) are also discussed.

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Benchmark experiment of neutron penetration through iron and concrete shields using 138, 243 and 387 MeV quasi-monoenergetic neutrons part-II:Measurements of neutron energy spectra

Author: Yosuke Iwamoto[1]

Co-authors: Akihiko Masuda [2]; Atsushi Tamii [3]; Christian Pioch [4]; Christian Theis [5]; Daiki Satoh [1]; Eduard Feldbaumer [5]; HIroshi Nakashima [1]; Hiroshi Iwase [6]; Hiroshi Yashima [7]; Jun Nishiyama [2]; Kichiji Hatanaka [3]; Lukas Jaegerhofer [5]; Masayuki Hagiwara [6]; Takashi Nakamura [8]; Tatsuhiko Sato [1]; Tetsuo Matsumoto [2]; Toshiro Itoga [9]; Vladimir Mares [4]; Yoshihiro Nakane [1]; Yukio Sakamoto [1]

[1] *Japan Atomic Energy Agency*

[2] *Advanced Industrial Science and Technology*

[3] *RCNP, Osaka university*

[4] *German Research Center for Environmental Health*

[5] *CERN*

[6] *KEK*

[7] *Kyoto University*

[8] *Tohoku University*

[9] *RIKEN*

Corresponding Author: iwamoto.yosuke@jaea.go.jp

The neutron energy spectra penetrating 10 to 100 cm thick iron and 25 to 200 cm thick concrete shields have been measured using 138, 243 and 387 MeV quasi-monoenergetic neutron sources at the Research Center for Nuclear Physics (RCNP) facility, Osaka University, Japan. The source neutrons were produced from a 1 cm thick lithium target bombarded with 140, 245 and 388 MeV protons. Two types of NE213 liquid organic scintillators （12.7-cm-diam x 12.7-cm-length and 25.4-cm-diam x 25.4-cm-length）and Bonner ball neutron spectometers were used for the neutron energy spectrum measurement. The response function and the neutron detection efficiency for an NE213 have already been measured. The TOF and unfolding methods were applied to estimate the energy spectra behind the shield in the peak energy region and continuous energy region, respectively. We have also measured the neutron energy spectra and angular distribution of the source neutron above 1 MeV in the angular range from 0 to 30 degrees with the TOF method. All measured data were compared with the PHITS Monte Carlo calculations.

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INTER-COMPARISON OF MEDIUM-ENERGY NEUTRON ATTENUATION IN IRON AND CONCRETE (8)

Author: Hideo Hirayama[1]

Co-author: Hiroshi Nakashima [2]

[1] *KEK, High Energy Accelerator Research Organizatio*

[2] *Japan Atomic Energy Agency*

Corresponding Author: hideo.hirayama@kek.jp

Same problems at SATIF9 were used for inter-comparison mainly to compare between AGS experiments provided by H. Nakashima with various codes. As the new item to be sent by participants, "particles treated to obtain the results"is added,
This paper presents a comparison of the neutron attenuation length of iron and concrete sent to the organizer by the end of April, including results presented at previous SATIF meetings and future themes resulting from this inter-comparison.

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JASMIN: Japanese-American Study of Muon Interactions and Neutron detection

Author: Hiroshi Nakashima[1]

Co-authors: Anthony Leveling [2]; David Boehnlein [2]; Hee-seock Lee [3]; Hideo Hirayama [4]; Hiroshi Iwase [4]; Hiroshi Matsumura [4]; Hiroshi Yashima [5]; Hiroyuki Arakawa [6]; Iwamoto Yosuke [1]; Kamran Vaziri [2]; Kenji Ishibashi [6]; Koji Niita [7]; Koji Oishi [8]; Masayuki Hagiwara [4]; Nikolai Mokhov [2]; Nobuhiro Shigyo [6]; Norihiro Matsuda [1]; Norikazu

Kinoshita [9]; Shun Sekimoto [5]; Syuichi Ban [4]; Takashi Nakamura [10]; Toshiya Sanami [4]; Tsuyoshi Kajimoto [6]; Yoshimi Kasugai [1]; Yukio Sakamoto [1]

[1] *Japan Atomic Energy Agency*

[2] *Fermi National Accelerator Laboratory*

[3] *Pohang Accelerator Laboratory*

[4] *High Energy Accelerator Research Organization*

[5] *Kyoto University*

[6] *Kyushu University*

[7] *Research Organization for Information Science & Technology*

[8] *Shimizu Corporation*

[9] *Tsukuba University*

[10] *Tohoku University*

Corresponding Author: nakashima.hiroshi@jaea.go.jp

Experimental studies of shielding and radiation effects at Fermi National Accelerator Laboratory (FNAL) have been carried out under collaboration between FNAL and Japan, aiming at benchmarking of simulation codes and study of irradiation effects for upgrade and design of new high-energy accelerator facilities. The purposes of this collaboration are (1) acquisition of shielding data in a proton beam energy domain above 100GeV; (2) further evaluation of predictive accuracy of the PHITS and MARS codes; (3) modification of physics models and data in these codes if needed; (4) establishment of irradiation field for radiation effect tests; and (5) development of a code module for improved description of radiation effects.
A series of experiments has been performed at the Pbar target station and NuMI facility, using irradiation of targets with 120 GeV protons for antiproton and neutrino production, as well as the M-test beam line (M-test) for measuring nuclear data and detector responses. Various nuclear and shielding data have been measured by activation methods with chemical separation techniques as well as by other detectors such as scintillator with a veto counter, phoswich detector and a Bonner ball counter. Analyses with the experimental data are in progress for benchmarking the PHITS and MARS codes. In this presentation recent activities and results will be reviewed.

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Verification of Monte-Carlo Transport Codes FLUKA, MARS and SHIELD

Author: Vera Chetvertkova[1]

Co-authors: Edil Mustafin [2]; Ivan Strasik [2]; Ludmila Latysheva [3]; Nikolai Sobolevskiy [3]

[1] *Goethe University, Frankfurt am Main; GSI, Darmstadt*

[2] *GSI, Darmstadt*

[3] *INR RAS, Moscow, Russia*

Present study is a continuation of the project "Verification of Monte-Carlo transport codes" which is running at GSI as a part of activation studies of FAIR relevant materials. It includes two parts: verification of stopping modules of FLUKA, MARS and SHIELD-A (with ATIMA stopping module) and verification of their isotope production modules. The first part is based on the measurements of energy deposition function of uranium ions in copper and stainless steel. The irradiation was done at 500 MeV/u and 950 MeV/u, the experiment was held in GSI in September 2004 –May 2005. The second part was based on gamma-activation studies of aluminum target irradiated with argon beam of 500 MeV/u in August 2009. Experimental depth profiling of the activation of the target is compared with the simulations.

Summary:

The comparison of experimentally achieved energy deposition function and the results of simulations show that FLUKA overestimates the range of uranium ions by 5% for 500 MeV/u and 10% for 950 MeV/u uranium beam. The ranges calculated by MARS and SHIELD-A give discrepancies below 5%, depending on the energy of the incident ion, which coincides with the measured ranges within the accuracy of the measurement.
Comparing the experimental and simulated depth profiles of the activated isotopes one could see that in case of Na-22 the codes show similar behaviour of the activation, though the discrepancies in the number of activated particles per incident ion per unit of depth are still observed, which could be explained by differences in cross sections. For this case FLUKA shows better agreement with the experiment, than MARS and SHIELD-A. In case of Be-7 the results of simulations differ in behaviour with the experimentally achieved ones, which could be explained by physical models implied in the codes.

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Benchmark experiment of neutron penetration through iron and concrete shields using 243 and 387 MeV quasi-monoenergetic neutrons part-I: Measurement and calculation of neutron depth-dose distribution and attenuation length.

Author: Hiroshi Iwase[1]

Co-authors: Akihiko Masuda [2]; Atsushi Tamii [3]; Christian Theis [4]; Daiki Sato [5]; Eduard Feldbaumer [4]; Hiroshi Nakashima [5]; Hiroshi Yashima [6]; Jaegerhofer Lukas [4]; Jun Nishiyama [2]; Kichiji Hatanaka [3]; Masayuki Hagiwara [1]; Pioch Christian [7]; Takashi Nakamura [8]; Tatsuhiko Sato [5]; Tetsuro Matsumoto [2]; Toshiro Itoga [9]; Vladimir Mares [7]; Yoshihiro Nakane [5]; Yosuke Iwamoto [1]; Yukio Sakamoto [5]

[1] *KEK*

[2] *Advanced Industrial Science and Technology*

[3] *RCNP, Osaka University*

[4] *CERN*

[5] *Japan Atomic Energy Agency*

[6] *Kyoto University*

[7] *German Research Center for Environmental Health*

[8] *Tohoku University*

[9] *Riken*

Corresponding Author: hiroshi.iwase@kek.jp

A shielding experiment using 243 and 387 MeV quasi-monoenergetic neutrons have been performed at the Research Center for Nuclear Physics (RCNP), Osaka University, Japan. Neutron energy spectra and doses behind concrete with 25, 50, 100, 200 and 300 cm thicknesses and iron with 10, 20, 40, 70, and 100 cm thicknesses have been measured. Two different sizes of NE213 liquid scintillators of 5" and 10" and two types of Bonner ball neutron spectometers were used for the neutron energy spectrum measurement. Details and the results of the neutron spectrometry will be presented in the next presentation (part II).

The measured neutron energy spectra are folded with the dose conversion factor to estimate the neutron doses. Neutron doses were also directly measured by several dosimeters of Fuji wide-range REM counter, Thermo wide-range REM counter WENDI-II, Fuji REM counter, ALNOR REM counter, Chiyoda photo-luminescence personal dosimeter, Nagase Landauer Luxel personal dosimeter, and the DARWIN multi particle dosimeter. Theoretical estimation of neutron energy spectrum and dose distributions behind the concrete and iron shields were also performed by the general-purpose particle transport Monte-Carlo code PHITS. A global comparison is carried out on neutron doses obtained by several methods both experimentally and theoretically as a function of the thickness of the shielding materials. Neutron dose attenuation lengths of 243 and 387 MeV neutrons for concrete and iron are finally estimated.

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Bonner Sphere Measurements in quasi-monoenergetic p-Li neutron fields of 243 and 387 MeV

Author: Vladimir Mares[1]

Co-authors: Christian Pioch [1]; Hiroshi Iwase [2]; Takashi Nakamura [3]

[1] *Helmholtz Zentrum Muenchen, Institute of Radiation Protection, Germany*

[2] *Radiation science, KEK, Tsukuba, Japan*

[3] *Cyclotron and Radioisotope Center, Tohoku University, Sendai, Japan*

Corresponding Author: mares@helmholtz-muenchen.de

This paper describes the results of neutron spectrometry using Bonner Sphere Spectrometer (BSS) at the ring cyclotron facility at the Research Center for Nuclear Physics (RCNP), Osaka University, Japan. The BSS system consists of 15 polyethylene (PE) spheres with spherical 3He proportional counters in their center. It also includes two PE spheres with lead shells inside, to increase their response to high-energy neutrons above 10 MeV. A quasi-monoenergetic neutron fields at RCNP were generated from a 10 mm thick Li target using the 7Li(p,n)7Be reaction, injected by 245 and 388 MeV protons. The neutrons produced at 0° and 30° were extracted into the time-of-flight (TOF) tunnel of 100 m length through the concrete collimator of 10 x 12 cm2 aperture and 150 cm thickness. The neutron energy spectra were measured at distance of 41 m from the target in the TOF tunnel. To deduce the energy spectra of neutrons from thermal to 1 GeV, an unfolding method with MSANB code was used together with response functions obtained by neutron transport calculations using the MCNP/LAHET code. The neutron energy spectra are discussed in terms of neutron fluence rates and ambient dose equivalent H*(10). The BSS results are also compared to neutron energy spectra measured by a NE213 organic liquid scintillator using the TOF method.

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A Geant4 Physics List for Shielding Calculations

Author: Tatsumi Koi[1]

Co-author: Geant4 hadronic working group on behalf of the Geant4 hadronic working group [2]

[1] *SLAC*

[2] *Geant4 Collaboration*

Corresponding Author: tkoi@slac.stanford.edu

Geant4 is a toolkit for the simulation of the passage of particles through matter. It is widely used in many domains including high energy physics, nuclear physics, astrophysics, space science and medical physics.
Members of the Geant4 hadronic working group have been involved in shielding calculations during the past four years, and have participated in the "Inter-comparison of Medium-Energy Neutron Attenuation in Iron and Concrete" project since SATIF8.
The toolkit approach of Geant4 allows the users to select amongst the physics models and cross sections those which are best suited to their application domain and use case. These elements are assembled into a "Physics List" class, the details of which may vary significantly between use cases. We present a Physics List tailored for shielding calculations. It involves a selected set of improved physics models and cross sections. We explain this physics list and the selection of models. Comparisons with data will be shown, to illustrate the effects of various choices.

Session 3 - Benchmarking code/code & code/experimental data / 27

Secondary Radiation Measurement at BigRIPS of RIKEN RIBF

Author: Yoshitomo Uwamino[1]

Co-authors: Atsuko Akashio [1]; Atsushi Yoshida [1]; Hiroki Mukai [1]; Hiroyuki Fukuda [1]; Hisao Sakamoto [1]; Koichi Yoshida [1]; Rieko Higurashi-Hirunuma [1]

[1] *RIKEN Nishina Center for Accelerator-Based Science*

Corresponding Author: uwamino@riken.jp

RIKEN RIBF (Radioactive Isotope Beam Factory) is a big heavy-ion accelerator complex consists of a linac and five cyclotrons, of which last stage accelerator is a superconducting ring cyclotron (SRC). The maximum acceleration energy of it is 400 MeV/u for ions lighter than Ar and 350 MeV/u for heavier ions up to uranium. The accelerated beam is transported to BigRIPS (Big RIKEN Projectile-fragment Separator), which produces secondary RI beams.
To measure the secondary neutron field, activation samples of C, Al, Au and Bi were placed around BigRIPS, where the 345-MeV/u 238U86+ and 48Ca20+ beams were stopped. The maximum beam intensities were about 2x10ˆ9 particle/s for uranium and 1x10ˆ12 particle/s for calcium. The doses due to neutrons and photons were also measured with the thermoluminescence dosimeter (TLD). The thermal neutron sensitive TLD was inserted in a specially designed moderator of which sensitivity function had a similar shape of the dose equivalent conversion factor.
The activated samples were measured with Ge detectors, and the production of 12C(n,2na)7Be, 12C(n,2n)11C, 27Al(n,a)24Na, 27Al(n,2na)22Na, 197Au(n,g)198Au, 197Au(n,2n-4n)196Au-194Au, 209Bi(n,4n-10n)206Bi-200Bi were observed. The reaction rates spanned between 10ˆ-33 and 10ˆ-27 ([beam ion]ˆ-1 [sample atom]ˆ-1). The doses obtained with TLD spanned between 10ˆ-21 and 10ˆ-16 (Sv [beam ion]ˆ-1). These results were compared with the calculations of the Phits heavy-ion Monte Carlo transport code.

Session 1 - Source term and related topics / 28

Neutron energy spectrum from 120 GeV protons on a thick copper target

Author: Nobuhiro Shigyo[1]

Co-authors: Anthony Leveling [2]; Aria Meyhoefer [2]; David Boehnlein [2]; Doug Jensen [2]; Hee-Seock Lee [3]; Hiroshi Yashima [4]; Kamran Vazili [2]; Kiwamu Saito [5]; Masayuki Hagiwara [5]; Nakashima Hiroshi [6]; Nikolai Mokhov [2]; Ramberg Erik [2]; Richard Coleman [2]; Sakamoto Yukio [6]; Toshiya Sanami [5]; Tsuyoshi Kajimoto [1]; Yoshimi Kasugai [6]; Yosuke Iwamoto [6]

[1] *Kyushu university*

[2] *FNAL*

[3] *PAL*

[4] *Kyoto university*

[5] *KEK*

[6] *JAEA*

Neutron energy spectrum from 120 GeV protons on a thick copper target was measured at the Meson Test Beam Facility (MTBF) at Fermi National Accelerator Laboratory (FNAL), USA. The data allows for evaluation of neutron production process implemented in theoretical simulation codes. It also helps exploring the reasons for some disagreement between calculation results and shielding benchmark data taken at high energy accelerator facilities, since it is evaluated separately from neutron transport.
The experiment was carried out using a 120 GeV proton beam of 3E5 protons/spill. Since the spill duration was 4 seconds, proton-induced events were counted pulse by pulse. The intensity was maintained using diffusers and collimators installed in the beam line to MTBF. The protons hit a copper block target the size of which is 5cm x 5cm x 60 cm long. The neutrons produced in the target were

measured using NE213 liquid scintillator detectors, placed 5 m away from the target, at 30 and 90 degrees with respect to the proton beam axis. The neutron energy was determined by time-of-flight technique using timing difference between the NE213 and a plastic scintillator located just before the target. A detection efficiency of NE213 was determined on basis of experimental data from the high energy neutron beam line at Los Alamos National Laboratory, USA. The neutron spectrum was compared with the results of multi-particle transport codes, PHITS and MARS, to validate the implemented theoretical models. The apparatus would be applied to future measurements to obtain a systematic data set for secondary particle production on various target materials.

Session 2 - Induced radioactivity / 29

Nuclide inventory in proton irradiated lead –comparison of simulation and measurement

Author: Daniela Kiselev[1]

Co-authors: Dorothea Schumann [1]; Hans-Arno Synal [2]; Jörg Neuhausen [1]; Peter W. Kubik [2]; Sabrina Lüthi [1]; Vasily Alfimov [2]; Yong Dai [1]

[1] *Paul Scherrer Institut*

[2] *ETH Zürich*

Corresponding Author: daniela.kiselev@psi.ch

The ring cyclotron at the Paul Scherrer Institute's (PSI) accelerator facility produces at present protons of 590 MeV with a current of up to 2.3 mA. After penetrating two graphite targets with an effective thickness of 0.5 cm and 4 cm, the beam is dumped into the target of the neutron spallation source SINQ. This target consists of several rows of steel tubes (nowadays Zircaloy) filled with lead. After 2 years in operation, the target has become highly activated and needs to be replaced due to the fatigue of the material. After a cooling period, the target will have to be disposed as radioactive waste. For this procedure the nuclide inventory is required by the authorities. For components directly activated by the proton beam, it is calculated using MCNPX coupled to build-up and decay codes like SP-FISPACT07 and Cinder'90.

The calculated nuclide inventory is compared to measured activities of several isotopes extracted from a central lead rod of SINQ target 4, which was irradiated with 10 Ah. The rod was cut into several pieces. Two pieces from different positions along the lead rod were analyzed employing radiochemical preparation where necessary. The gamma-measurements were made with a high-purity germanium detector (HPGe). The beta-activities were determined with Liquid Scintillation Counting (LSC). For long-lived radionuclides such as Al26 and Cl36, Accelerator Mass Spectrometry (AMS) was used. Due to the position of the two samples, they have seen different compositions of proton and neutron flux spectra, which leads to a different nuclide inventory. Since the sizes of the samples are quite small, more effort was needed to achieve a reasonable statistical error in the Monte Carlo simulation.

In addition, the dose rates around the target were measured during the remote-controlled dismantling in the hotcell. They were compared to the predictions made with MCNPX and Cinder'90.

Session 2 - Induced radioactivity / 30

Activation studies for a beta-beam Decay Ring (DR): residual dose rates during maintenance and airborne activity.

Author: Stefania Trovati[1]

Co-author: Matteo Magistris [2]

[1] *EPFL (Lausanne) - CERN*

[2] *CERN*

Corresponding Author: stefania.trovati@cern.ch

In a future beta-beam facility radioactive ions (6He and 18Ne) are produced, accelerated and then stored in a large Decay Ring (DR), where they eventually produce anti-neutrino and neutrino beams through β± decay. CERN is one of the candidate sites for the beta-beam facility, as existing machines like the Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS) could be used for the acceleration.
The DR is composed of two long straight sections and two arcs. The straight sections host the collimators and two bumps. The beam is injected into the ring at nearly 92 GeV per nucleon. Beam losses occur in different sections of the machine: relevant losses include collimation losses in the collimation section and the bumps, and decay losses in the magnets in the arcs.
This work focuses on two radiation protection aspects related to the operation of the DR, namely the induced radioactivity and the air activation generated by collimation and decay losses. All the calculations are performed with the Monte Carlo transport code FLUKA and are based on a continuous three-month operation. The induced radioactivity in the machine components and the expected residual dose rates inside the tunnel during maintenance are calculated for three different waiting times. Airborne activity is evaluated through the convolution of predicted particle spectra in the tunnel with isotope-production cross-sections. Using activity-to-dose coefficients, previously calculated for the ISOLDE facility at CERN, and a laminar flow model for the air diffusion, the airborne activity is converted into effective dose to the reference population group.
The results show that residual dose rates during maintenance decrease significantly in a week after the shutdown of the machine, reaching values that correspond, according to CERN area classification, to a limited stay area. The effective dose given to the reference population in one year of operation is below the reference value for CERN emissions into the environment.

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Radiation Protection Aspects of the SPES facility at LNL

Authors: Demetre Zafiropoulos[1]; Lucia Sarchiapone[1]

[1] *INFN*

Corresponding Author: lucia.sarchiapone@lnl.infn.it

The SPES (Selective Production of Exotic Species) Project will be built at the National Laboratories in Legnaro (Italy) of the National Institute of Nuclear Physics (INFN). Its goal will be the development of radioactive ion beams and the consequent re-acceleration with the already existing Linac, to perform forefront research in the frame of nuclear physics. Radiation protection aspects play along with every stage of the project e.g. civil construction planning, control system design and special technological plants. These aspects have been studied with the Monte Carlo transport code FLUKA.

Summary:

For the production of the primary beam at the SPES facility a 70 MeV proton cyclotron will be used with a maximum current on target of 300 microA. The target is made of 30 g of uranium carbide and the foreseen neutron yield is 1E+14 per second.
All the shielding aspects of the facility have been investigated as well as the activation of the material interacting with the primary beam and the issue of the air activation. Preliminary decommissioning considerations concerning the shielding concrete walls are also made and other new shielding techniques recently proposed have been taken into account especially with their shielding properties and activation under long irradiation times.

Session 5 - Medical & industrial accelerators / 32

Optimized design of local shielding for the IFMIF/EVEDA beam dump

Author: Mauricio Garcia[1]

Co-authors: Alicia Mayoral [1]; Beatriz Brañas [2]; Candan Töre [3]; Daniel López [1]; Francisco Ogando [1]; Javier Sanz [1]; José Manuel Arroyo [2]; Patrick Sauvan [1]; Pedro Ortego [3]

[1] *UNED*

[2] *CIEMAT*

[3] *SEA*

Corresponding Author: maurigarciac@hotmail.com

IFMIF will be an accelerator-based neutron source to test candidate materials for nuclear fusion reactors. During the Engineering Validation and Design Activities (EVEDA) phase, a prototype accelerator (125 mA CW 9 MeV deuterons) will be tested in Rokkasho (Japan). As no target is foreseen for the accelerated beam during this phase, a beam dump is required to stop it during commissioning and accelerator tests. The piece that stops the beam is a copper cone with a 250 cm length and 30 cm aperture diameter [1]. The impact of the deuterons on its surface gives rise to activation and neutron production at a rate up to 4,6E+14 neutrons per second.

This work describes the design of a local shielding with improved efficiency. Different geometries and materials have been considered, and the design has been optimized taking into account the origin of the doses, the effect of the walls of the accelerator vault and the space restrictions. The initial idea was to shield the beam stopper with a large water tank of easy transport and dismantling but it was shown to be insufficient to satisfy the limit requirements, basically due to photon dose, and hence a denser shield combining hydrogenous and heavy materials was preferred.

It will be shown that, with this new shielding, dose rate outside the accelerator vault during operation comply with the legal limits and unrestricted maintenance operations inside most of the vault are possible after a reasonable cooling time after shutdown.

MCNPX has been used for transport calculations, with specific care for the particle source from deuteron interactions, and ACAB for activation analysis. This work describes the local shielding design process and the most relevant results obtained from the simulations.

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Session 6 - Present status of data and code libraries / 33

INCL4.5 and Abla07 - Improved versions of the intranuclear cascade (INCL4) and deexcitation (Abla) models

Author: jean-christophe david[1]

Co-authors: Alain Boudard [1]; Aleksandra Kelic [2]; Davide Mancusi [3]; Joseph Cugnon [3]; Sylvie Leray [1]; Valentina Ricciardi [2]

[1] *CEA-Saclay*

[2] *GSI*

[3] *University of Liège*

Corresponding Author: jean-christophe.david@cea.fr

The two codes INCL4.2 (Intra-nuclear cascade) and Abla (deexcitation), combined to describe spallation reactions, have been improved in the last years. The main points were the light charged particle emission and IMF (Intermediate Mass Fragment) emission. The new versions, INCL4.5 and Abla07, give now good results in particular on tritium and helium production. An international benchmark, where these two codes participated, shows that this spallation model combination is one of the most reliable to reproduce particle and residue production in a wide projectile energy range. These two models have been implemented recently in MCNPX2.7 (beta version).
Significant improvements in microscopic results will be shown and new calculations for the Megapie target will be compared to the previous results.

Session 3 - Benchmarking code/code & code/experimental data / 34

A new benchmark of spallation models

Author: jean-christophe david[1]

Co-authors: Alexander Konobeyev [2]; Detlef Filges [3]; Franz Gallmeier [4]; Guenter Mank [5]; Mayeen Khandaker [5]; Naohiko Otsuka [5]; Rolf Michel [6]; Sylvie Leray [1]; Yair Yariv [7]

[1] *CEA-Saclay*

[2] *FZK*

[3] *FZJ*

[4] *ORNL*

[5] *IAEA*

[6] *University Hannover*

[7] *Soreq*

Corresponding Author: jean-christophe.david@cea.fr

Spallation models have to be benchmarked in order to use the best one according the reactions studied and/or to know their reliabilities. Developments of spallation models are linked to experimental results and this explains why fifteen years ago a first benchmark has been launched, restricted to particle production, followed by a second one on residues. Since then new data have been measured and computer tools are improved day after day, so three institutes, CEA-Saclay (France), Soreq (Israel) and FZJ (Germany), decided to carry out a new benchmark, under the auspices of the IAEA, taken into account all types of results, particle and residue production, with a possibility to update the data (experimental and code calculation) via a web site.
An experimental database has been defined during a first workshop held in Trieste (ICTP) in February 2008 covering the whole energy range with the most important targets. Then these data have been collected and uploaded on the web site (www-nds.iaea.org/spallations) as the calculation results provided by all developers willing to participate. Seventeen different models or model combinations have been received. All these results have been processed (Comparisons with experimental data) and made available for everybody on the web site. A second workshop, held at the CEA-Saclay in February 2010, has presented the conclusions of this benchmark: General trends according observables, energies and targets, and specific qualities and shortcomings of each model.
This is the first time that so many spallation models and experimental data are compared, and all results made available to everybody on a web site. Web site and results will be presented.

Session 6 - Present status of data and code libraries / 35

Methodology to address radioprotection and safety issues in the IFMIF/EVEDA accelerator prototype

Author: Javier Sanz Gozalo[1]

Co-authors: Alicia Mayoral Esteban [1]; Daniel Lopez Gonzalez [1]; Francisco Ogando [1]; Mauricio Garcia Camacho [1]; Patrick Sauvan [1]; Philippe Joyer [2]; Valentin Blideanu [2]

[1] *UNED*

[2] *CEA/IRFU*

Corresponding Author: alippih@hotmail.com

International fusion materials irradiation facility (IFMIF) is one of the three projects of the fusion broader approach between Japan and the European Union, planned to be performed in parallel of ITER project. The objective of IFMIF is to study the behaviour under irradiation of materials and components in conditions close to a nuclear fusion reactor. Engineering validation and engineering design activities (EVEDA) is the first phase of the IFMIF project.
In the IFMIF/EVEDA accelerator prototype, deuteron interacts with the materials of the accelerator components due to beam losses and in the beam dump, where the beam is stopped. The production of neutrons/photons and radioactive inventories due to deuteron-induced reactions is a major issue for radioprotection and safety assessment. In addressing these issues some developments regarding computational tools and nuclear data are required in order to solve the following limitations:
i) The built-in nuclear models included in current MC codes do not allow predicting, with reasonable accuracy the production of secondary particles and residuals from deuteron interactions in the energy range up to 9MeV.
ii) The lack of transport coefficient data for diffusion simulation to determine the deuterium concentration profile inside the copper lattice (required for neutron and tritium production from d-D reaction)
We present in this paper the work we are performing in order to have a computational methodology able to address the major radioprotection and safety issues in the IFMIF/EVEDA operational scenarios.
Firstly, we present the outcome from a benchmark performed to assess the availability and quality of cross section data for neutron generation due to incident deuterons. Calculations for d-Material interactions are performed using the nuclear models included in MCNPX and PHITS, as well as the dedicated nuclear model code TALYS and corresponding TENDL2009 data library. The ENDF/B-VII.0 data library was used for d-D interactions.
Secondly, the need of some extensions to current MC codes is required. A solution to the limitations above indicated is the MCUNED code, an extension to current MCNPX code, which main features will be presented, showing its power in addressing like-EVEDA problems.
Thirdly, as for deuteron activation cross sections, results from the above-mentioned benchmark are presented and the pros and cons of using EAF2007 and TENL2009 data libraries are discussed. Regarding activation codes, ACAB is proposed as one of the reasonable options.
And finally, the diffusion transports coefficients proposed to be used by the TMAP7 code for deuterium and tritium profiles assessments is presented as well as its impact compared with others standard approaches.

Summary:

The production of neutrons/photons and radioactive inventories due to deuteron-induced reactions is a major issue for radioprotection and safety assessment. In addressing these issues in the IFMIF/EVEDA accelerator prototype some developments regarding computational tools and nuclear data have been required. The methodology to address it is presented.

Session 1 - Source term and related topics / 36

Perturbation of phase space downstream by parameters upstream

Author: Mary PW Chin[1]

[1] *European Spallation Source & CERN*

Corresponding Author: mary.chin@cern.ch

In a MW (p,xn) neutron facility GeV-range protons impinge a target where each proton generates an eventful history. As each history develops upstream towards downstream, the primary and subsequent secondaries penetrate the target and traverse the various components in the assembly (including the moderator and the reflector). Useful neutrons will survive and exit the beam line at the desired energy range at the desired timing. The remaining neutrons and other particles which emerge will require radiation protection and shielding attention. Nonetheless all emerging particles populate the emerging radiation phase space.

The irradiation conditions upstream (e.g. the beam energy and footprint, the target dimensions and composition) may perturb the emerging radiation phase space (downstream) to different extents. The emerging phase space could be more sensitive to some parameters and less sensitive to others. For instance, doubling the beam energy, doubling the beam size or doubling the target dimensions is unlikely to unanimously double the neutron fluence and footprint exiting the moderator. This study quantifies the perturbations.

Session 1 - Source term and related topics / 37

Shielding and activation calculations for a 3-10 PW ELI high intensity laser facility

Author: Anna Ferrari[1]

Co-authors: Bedrich Rus [2]; Daniele Margarone [2]; Jan Prokupek [2]; Tom Cowan [3]

[1] *Institut für Sichereitsforschung and Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, Dresden, Germany*

[2] *Institute of Physics of the Czech Academy of Science and PALS center, Prag, Czech Republic*

[3] *Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, Dresden, Germany*

Corresponding Author: a.ferrari@fzd.de

In recent years the dramatic rise in attainable laser intensity has triggered a strong evolution of the research field, that is associated with the non-linear laser-matter interaction: production and acceleration of electrons up to 1 GeV over accelerating distances around 1 mm (to be compared to the 100 m, that are typical for conventional accelerators) are a visible result of this evolution.
At the existing laser facilities in the 100 TW range, low-emittance protons are accelerated up to 20-30 MeV energies from thin (few tens of micrometers) solid metallic targets. The present limit in terms of kinetic energy has been recently set at the LANL 200 TW Trident laser facility, where from micro-cone targets proton energies in excess of around 67.5 Mev have been observed.
The production of laser-accelerated, high energy and high current particle beams requires a proper shielding assestment, especially when high intensity laser systems operate in repetition rate (typically in the range 0.1-10 Hz).
The ELI (Extreme Light Infrastructure) future facility in Czech Republic is one of the four european facilities foreseen in this project: different optional laser beam-lines will offer a versatile electron source and proton/ion source, emitting in an unprecedented energy range (until around 40 GeV at 10 PW, for the electron case). For this facility a first extensive study, that includes shielding and activation calculations for the most critical cases, has been performed. Starting from analytical calculations, as well as from dedicated simulations, the main radiation fields produced in the laser-matter interaction have been defined. These fields have been then characterized as "source terms" in a full simulation with the Monte Carlo code FLUKA, where the produced secondary radiation has been studied to assess a proper shielding. The unique features of the FLUKA code, i.e. the possibility to calculate in the same simulation the development of the electromagnetic and hadronic showers in a very large energy range and the neutron production and transport until the thermal energies, as well as induced activity and residual dose rates, have been a key point for this choice.
The first results for the ELI shielding, together with the activation calculations, that drove several material solutions, are here presented and discussed.

Session 4 - Dosimetry / 38

Estimation of Entrance Surface Dosess (ESDs) for common medical X-ray diagnostic examinations in Radiological Departments in Mashhad-IRAN

Author: Sasan Esmaili[1]

Co-author: Mohammad Taghi Bahreyni Toossi [2]

[1] *Azad University of SANANDAJ*

[2] *Prof. of medical physics MUMS(Mashad university of medical sciences)*

Corresponding Author: sasan_esmaili@yahoo.com

Background: The British national radiological protection board (NRPB) introduced the use of diagnostic reference levels (DRLs) as an efficient standard for optimizing the radiation protection of patients. The physical parameter recommended for monitoring the (DRLs) in conventional radiography is the entrance skin dose (ESD) and methods for measuring it is clearly described in NRPB standard protocol.
Method: The data were collected for 1183 radiographs of adult patients. The sample of patients was chosen so that the weight of patients was between 50-80 kg. Eight conventional X-ray examinations were chosen for this study. Entrance surface dose (ESD) of individual patient was directly measured by thermoluminiscence dosimeter, TLD chips sealed in a plastic sachet were stuck on the skin of patient at the center of X-ray beam axis.
Results: In this study, 3rd quartiles of measured ESDs for patients undertaking a particular examination were selected as ESD for study sample, based on this assumption ESDs for X-ray examination included in this study are as follows: Chest PA- 0.37 mGy, Chest Lat- 1.8 mGy, Lumbar Spine AP- 3.6 mGy, Lumbar Spine Lat- 5.6 mGy, Pelvis AP- 3.5 mGy, Abdomen AP- 3.7 mGy, Skull PA- 2.96 and Skull Lat- 1.79 mGy.
Conclusion: The data were analysed statistically, and the minimum, median, mean, maximum, first and third quartile values of ESDs are reported. Finally, our results were compared with the proposed Iranian DRLs , the international reference dose values reported by the European Commission, the International Atomic Energy Agency and the National Radiological Protection Board. It is evident that ESDs obtained in this work for Abdomen AP, Pelvis AP, Lumbar AP and Lumbar Lat examination do not exceed DRLs values worked out by NPRB. On the contrary for Chest PA, Chest Lat, Skull PA and Skull Lat higher ESDs were acquired in this study compared with DRLs suggested by NRPB.there is no single reason for dose variations ,but,the reasons are complex,in general,low filtration, high mAs and low tube potential are associated with higher doses arising from application of various X-ray machines.

Keywords: ESD, Quality control, TLD, DRL.

Session 1 - Source term and related topics / 39

Shielding aspects of the new nELBE photo-neutron source

Author: Anna Ferrari[1]

Co-authors: Andreas Wagner [2]; Andrija Matic [2]; Arnd Junghans [2]; Eckart Grosse [3]; Evert Birgersson [2]; Isabel Kösterke [2]; Klaus-Dieter Schilling [2]; Ralph Massarczyk [3]; Roland Beyer [2]; Roland Hannaske [3]; Roland Schwengner [2]; Toni Kögler [3]

[1] *Institut für Sichereitsforschung and Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, Dresden, Germany*

[2] *Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, Dresden, Germany*

[3] *Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf and Technische Universität Dresden, Dresden, Germany*

Corresponding Author: a.ferrari@fzd.de

The radiation source ELBE at Forschungszentrum Dresden-Rossendorf (FZD) uses a superconducting LINAC to produce high brillance electron beams, that can be delivered with energies up to 40 MeV, intensities up to 1 mA and within a pulse width of less then 10 ps. With these parameters the electron beam is used also to produce an intense neutron beam, by stopping the electrons in a liquid lead radiator and producing then neutrons by bremsstrahlung photons through (gamma, n) reactions. The primary goal of the nELBE neutron beam-line is the measurement of neutron cross sections, of interest both for construction materials of fusion and fission reactors, where it is important to select materials with low activation cross sections, and for the handling of nuclear waste from GEN IV reactors, where a key point is the accurate knowledge of processes, that transmute long-lived radioactive nuclides into short-lived and finally stable ones.
To increase the neutron yield through an enhanced electron beam energy (up to 50 MeV) and to minimize several sources of background at the present time, a new neutron beam-line and a new, larger neutron experimental room have been designed. The optimization of the neutron/photon ratio, the elimination of external sources of radiation background, the minimization of the backscattered radiation from the walls and the possibility to have better experimental conditions inside the room are the main advantages of the new design.
To optimize the beam-line and to assess all the shielding aspects of the design, from the liquid lead target for the photoproduction until the last dump at the end of the photo-neutron beam-line, extensive simulations with the particle interaction and transport code FLUKA have been performed. Starting from the primary electron beam, the secondary radiation fields of photons and neutrons have been fully characterized. To have a cross-check of the results, the calculated values of the neutron yields at different energies of the primary beam have been compared with an independent simulation with the MCNP code, obtaining a very satisfactory agreement at the level of few percent
.
The area around the photoproduction target has been studied in a mixed field condition, while, for statistical reasons, the penetration of the beam through the collimator and, finally, in the neutron experimental room has been studied by writing a separate "source term" for the photon and the neutron radiation component.
All the results for the nELBE shielding, together with some aspects of the optimization of the photo-neutron beam-line, are here presented and discussed.

Session 2 - Induced radioactivity / 40

Estimates of Radiation Levels in the Main Linac Tunnel and Beam Dump Caverns for the CLIC Design Study

Author: Sophie Mallows[1]

Co-author: Thomas Otto [2]

[1] *School of Physics and Astronomy Schuster Building-University of*

[2] *CERN*

Corresponding Author: sophie.mallows@cern.ch

The Compact Linear Collider (CLIC) study investigates the feasibility of a high-energy electron-positron linear collider optimized for a centre of mass energy of 3 TeV. The total tunnel length will be about 48 km, requiring the main linacs to operate at very high electric accelerating gradients of 100 MV/m. The RF power will be produced by a 'two-beam acceleration method'in which a high intensity drive beam supplies energy to the main accelerating beam. The main beam will be accelerated from 9 GeV to 1.5 TeV and the drive beam decelerated from 2.37 to 0.237 GeV. Current designs include 24 beam dump caverns for each linac, positioned at the end of every drive beam decelerator sector.

Ionizing radiation in the tunnel and caverns can cause damage to materials, lead to errors in semiconductor devices and have long-term health effects on exposed humans. Calculating the potential radiation levels in all parts of the CLIC facility is therefore an important part of the CLIC design study.

The Monte-Carlo particle transport code FLUKA is used to simulate main and drive beam losses in the CLIC tunnel at several different energies. An irradiation pattern with cycles of 180 days continuous running followed by 185 days of shutdown is used. Estimates of residual dose rates inside the tunnel at several waiting times ranging from 4 hours to 4 months within several different shutdown periods between 1 to 11 years of operation are presented. With the exception of areas very close to the beamline, the residual dose rates in the tunnel are found to be less than 100 μSvh-1 at waiting times of 4 hours. According to CERN limits, most interventions in the tunnel during offline periods would therefore be achievable without necessitating detailed optimizations of interventions and strict control times.

In addition, FLUKA is used to simulate an electron beam impinging on a graphite and iron composite dump inside a drive beam dump cavern. The resulting residual dose rates are presented.

Session 3 - Benchmarking code/code & code/experimental data / 42

Measurement and simulation of radionuclide product yields in iron from 400 AMeV carbon ions

Author: Tatsuhiko Ogawa[1]

Co-authors: Kosako Toshiso [1]; Mikhail Morev [1]; Takeshi Iimoto [1]

[1] *University of Tokyo*

Corresponding Author: tatsuhiko.ogawa@cern.ch

Radioactive fragments induced in an iron target bombarded by 400 MeV/nucleon carbon ion beam were measured and compared with simulation carried out using Monte-Carlo radiation transport code FLUKA.
An iron target thicker than the stopping range of carbon ion beam was irradiated with a focused 400MeV/u carbon ion beam. After the irradiation, the iron target was disassembled to extract cylinders (2.0 cm of radius and 0.15 cm of thickness) coaxial with the ion beam line. Gamma-ray spectra of 41 samples were measured with a high purity germanium detector. Distribution of activity of 18 gamma-ray emitting fragments from 7Be to 58Co were measured as a function of depth.
This irradiation was simulated using FLUKA to reproduce activation inside cylinders induced by both primary ion beam and secondary particles produced by carbon ion based on the default nuclear model of FLUKA. Taking account of the build-up during the irradiation and decay after the irradiation, measured and simulated results were compared.
In general, the simulation and experiment agree within a factor of two. Particularly simulation underestimates activity of most of the nuclides by a factor of about 10 at the end of the range of ion beam, which is probably attributed to the dificiency of default nuclear reaction model (RQMD) to reproduce ion induced reactions below 100 MeV/u. Furthermore, it is found that simulation tends to give better estimate for heavier nuclides.

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Mega-Watt Beams: Energy Deposition, DPA, Shielding and Activation

Author: Nikolai Mokhov[1]

[1] *FERMILAB*

Corresponding Author: mokhov@fnal.gov

The next generation of accelerators for Mega-Watt proton and heavy-ion beams put unprecedented requirements on the accuracy of particle production predictions, the capability and reliability of the

codes used in planning new accelerator facilities and experiments, the design of machine, target and collimation systems, detectors and radiation shielding and minimization of their impact on environment. Recent advances in code developments are described for the critical modules related to these challenges. Examples are given for the most demanding areas: particle production in precision experiments, targetry, focusing devices, beam absorbers, radiation shielding, induced radioactivity and radiation damage. The current experimental activities in these areas are also described.

Session 4 - Dosimetry / 44

Calculations of radiation levels in the service caverns and on the surface at Point 1 of the Large Hadron Collider

Author: Zuzana Zajacova[1]

Co-author: Tatsuhiko Ogawa [2]

[1] *Conseil Europeen Recherche Nucl. (CERN)-Unknown-Unknown*

[2] *University of Tokyo*

Corresponding Author: zuzana.zajacova@cern.ch

The ATLAS detector is installed at Point 1 of the Large Hadron Collider. The underground infrastructure consists of the experimental cavern UX15, which houses the detector, and two lateral service caverns, USA15 and US15. The experimental cavern is connected with the surface by two large vertical shafts, PX14 and PX16. Calculations were performed with the FLUKA code to assess the prompt radiation levels in the underground service caverns and on the surface at Point 1. The FLUKA geometry reflected the actual design of the ATLAS detector and the civil engineering infrastructure. The estimated radiation levels are given and results and methods are compared with the initial shielding design studies for Point 1.

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The EURISOL Multi-MW Target Unit: Radiological protection and radiation safety issues

Authors: Raul Luís[1]; Yuriy Romanets[2]

Co-authors: Cyril Kharoua [3]; Daniela Ene [4]; Florin Negoita [5]; Isabel Goncalves [6]; Jeane-Christophe David [4]; Judilka Bermudezb [7]; Luigi Tecchio [7]; M Barbui [7]; O Alyakrinskiy [7]; Pedro Vaz [6]; Roberto Rocca [3]; Yacine Kadi [3]

[1] *Instituto Tecnologico e Nuclear (ITN)*

[2] *Instituto Superior Tecnico (IST)*

[3] *CERN*

[4] *CEA*

[5] *NIPNE*

[6] *ITN*

[7] *INFN-LNL*

Corresponding Author: yuriy.romanets@cern.ch

The research with radioactive beams has strengthened the link between technical developments and physics output. The study of radioactive beams allows us to follow the evolution of nuclear structure over extended regions in the nuclear chart. Two different ways of producing radioactive beams, in-flight separation and the ISOL approach, can be combined with different post-processing of the radioactive nuclei. In Europe, the recommendation is to construct separate facilities built on

these two complementary production schemes. Immediate priority is given to the in-flight project FAIR, where first experiments are planned for 2012. Highest priority for further projects is given to the next-generation ISOL facility EURISOL, which can be constructed in the next decade. An intense R&D programme is being carried out to bridge the technological gap between present day facilities and EURISOL. It is recognized that one needs to proceed via several intermediate stage projects, one of them being HIE-ISOLDE and others including SPIRAL2 at GANIL. Outside Europe several projects also exist. Funding is already secured for the upgrade of the RI Beam Science Laboratory at RIKEN and for ISAC2 at TRIUMF , and in the USA a large community around the FRIB project is working towards construction of a new facility.

The EURISOL (The EURopean Isotope Separation On-Line Radioactive Ion Beam) facility which detailed design has been achieved in 2009, aims at producing high intensity (100-1000 times higher than currently operating facilities) radioactive ion beams with energies up to 150 MeV/u. Such characteristics will be achieved due to the high power (Multi Mega Watt) delivered by a proton beam of energies in the 1-2 GeV range and intensities up to 4 mA in a high-density spallation target (liquid mercury, commonly referred to as the neutron converter). As a result of the spallation reactions induced by the proton beams in the converter, very high neutron fluxes (in excess of 1015 n cm-2 s-1) are produced to induced fission in surrounding targets containing fissile materials (Uranium). The produced fission fragments are then extracted, accelerated and mass-separated and delivered to the experimental areas where measurements are to be performed.

As a result of the high-intensity proton beam, of the high-power delivered to the converter (spallation target) and of the very high-neutron fluxes generated by spallation reactions, the Target Unit of the EURISOL facility is a critical component of the facility. The associated radiation safety and radiological protection aspects are extremely important and very complex. In this paper, the Monte Carlo simulations of the neutronics, dose-rate and activation of the several components of the EURISOL facility are detailed, in its MAFF configuration which allows an easier manipulation, repair and maintenance of the fission targets. The extremely high levels of the material activation (up to 1012 Bq g-1 in some cases) and dose rates (dose-equivalent ˜106 Sv h-1) could be a show stopper for the operation of the facility. Appropriate radiation shielding need to be designed and implemented in order to assure the safe confinement of the radiation inside the facility during operation.
The results reported in this study were obtained using the state-of-the-art Monte Carlo codes MCNPX and FLUKA. Analysis of the activation of the structural materials is performed and discussed.

Acknowledgements
We acknowledge the financial support of the European Community under the FP6 Research Infrastructure Action Structuring the European Research Area EURISOL DS Project Contract No. 515768 RIDS. The EC is not liable for any use that may be made of the information contained herein. Part of the work has also been supported by the Portuguese Foundation for the Science and Technology (FCT) in the framework of the projects CERN/FP/83586/2008 and POCI/FP/81951/2007.

Session 2 - Induced radioactivity / 46

Activation and neutronics studies for the CERN n_TOF facility with the FLUKA Monte Carlo code

Author: Elias Lebbos[1]

Co-authors: Alfredo Ferrari [1]; Marco Calviani [1]; Markus Brugger [1]; Michel Pangallo [1]; Paolo Cennini [1]; Pierre Carbonez [1]; Vasilis Vlachoudis [1]

[1] *CERN*

Corresponding Author: elias.lebbos@cern.ch

The n_TOF facility, a spallation neutron source, uses a pure lead target for production of neutrons with a 20 GeV proton beam extracted from the CERN Proton Synchrotron (PS). After four years of operation and three years of cooling, from 2001 to 2007, the target assembly has been successfully removed. After a detailed analysis of the target status, the decision to substitute it with a new target has been taken. Only within few months, a strong effort was put in the development of a new target and a new cooling system, both ready for a restart of the facility in 2008.

This study presents detailed results for the produced nuclide vector in the respective installation and target components, as well as a three-dimensional residual dose rate fields for different geometrical configurations. These calculations formed an important input to prepare and plan intervention scenarios, foresee proper waste disposal and help in the analysis of the target status.

For the design of the new target, numerous aspects were taken into account, including neutronics and activation calculations compared with the ones performed for the old target, and a respective comparison of several possible target configurations is presented in this paper. Furthermore, prompt dose calculations were performed with the finally chosen target design, which is based on a well detailed geometrical implementation in FLUKA, and the comparison with the measurements performed during the commissioning in 2008 are shown.

In 2009 a new target cooling station with improved performances has been installed. It includes a degassing system, which is used to maintain the oxygen level in the cooling water down to an average value of 40 ppb and two ion-exchanger cartridges to retain spallation products. In addition, the primary area is now also being ventilated and maintained with an underpressure of 40 Pa with respect to the surrounding atmospheric pressure. In this context, the impact of an unforeseen release of short lived isotopes from the exhaust stack are shown, as well as the actions taken to mitigate this issue.

Finally, the comparison of the expected fluence - in the experimental area - between the new and the old spallation target is shown, together with the results of the simulation using borated water in the moderator circuit, a recent upgrade of the facility currently in its final preparations.

Session 3 - Benchmarking code/code & code/experimental data / 47

MonteCarlo benchmarking: validation and progress

Author: Paola Sala[1]

[1] *CERN*

Calculational tools for radiation shielding at accelerators are faced
with new challenges from the present and next generations of particle
accelerators. All the details of particle production and transport
play a role when dealing with huge power facilities, therapeutic ion
beams, radioactive beams, and so on. Besides the traditional calculations
required for shielding, activation predictions have become an increasingly
critical component.
Comparison and benchmarking with experimental data is obviously
mandatory in order to buildup confidence in the computing tools, and to
assess their reliability and limitations. Thin target particle production
data are often the best tools for understanding the predictive power of
individual interaction models and improving their performances.
Complex benchmarks (eg thick target data, deep penetration etc) are
invaluable in assessing the overall performances of calculational tools
when all ingredients are put at work together.
A review of the validation procedures of Monte Carlo tools will be
presented with practical and real life examples. The interconnections
among benchmarks, model development and impact on shielding calculations
will be highlighted.

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Production of neutrons and spallation products by high-energy particle beams

Author: Takashi Nakamura[1]

[1] *Shimizu Corporation*

This review summarises data up to 2008 on energy and angular distributions of neutrons produced from thick targets of various materials bombarded by protons, deuterons, He and heavier ions having wide energy range from MeV to GeV. Total neutron yields are also presented. Production cross section data for spallation by proton to Ar ion are also summarized in this talk, as well as excitation functions, mass-yield distributions, and induced activities. Some data are also presented for photo-neutron production.

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Activation Calculations in Accelerator Environments –An Overview

Author: Franz Gallmeier[1]

[1] *ORNL*

Accelerator activation analyses involve radionuclide production terms from two different branches of analyses, directly from event generators, indirectly by folding fluxes with activation cross sections, for particle types and energy ranges where activation cross sections exist. Advances have been made in the predictive power of event generators, and also in activation cross section data bases.
Nowadays two approaches of performing activation analyses exist, firstly, the traditional way of sampling fluxes and radionuclides in transport analyses and feeding this information into external activation codes; and secondly, plugging in activation modules into transport codes solving for the radionuclide buildup and decay online on a per-event basis. Both methodologies will be discussed.
All the tools and data bases need verification. Benchmarking is an instrumental process for verification. An overview of benchmarking efforts will be given and the need of further benchmark experiments discussed.

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Corresponding Author: marco.silari@cern.ch

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