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Proceedings of the Specialists' Meeting on

Shielding Aspects of Accelerators, Targets and Irradiation Facilities

Arlington, Texas (USA)
28-29 April 1994

organised by the

Nuclear Energy Agency

Reactor Physics Committee (Japan)
Radiation Shielding Information Center (USA)

PUBLISHER'S NOTE

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The views expressed are those of the authors.

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

SUMMARY and CONCLUSIONS
OF
THE SPECIALISTS' MEETING

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1. Executive Summary

A Specialists' Meeting on **The Shielding Aspects of Accelerators, Targets, and Irradiation Facilities** was held in Arlington, Texas, 28-29 April, 1994. The meeting was jointly organized by the OECD/NEA, The Reactor Physics Committee of Japan and the Radiation Shielding Information Center, USA. Forty-five participants from seven countries and two international organizations attended.

About two-thirds of the time available was taken up with the presentation of invited review papers and presentations on recent developments covering a wide field of technical areas including transport code development, basic nuclear data, experimental shielding data, operational experience at particle accelerators etc.

The final session of the meeting was devoted to a discussion led by Drs. Ipe and Fasso` on the needs of the accelerator shielding community including the establishment of a newsletter to improve communication in the accelerator shielding community; exploration of the possibility of making needed cross-section measurements; addition of physical data and code information to the libraries of RSIC and the NEA Data Bank; training in the use of major radiation transport code systems; promotion of a second meeting on Simulating Accelerator Radiation Environment (SARE) with invitation extended to specialists interested in accelerators with energy below 1 GeV and finally, a request for a second specialists' meeting in 1995.

2. Introduction

Since Cockcroft and Walton's success in 1932, particle accelerators have extended steadily their application from the nuclear and high energy particle physics to other fields such as medicine and industry. During sixty years, higher and higher energy accelerators have been developed, creating the opportunities for new areas of scientific and technological applications.

In the history of nuclear energy, during half a century after the success of controlled nuclear chain reaction at the University of Chicago, accelerators have played a very important role in the steady advancement of science and technology. With the remarkable technological progress achieved recently, accelerators are expected to facilitate the basic research around nuclear energy and to push its development towards a key energy source in the next century. In this context, new accelerators and irradiation facilities are being designed and constructed in Member countries of OECD/NEA; examples are high intensity spallation sources, cold neutron moderator facilities, high neutron flux fusion material testing facilities, free electron laser facilities for uranium enrichment, synchrotron radiation sources, and high energy heavy ion facilities for material and biological research.

In viewing the present and future needs, it is expected that accelerators will be built of a greater variety, not only as far as their energy is concerned but also in their intensity, size and application; new, difficult and interesting shielding aspects do arise from this. The shielding aspects can be classified mainly according to accelerated particles and their energy. For example, proton accelerators can be divided as follows:

1. High energy accelerators: over several GeV, used mainly for nuclear and particle physics;

2. Medium energy accelerators: from about 100 MeV to several GeV;

3. Low energy accelerators: less than 100 MeV.

The accelerators belonging to item 1, such as SSC and LHC, which are used mainly for particle physics, bring about new and difficult issues with increasing accelerated energy, the solution of which may be rather an art than a science, although recent progress of computer technology makes the use of Monte Carlo codes simulating particle transport partly possible.

In the accelerators of item 2, sophisticated data and methods are required for shielding design to realize effective applications and also to save construction costs. This type of accelerator is expected to be applied extensively for nuclear energy and basic research requiring intense beam currents. The Japanese Hadron Project (JHP) in INS and Engineering Technology Accelerator (ETA) for the transmutation of radioactive nuclides in JAERI, the LANL Accelerator-Driven Transmutation Technologies (ADT2) including Accelerator Transmutation of Wastes (ATW), Accelerator Production of Tritium (APT) and Accelerator Based Conversion (plutonium burning), and European Spallation Source (ESS) for condensed matter research are based on proton accelerators ranging from 0.6 - 1.6 GeV in energy and 0.4 - 300 mA in the current. Such high current accelerators are a challenge not only in accelerator technology but also in radiation shielding technology. Some of these projects include provision for power generation as a by-product, thereby raising even further shielding questions. Also the updating of existing spallation sources poses new challenging shielding problems. The handling of radiation and radioactivity is a crucial issue in the design of accelerators. However, present data and methods are definitely insufficient for the requirements.

The accelerators categorized into item 3 have been most widely used for basic research, medical and industrial purposes; therefore, both accurate and simplified methods, in general, are needed for shielding design. Nevertheless, today's state of the art is still insufficient to meet present requirements, because of lack of nuclear reaction data and the shortage of nuclear reaction theory in this energy region. Especially, d-Li intense neutron sources for a fusion material irradiation testing facility (FMIF), which is discussed under the ITER project, demands special aspects for shielding design to be addressed because of the energy of about 40 MeV and the high current of a few hundreds mA.

As for electron and heavy ion accelerators, the classification based on shielding aspects can be different from that of proton accelerators. It needs to be stressed that also for these accelerators, crucial shielding aspects are neutron production reactions and neutron shielding.

History

The first steps that led to the organization of this meeting date back to the 7th International Conference on Radiation Shielding (ICRS7) held in Bournemouth, England, and jointly organized by AEA Winfrith and the OECD/NEA.

- In September 1988, during ICRS7, an informal meeting on accelerator shielding was organized by Dr. Alberto Fasso`, gathering more than 20 participants; from the discussions it emerged that there is a lack of nuclear data and model codes for accelerator shielding and all participants stressed that international co-operation on these issues is needed.

- In December 1991, the shielding committee of Japan proposed a new project on accelerator shielding at the NEA/Nuclear Science Committee meeting as a follow up to the meeting in Bournemouth. This proposal was accepted and it was agreed to hold a Specialists' Meeting. Dr. Shun-ichi Tanaka organized a working group to prepare a provisional program and to promote the meeting in the reactor physics committee of JAERI.

- In September 1992, Dr. Ralph Thomas was invited to co-operate with the organization of the meeting and to be the general chair.

- In November 1992, the program presented by JAERI at the NEA/NSC meeting was endorsed.

- In January 1993, independently, the first meeting on Simulating Accelerator Radiation Environment (SARE) was held in Santa Fe, New Mexico.

- In May 1993, concrete actions to organize the meeting were started.

- In April 1994, the meeting took place and gathered 45 specialists working in this field.

3. Technical summary of presentations and discussions

a. Electron accelerators

Photons

Narrow beams present special dosimetry problems because the detector size is larger than the beam size (e.g., gas bremsstrahlung); with such small beams it is difficult to carry out dosimetry measurements. *Gas bremsstrahlung* has to be considered in the shielding of synchrotron radiation facilities, and calculations agree with measurements if proper care is taken in the modelling.

Neutrons

For mid- and high-energy neutrons, the dependence of source term on electron energy, target properties and emission angles, and the dependence of attenuation length on electron energy, shield material and angle is not well known. Improved instruments are needed for measuring neutrons in mixed fields with high photon dose rates. In general, basic photoneutron data files are needed.

b. Proton accelerators

Various transport computer codes produce reasonable agreement but experimental verification at all shielding depths is needed for the intermediate energy region. Better methods for measuring high-energy dose equivalents are needed. Simple methods for dose equivalent calculations have been developed based on state of the art simulation (i.e. FLUKA, LAHET, etc), but the resulting attenuation lengths need to be checked for consistency against the ones determined in the 1960s.

c. All accelerators

It was recognized that criteria such as maximum credible accident, possible beam loss scenarios, credit for active protection systems, reasonable dose equivalent limits for accidents, etc, are issues that will need increased attention in the future.

d. Spallation target stations and medium energy accelerators

Neutron cross sections can be calculated using HETC for energies above 800 MeV by extending the DLC-119/HILO86 multigroup library above 400 MeV. Coupling Monte Carlo with one-dimensional discrete ordinates calculations works well as long as the coupling surface is far enough from the target so neutrons are the dominant particle. Coupling with two-dimensional discrete ordinates codes should be considered for studying streaming problems.

Intermediate energy heavy ions

Measured differential neutron and proton data are reproduced fairly well by Intranuclear Cascade Evaporation (INCE) codes (100-800 MeV), but the resulting attenuation length and the geometry under which they were determined need to be compared with those determined in the 1960s. The QMD code is an alternative still being developed. Systematic measurements, including neutron production cross sections, are needed for a range of ions. Theoretical models for neutron yields calculations need to be benchmarked.

Takasaki Ion Accelerators for Advanced Radiation Application (TIARA)

The quasi-monoenergetic neutron source facility in Japan has been developed for shielding experiments and cross section measurements (20-90 MeV) and Monte Carlo and discrete ordinates codes using HILO86 have been used to compare with measurements. Interest was expressed in exploring the possibility of the international community making proposals to JAERI for use of the neutron beam line.

e. Computer codes and data

Reports on the various major shielding code systems were made. It is felt that the NEA DB and RSIC can provide beneficial services to the accelerator shielding specialists by packaging and disseminating modern frozen versions of the transport and auxiliary codes and data libraries in common use. That is not the current situation. It is recommended that the Centers obtain the packages listed below or up-to-date versions of them (and any other that might be recommended).

Hadronic and electromagnetic cascades, low-energy neutron transport:

ANCAS (INR Moscow)
CALOR93 (ORNL)
EGS4 (SLAC)
FLUKA93 (INFN/CERN)
FLUNEV (DESY)
GEANT (CERN), GCALOR (CERN/ORNL)
HERMES (KFA)
HETC-3STEP (KYUSHU)
LAHET Code System (LANL)
MARS12 (FERMILAB)
SITA(DUBNA)
SHIELD(INR Moscow)

Intermediate Energy Nuclear Models:

ALICE92 (LLNL)
CEM92M (DUBNA)
FKK-GNASH (LANL)
KAPSIES (ECN)
MCEXITON (JAPAN)
NUCLEUS (JAERI)
QMD (ITP-Frankfurt)
STAC-8 (JAERI)

Miscellaneous:

ASTAR,PSTAR,ESTAR (NIST) - stopping power for alpha, proton, electron
CASL (KFA) -
CINDER90 (LANL) - isotope inventory calculation

Extensive work is being carried out in code development for relativistic heavy ion physics, however this aspect has not been covered by participants.

4. Data needs and suggestions expressed by the participants

a. Basic atomic and nuclear data

Shielding of modern high-intensity accelerators in the intermediate energy range (<5 GeV) requires double differential cross sections for neutrons, pions, light and heavy ions (at least up to A=18), for energies between 20 MeV and 5 GeV. At the present time these data are scarce and scattered among internal reports and journal articles.

Efforts should be made on two fronts: first, to compile existing data in a computer-readable form, and second, to carry out experiments to fill the main gaps. A search of available nuclear models which could be used to complement experimental data would also be useful. Other data of interest include isotope production data, total and elastic cross sections, and thick target yields and angular distributions for the particles and energies listed above.

In some cases, new experimental data are required to resolve conflicts between different experiments, or to confirm data which are in apparent conflict with the most widely used models. As an example there are inconsistencies in the available data for pion absorption cross sections in the resonance region, and trends such as pi- charge exchange versus A should be confirmed by further experiments. Concerning electron accelerators, there is a lack of knowledge about forward *bremsstrahlung* yields from thick targets at energies higher than 100 MeV. The existing compilations of photonuclear cross sections (Dietrich and Berman) are useful but insufficient: they cover only a limited number of nuclei and some of the most common ones (e.g., iron) are missing. In addition, only the giant resonance energy range is considered, and only photoneutron production is reported. There is a need for total photonuclear cross sections, photoneutron yields from thin and thick targets, photoneutron angular distributions for all most common elements at all energies. In the highest energy range (E>200 MeV), photopion yields and angular distributions are necessary [1]. More generally, there is a lack of available data for double differential cross sections of pion emission in nuclear interactions by any kind of projectile (proton, neutron, pion, photon) at energies larger than 300 MeV. Other data needs concern albedo of neutrons with energies higher than 20 MeV (useful for streaming calculations), isotope production data (possibly for thin targets), and (n, gamma) cross sections above 20 MeV. The lack of (n, gamma) data for barium isotopes below 20 MeV was also mentioned.

b. Shielding experiments

Forward and lateral attenuation should be measured up to at least 5 or 6 m of concrete for proton and ion accelerators with energies lower than 5 GeV. There is a particular need for data in the 100-800 MeV/m energy range. The dependence on energy of attenuation length and apparent source term should be established with better accuracy than at present. It was stressed that the results should be expressed also in terms of fluence or other basic physical quantity in order to allow a re-evaluation of the data in case new dose conversion coefficients should apply [2]. At electron accelerators, forward and lateral attenuation curves should be measured in order to check the semi-empirical formulae in general use. This information is needed for both thin and thick targets, and should include thin shielding layers.

c. Other experimental information

There is a need for better measurements of many activation detector excitation functions, in particular 11-C production by neutrons and pions in the energy range above 100 MeV. Determining the response function above 20 MeV of other detectors (instruments based on moderation, scintillators) with monochromatic neutron beams would also be useful. A measurement of target heating with targets of low atomic number was suggested in order to resolve existing conflicting calculated data.

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1 All the data mentioned do not need to be available for all nuclei but should span the whole range of atomic masses in order to allow complete benchmarking of nuclear reaction models

2 All details of the shielding layout should be reported especially concerning density and composition of the materials. The adopted definition of attenuation length should always be stated clearly.

d. Improvements in modeling and computer codes

Light and heavy ions are not treated by existing Monte Carlo transport codes, or are with an accuracy not yet comparable with that of reactions induced by protons and neutrons. Models are needed to implement satisfactory event generators. The intranuclear cascade model for hadron interactions in the intermediate energy range has been used successfully for over 20 years. However some deficiencies are well known, in particular, the backward particle emission and the emission at very small angles is not satisfactory. Improvements based on modern physical concepts which have already shown promising results in some recent code developments can help solving most known problems. Also fragmentation models are necessary to improve residual nuclei predictions.

Several participants expressed their wish for more friendly user interfaces, tools to set up and debug geometries, techniques for automatic biasing. All such suggestions were aiming at making the use of Monte Carlo codes more reliable and easier to operate by specialists with a limited experience. In this same spirit, a suggestion was made to provide guidance against common errors which could lead to gross mistakes in the calculated results.

In order to improve the basic physical data used by code developers, it was suggested that recent compilations be made available in computer-readable form such as those published by Cullen et al., (LLNL) on photon and electron interactions. Several participants indicated that there appears to be hardly any effort on code development for high energy codes when compared with low energy codes; participants have stressed that further code development is necessary to achieve better accuracy in shielding calculations. Finally, the importance of semi-empirical shielding codes was stressed. These are mainly based on the concepts of source term and attenuation length, and often allow a quick and conservative estimate of shield effectiveness. The existing ones should be extended and refined to cover wider ranges of energies and shielding thicknesses, and the development of new ones, especially for forward shielding, should be encouraged. A special issue was raised about the quality control of computer programs. It was suggested that a theoretical analysis be made about models and experimental data, aiming at identifying common features and differences among various codes, so that the cause of discrepancies in the results could be traced.

e. Other requests

Various other proposals were brought forward during the workshop. Anthropomorphic phantom geometries and composition should be standardized and made available to all. Drs Roussin and Sartori agreed to provide this information through RSIC and the NEA Data Bank.

The shielding community is concerned about some potential difficulties faced in applying the recent recommendations of ICRP Publication 60 to high energies and would encourage the ICRP and ICRU to remove present inconsistencies in quality factors and weighting factors. It was pointed out that the ambient dose equivalent as an operational quantity may not be always suitable in high-energy accelerator environments and a dose-quantity appropriate for shield calculation was recommended. Other questions which were debated were: which area is relevant for dose measurement (or for scoring in the case of Monte Carlo calculations) when the irradiation takes place in a narrow beam? which scenarios should be assumed for accidental beam losses?

Finally, a "blind" intercomparison of unfolding codes was proposed, similar to those which are being sponsored by EURADOS for low-energy neutron spectra.

5. Recommendations and agreed actions

The discussion led to the proposal of a number of concrete actions, which can be accomplished with a relatively small effort in the short term and which would have immediate beneficial impact on improving range and quality of data and modeling computer codes (persons or organisations having accepted to carry out the actions are given in parentheses).

- collect and make available anthropomorphic phantom geometries including material compositions as used in Monte Carlo radiation transport codes (RSIC, NEADB, PTB, GSF);

- collect and make available existing data on:

  * thin target measurements (p, n, pi, HI) (A. Ferrari, L. Waters, E. Sartori),
  * thick target measurements (T. Nakamura),
  * deep penetration measurements (T. Nakamura),
  * photonuclear data (A. Fasso`, W.R. Nelson, R.W. Roussin, Y. Kikuchi);

- Contact ICRP and ICRU about dosimetry issues (R. Thomas);

- agree on definitions of attenuation length and source term parameters (aH, H0) (H. Dinter, G. Stevenson, T. Nakamura);

- establish regular exchanges of relevant publications among participants;

- set up an electronic network listserver for exchange of communications (W. R. Nelson, R. Donahue);

Other actions were agreed upon that will require larger efforts and coordination:

- courses on intermediate energy transport codes to ensure correct understanding of their models and their correct use;

- experiments-measurements:

  1. at LANL, USA:

  * pi+ and pi- projectiles double differential pion cross sections in the exit channel double differential proton/neutron cross sections in the exit channel,

  * proton/neutron projectiles double differential proton cross sections in the exit channel high resolution measurements in the forward direction double differential pion production some of these data sets are already available, but a systematic study should be carried out to identify and then obtain those which are missing or incomplete,

  2. at TIARA and other facilities in Japan:

  * excitation functions of activation detectors (C-11, Bi),

  * monoenergetic calibration of active instruments;

- follow-up meeting in 18 months to monitor progress on the different actions, to discuss and exchange ideas in code development and validation, decide further actions to speed-up progress. (Tentative date and place, October 1995, in Nice, France, in connection with the SARE meeting).

Proceedings of Second Specialists' Meeting on

SHIELDING ASPECTS OF ACCELERATORS, TARGETS AND IRRADIATION FACILITIES

CERN
Geneva, Switzerland
12-13 October 1995

organised by the

OECD Nuclear Energy Agency

the Shielding Working Group of the Reactor Physics Committee – Japan

the Radiation Shielding Information Center – U.S.A.

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-PERATION AND DEVELOPMENT

EXECUTIVE SUMMARY

1. Introduction

Two specialists' meetings on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF) were held so far:

- SATIF-1 at Arlington, Texas, 28-29 April 1994,
- SATIF-2 at CERN, Geneva, 12-13 October 1995.

Both meetings were jointly organised by the OECD/NEA, the Shielding Working Group of the Reactor Physics Committee of Japan and the RSIC (U.S.A.).

The objective of the first meeting was to exchange information in this field among scientists, to identify areas that would benefit from international co-operation and to propose a programme of work and initiatives in order to achieve progress in priority areas. The results of the meeting were published at the beginning of 1995 and were widely distributed ("Shielding Aspects of Accelerators, Targets and Irradiation Facilities", OECD, 1995, ISBN 92-64-14327-0)

The objectives of the second meeting were to review the progress made since the first meeting in the topics discussed, monitor the status of the agreed actions concerning basic data, methods, codes and experiments required for shielding calculations, identify and initiate new concrete co-operative actions to meet the requirements of this discipline and improve the common understanding of the different problems that have technical and safety significance.

A considerable amount of work has been achieved since the first meeting and which is reported in these proceedings covering the second meeting. This second meeting was held in conjunction with another meeting, the second one on Simulating Accelerator Radiation Environments (SARE-2). The specific objectives of the two meetings are different but in order to avoid potential overlap they were reviewed again and it was agreed that they should continue to be held in conjunction with each other because of their complementarity but should aim at separate objectives.

The programme of the meeting is enclosed as Appendix A and the list of about 50 participants is given in Appendix B.

2. Second meeting (SATIF-2)

The meeting was opened by T. Nakamura from the Tohoku University, Chairman of the Shielding Working Group of the Reactor Physics Committee of Japan.

It was attended by 47 experts from 11 countries and 2 international organisations.

The programme of the meeting is enclosed as Appendix A and the list of participants as Appendix B.

3. Technical summary of presentations and discussions

Most technical issues identified at SATIF-1 are still relevant. They are recalled here on the left half of the page, while specific actions are listed on the right half of the page.

3.1 Electron accelerators

a) Photons

Narrow beams present special dosimetry problems because the detector size is larger than the beam size (e.g., gas bremsstrahlung); with such small beams it is difficult to carry out dosimetry measurements. Gas brems-strahlung has to be considered in the shielding of synchrotron radiation facilities, and calculations agree with measurements if proper care is taken in the modelling.

A report describing the issue has been published as CERN/TIS/RP/JM 95-06 by G. Stevenson.
It is suggested that a subgroup is formed to prepare an update at SATIF-3. (N. Ipe - Chair, T. Gabriel, G. Stevenson, S. Ban, M. Pelliccioni).

b) Neutrons

For mid- and high-energy neutrons, the dependence of source term on electron energy, target properties and emission angles, and the dependence of attenuation length on electron energy, shield material and angle is not well known.

P. Degtyarenko and G. Stapleton (CEBAF) will collaborate with SLAC and provide an update at SATIF-3.

Improved instruments are needed for measuring neutrons in mixed fields with high photon dose rates.

M. Hoepfert and G. Stevenson (CERN), N. Ipe (SLAC), S. Ban (KEK) P. Degtyarenko (CEBAF) will co-operate in this.

In general, basic photoneutron data files are needed.

Work is in progress in Japan, Fasso` has collected cross-sections.

3.2 Proton accelerators

Various transport computer codes produce reasonable agreement but experimental verification at all shielding depths is needed for the intermediate energy region. Better methods for measuring high -energy dose equivalents are needed. Simple methods for

Experiments carried out at ISIS (Japan).

dose equivalent calculations have been developed based on state of the art simulation (i.e., FLUKA, LAHET, etc.), but the resulting attenuation lengths need to be checked for consistency against the ones determined in the 1960's.

This is difficult, but attempts have been made below 400 MeV (P. Tabarelli).

3.3 All accelerators

It was recognized that criteria such as maximum credible accident, possible beam loss scenarios, credit for active protection systems, reasonable dose equivalent limits for accidents, etc., are issues that will need increased attention in the future.

"The Control of Prompt Radiation Hazards at Accelerator Facilities" in draft form has been prepared by G. Stapleton (CEBAF). There exists also a CERN internal report (G. Stevenson, M. Hoepfert).

3.4 Spallation target stations and medium energy accelerators

a) Neutrons

Neutron cross sections can be calculated using HETC for energies above 800 MeV by extending the DLC-119/HILO86 multigroup library above 400 MeV. Coupling Monte Carlo with one-dimensional discrete ordinates calculations works well as long as the coupling surface is far enough from the target, so neutrons are the dominant particle.

Coupling with two-dimensional discrete ordinates codes should be considered for studying streaming problems.

Work in progress for low-energy transport by R. Lillie and J. Johnson (ORNL) S. Lee and R. Alcouffe (LANL).

b) Intermediate energy heavy ions

Measured differential neutron and proton data are reproduced fairly well by Intranuclear Cascade Evaporation (INCE) codes (100-800 MeV), but the resulting attenuation length and the geometry under which they were determined need to be compared with those determined in the 1960's.

Proposal made at LANL.
Update at SATIF-3.

The QMD code is an alternative still being developed.	The first stage has been developed (H. Nakashima). Update will be provided at SATIF-3.
Systematic measurements, including neutron production cross sections, are needed for a range of ions.	Work is in progress in Japan: 3 accelerators: – 70 MeV/nucleon, – 100 MeV/nucleon, – 800 MeV/nucleon. Update at SATIF-3.
Theoretical models for neutron yields calculations need to be benchmarked.	QMD code can be used. R. Donahue will provide data and T. Gabriel will carry out the work and report at SATIF-3.
Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) The quasi-monoenergetic neutron source facility in Japan has been developed for shielding experiments and cross-section measurements (20-90 MeV) and Monte Carlo and discrete ordinates codes using HILO86 have been used to compare with measurements.	
Interest was expressed in exploring the possibility of the international community making proposals to JAERI for use of the neutron beam line.	T. Nakamura should be contacted. It is open for universities.

c) Computer codes and data

Reports on the various major shielding code systems were made. It is felt that the NEADB and RSIC can provide beneficial services to the accelerator shielding specialists by packaging and disseminating modern frozen versions of the transport and auxiliary codes and data libraries in common use. That is not the current situation. It is recommended that the Centers obtain state-of-the-art codes.	Codes have reached a certain maturity today. Further progress is being made. Several new codes were released to the information centers as reported in the last paper of the proceedings. Several other codes have been discussed at SATIF-2 which have not yet been released yet. These are:

FLUKA95, LAHET2.8, MARS13(95), CINDER95, GEANT3.21, DPMJET-II, STRUCT, DTUNUC, GCALOR, SENSIBL, DTUJET, HILO86R, MUCARLO, MCPHOTO, PHOJET, QMD, DINREG, NMTC-3STEP, HETC-3STEP, NMTC-ISOBAR, HERMES, PKN-H, HETC95, SINBAD, PEREGRINE, QKERMA.

RSIC and the NEADB recommend that this codes are released and shared among the international experts.

Extensive work is being carried out in code development for relativistic heavy ion physics, however this aspect has not been covered by participants.

4. Data needs and suggestions expressed by the participants

4.1 Basic atomic and nuclear data

Shielding of modern high -intensity accelerators in the intermediate energy range (< 5 GeV) requires double differential cross-sections for neutrons, pions, light and heavy ions (at least up to A=18), for energies between 20 MeV and 5 GeV. At the present time these data are scarce and scattered among internal reports and journal articles.

Efforts should be made on two fronts:
first, to compile existing data in a computer-readable form;

Some data has been collected by A. Ferrari, by LANL and by the NEA Data Bank (Intermediate Energy EXFOR data base).

and second, to carry out experiments to fill the main gaps.

Experimental Facilities capable of carrying out these experiments are located at LANL and SATURNE in France.

A search of available nuclear models which could be used to complement experimental data would also be useful.

A lot of work is in progress by many facilities. E. Menapace agreed to co-ordinate efforts within Subgroups 12+13 of WPEC.

Other data of interest include isotope production data, total and elastic cross sections, and thick target yields and angular distributions for the particles and energies listed above.

The NEADB has collected some data in a data base. Experts from Japan, LANL and Fasso` have also some data available.

In some cases, new experimental data are required to resolve conflicts between different experiments, or to confirm data which are in apparent conflict with the most widely used models. As an example there are inconsistencies in the available data for pion absorption cross-sections in the resonance region, and trends such as pi-charge exchange versus A should be confirmed by further experiments.

Concerning electron accelerators, there is a lack of knowledge about forward brems-strahlung yields from thick targets at energies higher than 100 MeV.

Work being carried out at SLAC.

The existing compilations of photonuclear cross sections (Dietrich and Berman) are useful but insufficient: They cover only a limited number of nuclei and some of the most common ones (e.g., iron) are missing. In addition, only the giant resonance energy range is considered, and only photoneutron production is reported. There is a need for total photonuclear cross-sections, photo-neutron yields from thin and thick targets, photoneutron angular distributions for all most common elements at all energies.

A. Fasso` has collected some data.

In the highest energy range (E > 200 MeV), photopion yields and angular distributions are necessary. More generally, there is a lack of available data for double differential cross sections of pion emission in nuclear interactions by any kind of projectile (proton, neutron, pion, photon) at energies larger than 300 MeV.

Other data needs concern albedo of neutrons with energies higher than 20 MeV (useful for streaming calculations),

Isotope production data (possibly for thin targets), and (n, gamma) cross sections above 20 MeV.

The lack of (n, gamma) data for barium isotopes below 20 MeV was also mentioned.

Work in progress at ENEA Bologna (G. Maino, G.C. Panini).
Updates will be provided at SATIF-3.

4.2 Shielding experiments

Forward and lateral attenuation should be measured up to at least 5 or 6 m of concrete for proton and ion accelerators with energies lower than 5 GeV. There is a particular need for data in the 100-800 MeV/m energy range. The dependence on energy of attenuation length and apparent source term should be established with better accuracy than at present. It was stressed that the results should be expressed also in terms of fluence or other basic physical quantity in order to allow a re-evaluation of the data in case new dose conversion coefficients should apply. At electron accelerators, forward and lateral attenuation curves should be measured in order to check the semi-empirical formulae in general use. This information is needed for both thin and thick targets, and should include thin shielding layers.

4.3 Other experimental information

There is a need for better measurements of many activation detector excitation functions, in particular 11 -C production by neutrons and pions in the energy range above 100 MeV.

Work being carried out at CYRIC (T. Nakamura).

Determining the response function above 20 MeV of other detectors (instruments based on moderation, scintillators) with mono-chromatic neutron beams would also be useful. A measurement of target heating with targets of low atomic number was suggested in order to resolve existing conflicting calculated data.

LINUS at INFN Milan and Frascati. Similar REMmeter by S. Ban.

4.4 Improvements in modelling and computer codes

Light and heavy ions are not treated by existing Monte Carlo transport codes, or are with an accuracy not yet comparable with that of reactions induced by protons and neutrons. Models are needed to implement satisfactory event generators.

The intranuclear cascade model for hadron interactions in the intermediate energy range has been used successfully for over 20 years. However some deficiencies are well known, in particular, the backward particle emission and the emission at very small angles is not satisfactory. Improvements based on modern physical concepts which have already shown promising results in some recent code developments can help solving most known problems.

Work in progress.

Also fragmentation models are necessary to improve residual nuclei predictions.

A special issue was raised about the quality control of computer programs. It was suggested that a theoretical analysis be made about models and experimental data, aiming at identifying common features and differences among various codes, so that the cause of discrepancies in the results could be traced.

5. Recommendations and agreed actions

This section compares the recommendations made at SATIF-1 and describes the achievements reported at SATIF-2. (In parenthesis the names of the persons or organisations involved in specific work are given).

Action	*Achievements/Further Action*
1. Collect and make available anthropo morphic phantom geometries including material compositions as used in Monte Carlo radiation transport codes (RSIC, NEADB, PTB, GSF);	Work in progress as reported in "Anthropomorphic Computational Models" (Sartori, NEA). Put on World Wide Web before the next meeting (L. Waters, LANL). Differences in models will be stated.
2. Collect and make available existing data on:	
– Thin target measurements (p, n, pi, HI) (A. Ferrari, L. Waters, E. Sartori);	Some data has been collected (A. Ferrari) Provide data to E. Sartori (NEADB) for open distribution by SATIF-3. (A. Fasso`, A. Ferrari).
– Thick target measurements (T. Nakamura);	Neutron targets work is in progress (K. Hayashi). Send data to T. Nakamura who will send it later to NEA (G. Stevenson, A. Ferrari). They will be included in the SINBAD.
– Deep penetration measurements (T. Nakamura);	• Collection started (T. Nakamura); • KEK reported on this; • Data will be available at SATIF-3; • Experiments at ISIS in progress. L. Waters and G. Stevenson will send data to T. Nakamura which will be sent later to E. Sartori for inclusion into the Shielding Experiment Data Base SINBAD; (RSIC, NEADB)

– Photonuclear data (A. Fasso`, W.R. Nelson, R.W. Roussin, Y. Kikuchi);	For E < 140 MeV data is provided by Japanese Nuclear Data Center (JAERI) File will be released in 1996. Available data should be summarised at SATIF-3 by information centres.

The following has been added to the wishlist at SATIF-2:
New experiments should be carried out to get giant resonance photonuclear cross section in the GDR range, as existing data is scarce.

3. Contact ICRP and ICRU about dosimetry issues (R. Thomas);	A report on this is needed for SATIF-3. (N. Ipe, R. Thomas).
4. Agree on definitions of attenuation length and source term parameters (aH, H0) (H. Dinter, G. Stevenson, T. Nakamura);	A subgroup should be formed to discuss this: (H. Hirayama, Chair, A. Ferrari, L. Waters, T. Gabriel, K.Tesch, N. Mokhov, G. Stevenson). • Attenuation length in iron + concrete was calculated using the HILO86 library and PIC-N codes. Neutron buildup factors were studied by Y. Sakamoto and K. Shin; • Calculations for protons (100-400 MeV) from 0-180 degrees done by P. Tabarelli.
5. Establish regular exchanges of relevant publications among participants;	Participants from Japan have sent out publications. Other groups are encouraged to do so too.
6. Set up an electronic network listserver for exchange of communications. (W. R. Nelson, R. Donahue);	Done by R. Donahue at SLAC. Circulate list of subscribers with their e-mail addresses.

Other actions were agreed upon that require larger efforts and coordination:

7. Courses on intermediate energy transport codes to ensure correct understanding of their models and their correct use;

8. Experiments-measurements:

   a) at LANL, U.S.A.:

   – pi+ and pi- projectiles
   double differential pion cross-sections in the exit channel double differential proton/neutron cross sections in the exit channel;

- Tutorial on FLUKA at ANS, April'96.
- EGS4 Course in Montpellier, June'96.
- For tutorial on LAHET contact L. Waters.
- For scheduling sign up on RSIC or NEADB.

A thesis is being prepared on this.

– proton/neutron projectiles double differential proton cross sections in the exit channel high resolution measurements in the forward direction double differential pion production;	Proposal has been submitted. C(n.2n) data measured at LANL needs to be analysed. An update should be provided at SATIF-3.
b) at TIARA and other facilities in Japan:	
– excitation functions of activation detectors (C-11, Bi);	Carried out by T. Nakamura. Work in progress. An update will be provided at SATIF-3
– monoenergetic calibration of active instruments;	Carried out by S. Ban for REMmeter. Collaboration L. Waters, S. Ban, G. Stevenson, M. Pelliccioni. Update will be provided by S. Ban at SATIF-3
c) follow-up meeting in 18 months to monitor progress on the different actions, to discuss and exchange ideas in code development and validation, decide further actions to speed-up progress.	2nd meeting held at CERN in conjunction with SARE-2. SATIF-3 and SARE-3 scheduled for May 1997 in Japan. Further meetings possibly in conjunction with ANS Topical, Nashville'98.

Further, the following recommendations were retained from the SATIF-1:

All the data mentioned do not need to be available for all nuclei but should span the whole range of atomic masses in order to allow complete benchmarking of nuclear reaction models

All details of the shielding layout should be reported especially concerning density and composition of the materials. The adopted definition of attenuation length should always be stated clearly.

Evaluated data versus nuclear models

This issue was debated at length and transport code developers, who essentially would be the clients of an evaluated data library encompassing the full energy range, came to the following conclusions:

- Rather coarse evaluated data sets would demand about 4 megabytes of computer storage per nuclide and in view of the many nuclides involved in realistic cases such a library would make large demands on computer resources.
- Evaluated data libraries are updated rather infrequently and therefore improved modelling and data will reach the user only very late

- New experimental data can be used for improving the nuclear model performance included in the code and thus the improved data are immediately available for the transport calculation. All codes contain now pre-equilibrium models.

- The upper energy limit for data evaluations in the intermediate energy range is still debated. Some say that they feel comfortable only with libraries up to 100 MeV. HILO-86 goes up to 400 MeV not without problems. All agree that beyond 350 MeV evaluated data libraries are not useful.

Recommendations to NEA/NSC Working Party on International Evaluation Co-operation – WPEC – Subgroup 13 on Intermediate Energy Data

Being a major concern of the SATIF experts' group that of shielding, particular emphasis is placed on shielding experiments and modelling codes for radiation/particle transport and their benchmarking.

As the transport codes generate cross-sections through nuclear models in the higher energy part of the particle spectrum, a specific need exists to verify the cross-section generation modules of such systems against basic data as measured from "thin target" experiments.

A score of such measurements have been carried out over the years and many have been compiled into the EXFOR data base. Several, newer experiments have been compiled recently and the experts' group has expressed their high interest in this activity and recommends that it is continued.

The specialists' encourage Subgroup 13 to continue their work in improving data and to ensure that experimental data for thin and thick targets continue to be included into the international EXFOR data base.

Benchmark session at the SATIF-3 meeting

A specific session on the benchmark experiment analysis should be organised in which results relative to several selected shielding experiments calculated with various computer codes and cross section data sets should be compared. The objective is to identify problems and clarify limitations in computer codes, cross section data and experimental data by analysing the same experiments at different organisations.

Future meetings, their scope and objectives, recommendation to NEANSC

The objectives of both SARE and SATIF were reviewed and are described in the following:

- SARE:
  - Presentation of developments, new work and experience in simulating radiation environments,
  - Exchange of information.

- SATIF:

  - Identification of needs and carrying out experiments to improve the knowledge of thin and thick target neutron yields, neutron penetration, streaming, skyshine etc.;
  - Proposals, discussion and execution of shielding experiments in support of improved shield modelling;
  - Exchange of information on the present status of computer codes and nuclear data files in use;
  - Selection of shielding benchmark experiments and international collaboration of benchmark calculations;
  - High energy dosimetry aspects including anthropomorphic computing models;
  - Draw conclusions about work carried out and report to NEA NSC.

It is recommended that the specialists' meetings of SATIF be transformed into regular meetings under the responsibility of a specific Task Force on Shielding Aspects of Accelerators, Targets and Irradiation Facilities [1].

Organisers and participants have proposed that future meetings be held about every 18 months and each time in a different geographical area with the aim of arranging through this rotation larger participation of hosting country's scientists in connection with visits to National Accelerator Facilities. This approach has proven so far to be effective and to allow improved international contacts.

One of the recommendations issued at the last meeting is to hold the next meeting in Japan in 1997, after having held the first two in USA and Europe respectively.

The suggestions for the next meetings are as follows:

- SARE-3 at KEK, Tsukuba from 7-9 May 1997;
- SATIF-3 at CYRIC, Tohoku University from 12-13 May 1997.

The organising committee would be set up by the the Shielding Working Group of the Reactor Physics Committee of Japan.

A preliminary membership for the scientific committee has been proposed from:

- Europe: F. Clapier (CNRS), A. Ferrari (INFN),
- Japan: T. Nakamura (U-Tohoku), H. Hirayama (KEK),
- U.S.A.: A. Fasso` (SLAC), T. Gabriel (ORNL), N. Mokhov (Fermilab), R. Roussin (RSIC), L. Waters (LANL),
- International organisations: G. Stevenson (CERN), E. Sartori (NEA)

[1] The NEA Nuclear Science Committee has approved the setting-up of such a Task Force at its 7th meeting held on 29-30 May 1996.

NUCLEAR SCIENCE COMMITTEE

Proceedings of the Third Specialists Meeting on

SHIELDING ASPECTS OF ACCELERATORS, TARGETS AND IRRADIATION FACILITIES

Tohoku University
Sendai, Japan
12-13 May 1997

jointly organised by

OECD/NEA
Shielding Working Group of the Reactor Physics Committee of Japan
Radiation Safety Information Computational Centre
Tohoku University

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

EXECUTIVE SUMMARY

The main objectives of the SATIF meetings are:

- to promote the exchange of information among scientists in this particular field;
- to identify areas where international co-operation can be fruitful;
- to carry on a programme of work in order to achieve progress in specific priority areas.

The first SATIF meeting (SATIF-1) took place on 29-30 April 1994 in Arlington, Texas (USA), and the second meeting (SATIF-2) was held from 12-13 October 1995 at CERN (European Laboratory for Particles Physics) in Geneva, Switzerland.

In the meantime, the seventh meeting of the NEA Nuclear Science Committee, held on 29-30 May 1996, approved the setting up of a specific Task Force on Shielding Aspects of Accelerators, Targets and Irradiation Facilities. As a consequence, the SATIF specialists meetings became regular meetings of this Task Force.

The third Specialists Meeting on Shielding Aspects of Accelerators Targets and Irradiation Facilities (SATIF-3) took place from 12-13 May 1997 in Sendai, Japan. It was jointly organised by:

- the OECD Nuclear Energy Agency;
- the Shielding Working Group of the Reactor Physics Committee of Japan;
- the Radiation Safety Information Computational Center of the USA;
- Tohoku University.

About fifty specialists attended the meeting, including physicists, engineers and technicians from laboratories, institutes, universities and industries in France (IN2P3), Germany (DESY, KFA Jülich, University of Munich), Italy (INFN, ENEA, LNGS), Sweden (University of Uppsala), Japan (JAERI, KEK, RIKEN, INS, Universities of Tokyo and Kyoto, Mitsubishi, Hitachi), USA (ANL, CEBAF, Fermilab, LANL, RSICC and SLAC) and the Russian Federation (IHEP) as well as representatives from international organisations (OECD/NEA and CERN).

The meeting was organised in six sessions on the following topics:

- **Session 1** – Source Term and Related Data – Electron Accelerator
  - ***Subsession 1-1*** Gas Bremsstrahlung and Narrow Beam Dosimetry
  - ***Subsession 1-2*** Photoneutron and Photopion – DDX and Spectrum

- **Session 2** – Source Term and Related Data – Proton and Ion Accelerator
  - ***Subsession 2-1*** Thin Target Yield Measurements and Compilation
  - ***Subsession 2-2*** Thick Target Yield Measurements and Compilation
  - ***Subsession 2-3*** Spallation Neutron Source Facility
- **Session 3** – Shielding
  - ***Subsession 3-1*** Shielding Benchmark Problem – Review of Analysis
  - ***Subsession 3-2*** Attenuation Length – Definition and Intercomparison
  - ***Subsession 3-3*** Shielding Experiments and Compilation
- **Session 4** – Miscellaneous Topics
  - ***Subsession 4-1*** Neutron Facility for Shielding Experiments and Detector Calibration
  - ***Subsession 4-2*** Dosimetry and Instrumentation
  - ***Subsession 4-3*** Activation
  - ***Subsession 4-4*** Dose Conversion Coefficients and Anthropomorphic Phantom
- **Session 5** – Present Status of Computer Codes and Cross Section and Shielding Data Libraries
  - ***Subsession 5-1*** Current Status of Computer Codes and Data Sets for Accelerator Shielding Analysis
  - ***Subsession 5-2*** A Standard for Shielding Calculations
- **Session 6** – Discussions and Future Actions

About 24 papers were presented at the meeting. An extensive discussion took place during Session 6, with the following objectives:

- to review the progress achieved since the SATIF-2 meeting held on 12-13 October 1995 at CERN;
- to monitor the status of the agreed actions (on experiments, basic data, codes and methods) undertaken since then;
- to identify and initiate new co-operative actions;
- to improve common understanding of problems that have technical and safety significance.

It was generally recognised that substantial developments took place during this period and that significant progress has been achieved. However, in order to achieve further progress participants felt that substantial efforts should be developed and actions undertaken in several areas, including:

- basic data (new measurements, compilation of existing neutron, proton, light ion and pion cross-section data in the intermediate energy range above a few dozens of MeV, forward bremsstrahlung yields from thick targets at energies above 100 MeV, photoproduction data namely photonuclear cross-sections and photonuclear yields and angular distributions for all common elements at all energies, photopion yields and angular distributions at energies above 200 MeV, isotope production data, etc.).

- nuclear models and computer codes in the intermediate energy range (code validation, intercomparison of codes, comparison between experimental data and predictions from existing computer codes implementing nuclear models);

- shielding experiments (measurements of forward and lateral attenuation of iron and concrete for proton and ion accelerators up to a few tens of GeV and as deep as possible i.e. at least 5-6 meters, measurement of forward and lateral attenuation at electron accelerators);

- new or better measurements of many activation detector excitation functions (in particular C-11 production by neutrons and pions in the energy range above 100 MeV and Bi production);

- benchmark data (development of new benchmark exercises, further compilation of existing benchmark data sets, etc.);

- anthropomorphic computational models (compilation of existing models, phantom geometries and material compositions, dosimetric studies, etc.).

In the next section, a detailed list of the actions decided at the SATIF-3 Meeting is provided. Taking each of the presentations at SATIF-3, actions to be undertaken or continued and which concern the corresponding subject and/or related topics are listed as specific items; the names of those designated at the SATIF-3 Meeting to perform the monitoring and follow up of the work are indicated. The listed actions reflect and incorporate the assessment, made by the SATIF-3 participants, of the status of the actions undertaken since the SATIF-2 Meeting.

As can be seen in the relevant items, two important topics proposed by Japan which will be followed-up at the SATIF-4 Meeting concern shielding benchmark calculations and attenuation length calculations.

These areas will greatly benefit from the definition of new experiments and by undertaking new international intercomparison exercises.

The high quality of the SATIF-3 Meeting and its excellent organisation would not have been possible without the work of the Local Organising Committee and its Chairman Prof. T. Nakamura, and the continuous help of Dr. N. Yoshizawa.

Acknowledgements are also due to the members of the Scientific Committee of SATIF-3 (F. Clapier, A. Fassò, A. Ferrari, T. Gabriel, H. Hirayama, N. Ipe, B. Kirk, N. Mokhov, T. Nakamura, E. Sartori and L. Waters) for their contribution in shaping the technical programme.

New or continued actions decided at SATIF-3

Gas bremsstrahlung and narrow beam dosimetry

- **Narrow beam dosimetry – Organ and effective doses estimated between 1 MeV and 1 GeV** (*M. Pelliccioni*)
  - include more organs in the computations;
  - include more energies in the calculations;
  - extend energy range of the computations;
  - determine how adequately average doses over organs describe narrow beam effects;
  - co-ordinate effort to push official bodies (e.g. ICRP) to include narrow beams issues;
  - define a new quantity and agree on how to score it.
- **Gas bremsstrahlung measurements performed at APS** (*P.K. Job*)
  - compare with calculation.

Photoneutron and photopion data

- **Nuclear data evaluation for the JENDL Photonuclear Data File** (*T. Fukahori*)
  - make data available;
  - address question of how to handle targets for which data are not available.
- **Need for experimental data to build confidence in predicting spectra and angular distributions** (*N. Ipe, A. Fassò, S. Ban and P. Degtyarenko are involved in the different aspects*):
  - SLAC/KEK collaboration has finalised a proposal;
  - CEBAF is building detectors.
- **Giant dipole resonance photonuclear cross-sections** (*A. Fassò*)
  - check energy regions near threshold;
  - redo calculations with new version of PEANUT/FLUKA;
  - complete data with parametrisation for missing nuclei;
  - extend to heavier nuclei – **requesting support from NEA**.

- **PICA95 code** (*C.Y. Fu*)
  - make code available;
  - make gamma and pion cross-section data available;
  - comparison PICA95 and CEM95;
  - photopion yields and angular distributions are needed for E>200 MeV;
  - more generally, there is a lack of available data for double differential cross-sections of pion emission.

Thin target (measurements and compilations)

- **EXFOR database** (*P. Vaz*)
  - make access to data more user-friendly;
  - include database from LBL.

Thick target (measurements, compilations and needs)

- **Thick target yield measurements at TIARA, KEK, HIMAC** (*K. Shin*)
  (*Several measurements have been carried out*)
  - benchmark new version of QMD Model with measured data;
  - continue experiments at HIMAC;
  - need data for Deuterons and He-3.
- **Spallation sources** (*D. Filges, L. Charlton, H. Ikeda*)
  - data urgently needed for materials damage, gas production (H, He) for structural materials and lifetime limitations;
  - verification of cross-sections and nuclear models used for mercury;
  - residual nuclei distributions for residual radioactivity, afterheat and transmutation atom generation in target and structure materials, including recoiling nuclei in radiation damage;
  - verification of calculated integral and differential neutron flux density and secondary particle distribution from an engineered target-moderator-reflector system;
  - planned experiments – material irradiation at SINQ, LAMPF, Jülich;

- multiplicity, energy deposition, charged particle production on thin and thick targets at Cosy-Jülich;

- mercury target neutron performance and stress investigations at the AGS (BNL).

Data needed for RAD damage by photons (magnets)

Shielding (experiments, facilities, benchmarks and intercomparisons)

- **Shielding benchmark – Neutron transmission for iron and concrete for low, intermediate and high energy proton machines** (*Y. Nakane and K. Hayashi*)

  - Perform new benchmark experiments:

    1) 43 MeV and 68 MeV through iron and concrete shields (TIARA, JAERI);

    2) 230 MeV protons through concrete shields (Loma Linda);

    3) 500 MeV protons through iron beam stop and concrete shields (KEK);

    4) 1.5 -24 GeV protons through concrete shields (AGS, BNL);

    5) 12 GeV protons through concrete shields (PS-CERN, KEK);

    6) 24 GeV protons through iron beam dump (PS-CERN).

The following questions need further discussion:

- Add FLUKA results to Problem 1 in summary?

- Add 200 MeV benchmark problem?

- Add E>400 MeV results to intercomparisons to find asymptotic value of lambda(E)?

- Study total and low energy neutron dose equivalent/attenuation in iron separately?

- Study lambda_D (E) for incident protons?

- Add results of analytical (especially asymptotic) considerations to the intercomparisons?

Collaboration between code users and code developers is recommended before results are released.

- **Attenuation lengths** (*H. Hirayama*)

  - comparisons between codes;

  - comparison of iron cross-sections;

  - detailed comparison of neutron spectrum;

– comparison at higher energies;

– comparison for neutrons produced y high energy protons.

Need definition of attenuation length.

- **Shielding experiments at TIARA and ISIS – Dose equivalent rates behind concrete for target irradiated by 0.05-10 GeV proton beams** (*Y. Sakamoto*)

  – need deeper bulk shielding experiments at intermediate and high energy (neutrons) to verify shielding codes for accelerator facility design.

Plans exist to perform experiments at E>1GeV at KEK and AGS, BNL.

- **Neutron facility for shielding experiment and detector calibration** (*T. Nakamura*)

  – calibration and response measurements of various neutron detectors;

  – neutron scattering cross-section measurements;

  – charged particle production cross-section measurements;

  – neutron spectral and dose distribution in several media;

  – thin and thick target neutron yields by heavy ions.

- **CERN-CEC high energy reference field facility** (*M. Silari*)

  – beam time available in 1998-1999 – participants encouraged to make use of this opportunity;

  – shielding configuration of radiation dump.

Miscellaneous

- **Response functions of Bonner spectrometer in high energy neutron fields** (*V. Mares*)

  – perform simulations with MCNPX (LAHET-MCNP code merger) as soon as it will be released;

  – add another high energy channel.

- **Energy response of tissue equivalent proportional counter for neutrons of E>20 MeV** (*E. Gelfand*)

  – make instrument response functions and instrument design details available.

- **Test of activation detectors as neutron spectrometer (6-140 MeV)** (*F. Clapier*)

  – continue experimental work.

- **Computer version of Handbook on Radionuclide Production Cross-Section at Intermediate Energies** (*N. Sobolevski*)

  – make computer version available (limited subset).

Conversion coefficients

- **Conversion coefficients for high energy radiation** (*M. Pelliccioni*)

  – include photonuclear reactions;

  – provide results for pion calculations;

  – liaison ICRP-ICRU;

  – propose new operational quantity since ambient dose equivalent is not appropriate for high energies;

- **Conversion coefficients for high energy particles** (*S. Iwai*)

  – compile report including conversion coefficients for various anthropomorphic computational models and radiation types at high energies;

  – appoint working group (*L. Waters, S. Iwai, M. Pelliccioni, V. Mares*) which will submit a proposal to ICRP.

Computer codes and data sets for shielding analysis

- **Current status of computer codes and data sets for accelerator shielding analysis** (*B. Kirk, E. Sartori, P. Vaz*)

  – NEA/RSICC take a proactive role in exchanging information on new codes, etc., with SATIF participants;

  – continue work at RSICC and NEA/DB on the SINBAD database to include additional shielding benchmark experimental data sets;

  Participants to inform NEA/RSICC on availability of codes and data.

Anthropomorphic data

- **Collection of anthropomorphic data for dosimetry studies** (*E. Sartori, V. Mares*)

  – co-operate with R. Loesch, developer of the database being implemented at DOE;

  – get information on the code MRIPP.

- **GSF anthropomorphic computational models** (*V. Mares*)
  - make anthropomorphic computational models (often erroneously called “phantoms”) available.

Mares will contact authors.

Looking into the future...

The technological applications of accelerators, targets and irradiation facilities cover a wide range of domains, from basic research to accelerator based transmutation, material science or medicine.

The analysis and solution of shielding problems related to the development and operation of accelerators, targets and irradiation facilities involves the understanding of the physics of the interactions of different particles (neutrons, protons, electrons, photons, pions, light and heavy ions) in an energy range spanning over several orders of magnitude.

The community of participants in the SATIF meetings includes physicists, engineers and technicians coming from different fields of science and technology. Given the increasing number of facilities in operation, under construction, being commissioned or being planned, their diversity (proton accelerators, electron accelerators, spallation sources, radioactive nuclear beams, etc.) and the increasing complexity of the associated shielding problems, this community feels that an effective follow-through process will be necessary in order to make sure substantial progress is achieved, ensuring that a sound technical basis is established for proper licensing and operation of these facilities.

In this context, it was requested that the NEA strengthen its role of co-ordinating the collection and dissemination of experimental or evaluated data, computer programs, benchmark data sets and exercises. It was felt that an effective follow-up of the recommendations performed and actions undertaken in the different areas and fields concerned, could only benefit from the NEA role of providing secretariat and organisational support and assistance to the members of the Task Force and to their activities. In this framework, a specific follow-through process co-ordinated by the NEA has been established to regularly monitor the progress achieved and to collect and make available newly released relevant information (data sets , computer codes, etc.).

Finally, it was decided to hold the next SATIF meeting (SATIF-4) at Knoxville, Tennessee, USA, on 17-18 September 1998, before the ANS Topical Meeting on Accelerator Applications (AccApp ‘98) which will take place in Gatlinburg, Tennessee, USA, from 20-23 September 1998, and to assign the local organisation responsibility to the Oak Ridge National Laboratory (ORNL).

OECD DOCUMENTS

Proceedings of the Specialists' Meeting on

Shielding Aspects of Accelerators, Targets and Irradiation Facilities

Arlington, Texas (USA)
28-29 April 1994

organised by the
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Reactor Physics Committee (Japan)
Radiation Shielding Information Center (USA)

PUBLISHER'S NOTE

The following texts have been left in their original form to permit faster distribution at lower cost.
The views expressed are those of the authors.

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

SUMMARY and CONCLUSIONS OF THE SPECIALISTS' MEETING

1. Executive Summary
2. Introduction
3. Technical Summary of Presentations and Discussions
4. Data Needs and Suggestions Expressed by the Participants
5. Recommendations and Agreed Actions

1. Executive Summary

A Specialists' Meeting on **The Shielding Aspects of Accelerators, Targets, and Irradiation Facilities** was held in Arlington, Texas, 28-29 April, 1994. The meeting was jointly organized by the OECD/NEA, The Reactor Physics Committee of Japan and the Radiation Shielding Information Center, USA. Forty-five participants from seven countries and two international organizations attended.

About two-thirds of the time available was taken up with the presentation of invited review papers and presentations on recent developments covering a wide field of technical areas including transport code development, basic nuclear data, experimental shielding data, operational experience at particle accelerators etc.

The final session of the meeting was devoted to a discussion led by Drs. Ipe and Fasso` on the needs of the accelerator shielding community including the establishment of a newsletter to improve communication in the accelerator shielding community; exploration of the possibility of making needed cross-section measurements; addition of physical data and code information to the libraries of RSIC and the NEA Data Bank; training in the use of major radiation transport code systems; promotion of a second meeting on Simulating Accelerator Radiation Environment (SARE) with invitation extended to specialists interested in accelerators with energy below 1 GeV and finally, a request for a second specialists' meeting in 1995.

2. Introduction

Since Cockcroft and Walton's success in 1932, particle accelerators have extended steadily their application from the nuclear and high energy particle physics to other fields such as medicine and industry. During sixty years, higher and higher energy accelerators have been developed, creating the opportunities for new areas of scientific and technological applications.

In the history of nuclear energy, during half a century after the success of controlled nuclear chain reaction at the University of Chicago, accelerators have played a very important role in the steady advancement of science and technology. With the remarkable technological progress achieved recently, accelerators are expected to facilitate the basic research around nuclear energy and to push its development towards a key energy source in the next century. In this context, new accelerators and irradiation facilities are being designed and constructed in Member countries of OECD/NEA; examples are high intensity spallation sources, cold neutron moderator facilities, high neutron flux fusion material testing facilities, free electron laser facilities for uranium enrichment, synchrotron radiation sources, and high energy heavy ion facilities for material and biological research.

In viewing the present and future needs, it is expected that accelerators will be built of a greater variety, not only as far as their energy is concerned but also in their intensity, size and application; new, difficult and interesting shielding aspects do arise from this. The shielding aspects can be classified mainly according to accelerated particles and their energy. For example, proton accelerators can be divided as follows:

1. High energy accelerators: over several GeV, used mainly for nuclear and particle physics;

2. Medium energy accelerators: from about 100 MeV to several GeV;

3. Low energy accelerators: less than 100 MeV.

The accelerators belonging to item 1, such as SSC and LHC, which are used mainly for particle physics, bring about new and difficult issues with increasing accelerated energy, the solution of which may be rather an art than a science, although recent progress of computer technology makes the use of Monte Carlo codes simulating particle transport partly possible.

In the accelerators of item 2, sophisticated data and methods are required for shielding design to realize effective applications and also to save construction costs. This type of accelerator is expected to be applied extensively for nuclear energy and basic research requiring intense beam currents. The Japanese Hadron Project (JHP) in INS and Engineering Technology Accelerator (ETA) for the transmutation of radioactive nuclides in JAERI, the LANL Accelerator-Driven Transmutation Technologies (ADT2) including Accelerator Transmutation of Wastes (ATW), Accelerator Production of Tritium (APT) and Accelerator Based Conversion (plutonium burning), and European Spallation Source (ESS) for condensed matter research are based on proton accelerators ranging from 0.6 - 1.6 GeV in energy and 0.4 - 300 mA in the current. Such high current accelerators are a challenge not only in accelerator technology but also in radiation shielding technology. Some of these projects include provision for power generation as a by-product, thereby raising even further shielding questions. Also the updating of existing spallation sources poses new challenging shielding problems. The handling of radiation and radioactivity is a crucial issue in the design of accelerators. However, present data and methods are definitely insufficient for the requirements.

The accelerators categorized into item 3 have been most widely used for basic research, medical and industrial purposes; therefore, both accurate and simplified methods, in general, are needed for shielding design. Nevertheless, today's state of the art is still insufficient to meet present requirements, because of lack of nuclear reaction data and the shortage of nuclear reaction theory in this energy region. Especially, d-Li intense neutron sources for a fusion material irradiation testing facility (FMIF), which is discussed under the ITER project, demands special aspects for shielding design to be addressed because of the energy of about 40 MeV and the high current of a few hundreds mA.

As for electron and heavy ion accelerators, the classification based on shielding aspects can be different from that of proton accelerators. It needs to be stressed that also for these accelerators, crucial shielding aspects are neutron production reactions and neutron shielding.

History

The first steps that led to the organization of this meeting date back to the 7th International Conference on Radiation Shielding (ICRS7) held in Bournemouth, England, and jointly organized by AEA Winfrith and the OECD/NEA.

- In September 1988, during ICRS7, an informal meeting on accelerator shielding was organized by Dr. Alberto Fasso`, gathering more than 20 participants; from the discussions it emerged that there is a lack of nuclear data and model codes for accelerator shielding and all participants stressed that international co-operation on these issues is needed.

- In December 1991, the shielding committee of Japan proposed a new project on accelerator shielding at the NEA/Nuclear Science Committee meeting as a follow up to the meeting in Bournemouth. This proposal was accepted and it was agreed to hold a Specialists' Meeting. Dr. Shun-ichi Tanaka organized a working group to prepare a provisional program and to promote the meeting in the reactor physics committee of JAERI.

- In September 1992, Dr. Ralph Thomas was invited to co-operate with the organization of the meeting and to be the general chair.

- In November 1992, the program presented by JAERI at the NEA/NSC meeting was endorsed.

- In January 1993, independently, the first meeting on Simulating Accelerator Radiation Environment (SARE) was held in Santa Fe, New Mexico.

- In May 1993, concrete actions to organize the meeting were started.

- In April 1994, the meeting took place and gathered 45 specialists working in this field.

3. Technical summary of presentations and discussions

a. Electron accelerators

Photons

Narrow beams present special dosimetry problems because the detector size is larger than the beam size (e.g., gas bremsstrahlung); with such small beams it is difficult to carry out dosimetry measurements. *Gas bremsstrahlung* has to be considered in the shielding of synchrotron radiation facilities, and calculations agree with measurements if proper care is taken in the modelling.

Neutrons

For mid- and high-energy neutrons, the dependence of source term on electron energy, target properties and emission angles, and the dependence of attenuation length on electron energy, shield material and angle is not well known. Improved instruments are needed for measuring neutrons in mixed fields with high photon dose rates. In general, basic photoneutron data files are needed.

b. Proton accelerators

Various transport computer codes produce reasonable agreement but experimental verification at all shielding depths is needed for the intermediate energy region. Better methods for measuring high-energy dose equivalents are needed. Simple methods for dose equivalent calculations have been developed based on state of the art simulation (i.e. FLUKA, LAHET, etc), but the resulting attenuation lengths need to be checked for consistency against the ones determined in the 1960s.

c. All accelerators

It was recognized that criteria such as maximum credible accident, possible beam loss scenarios, credit for active protection systems, reasonable dose equivalent limits for accidents, etc, are issues that will need increased attention in the future.

d. Spallation target stations and medium energy accelerators

Neutron cross sections can be calculated using HETC for energies above 800 MeV by extending the DLC-119/HILO86 multigroup library above 400 MeV. Coupling Monte Carlo with one-dimensional discrete ordinates calculations works well as long as the coupling surface is far enough from the target so neutrons are the dominant particle. Coupling with two-dimensional discrete ordinates codes should be considered for studying streaming problems.

Intermediate energy heavy ions

Measured differential neutron and proton data are reproduced fairly well by Intranuclear Cascade Evaporation (INCE) codes (100-800 MeV), but the resulting attenuation length and the geometry under which they were determined need to be compared with those determined in the 1960s. The QMD code is an alternative still being developed. Systematic measurements, including neutron production cross sections, are needed for a range of ions. Theoretical models for neutron yields calculations need to be benchmarked.

Takasaki Ion Accelerators for Advanced Radiation Application (TIARA)

The quasi-monoenergetic neutron source facility in Japan has been developed for shielding experiments and cross section measurements (20-90 MeV) and Monte Carlo and discrete ordinates codes using HILO86 have been used to compare with measurements. Interest was expressed in exploring the possibility of the international community making proposals to JAERI for use of the neutron beam line.

e. Computer codes and data

Reports on the various major shielding code systems were made. It is felt that the NEA DB and RSIC can provide beneficial services to the accelerator shielding specialists by packaging and disseminating modern frozen versions of the transport and auxiliary codes and data libraries in common use. That is not the current situation. It is recommended that the Centers obtain the packages listed below or up-to-date versions of them (and any other that might be recommended).

Hadronic and electromagnetic cascades, low-energy neutron transport:

ANCAS (INR Moscow)
CALOR93 (ORNL)
EGS4 (SLAC)
FLUKA93 (INFN/CERN)
FLUNEV (DESY)
GEANT (CERN), GCALOR (CERN/ORNL)
HERMES (KFA)
HETC-3STEP (KYUSHU)
LAHET Code System (LANL)
MARS12 (FERMILAB)
SITA(DUBNA)
SHIELD(INR Moscow)

Intermediate Energy Nuclear Models:

ALICE92 (LLNL)
CEM92M (DUBNA)
FKK-GNASH (LANL)
KAPSIES (ECN)
MCEXITON (JAPAN)
NUCLEUS (JAERI)
QMD (ITP-Frankfurt)
STAC-8 (JAERI)

Miscellaneous:

ASTAR,PSTAR,ESTAR (NIST) - stopping power for alpha, proton, electron
CASL (KFA) -
CINDER90 (LANL) - isotope inventory calculation

Extensive work is being carried out in code development for relativistic heavy ion physics, however this aspect has not been covered by participants.

4. Data needs and suggestions expressed by the participants

a. Basic atomic and nuclear data

Shielding of modern high-intensity accelerators in the intermediate energy range (<5 GeV) requires double differential cross sections for neutrons, pions, light and heavy ions (at least up to A=18), for energies between 20 MeV and 5 GeV. At the present time these data are scarce and scattered among internal reports and journal articles.

Efforts should be made on two fronts: first, to compile existing data in a computer-readable form, and second, to carry out experiments to fill the main gaps. A search of available nuclear models which could be used to complement experimental data would also be useful. Other data of interest include isotope production data, total and elastic cross sections, and thick target yields and angular distributions for the particles and energies listed above.

In some cases, new experimental data are required to resolve conflicts between different experiments, or to confirm data which are in apparent conflict with the most widely used models. As an example there are inconsistencies in the available data for pion absorption cross sections in the resonance region, and trends such as pi- charge exchange versus A should be confirmed by further experiments. Concerning electron accelerators, there is a lack of knowledge about forward *bremsstrahlung* yields from thick targets at energies higher than 100 MeV. The existing compilations of photonuclear cross sections (Dietrich and Berman) are useful but insufficient: they cover only a limited number of nuclei and some of the most common ones (e.g., iron) are missing. In addition, only the giant resonance energy range is considered, and only photoneutron production is reported. There is a need for total photonuclear cross sections, photoneutron yields from thin and thick targets, photoneutron angular distributions for all most common elements at all energies. In the highest energy range (E>200 MeV), photopion yields and angular distributions are necessary [1]. More generally, there is a lack of available data for double differential cross sections of pion emission in nuclear interactions by any kind of projectile (proton, neutron, pion, photon) at energies larger than 300 MeV. Other data needs concern albedo of neutrons with energies higher than 20 MeV (useful for streaming calculations), isotope production data (possibly for thin targets), and (n, gamma) cross sections above 20 MeV. The lack of (n, gamma) data for barium isotopes below 20 MeV was also mentioned.

b. Shielding experiments

Forward and lateral attenuation should be measured up to at least 5 or 6 m of concrete for proton and ion accelerators with energies lower than 5 GeV. There is a particular need for data in the 100-800 MeV/m energy range. The dependence on energy of attenuation length and apparent source term should be established with better accuracy than at present. It was stressed that the results should be expressed also in terms of fluence or other basic physical quantity in order to allow a re-evaluation of the data in case new dose conversion coefficients should apply [2]. At electron accelerators, forward and lateral attenuation curves should be measured in order to check the semi-empirical formulae in general use. This information is needed for both thin and thick targets, and should include thin shielding layers.

c. Other experimental information

There is a need for better measurements of many activation detector excitation functions, in particular 11-C production by neutrons and pions in the energy range above 100 MeV. Determining the response function above 20 MeV of other detectors (instruments based on moderation, scintillators) with monochromatic neutron beams would also be useful. A measurement of target heating with targets of low atomic number was suggested in order to resolve existing conflicting calculated data.

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[1] All the data mentioned do not need to be available for all nuclei but should span the whole range of atomic masses in order to allow complete benchmarking of nuclear reaction models

[2] All details of the shielding layout should be reported especially concerning density and composition of the materials. The adopted definition of attenuation length should always be stated clearly.

d. Improvements in modeling and computer codes

Light and heavy ions are not treated by existing Monte Carlo transport codes, or are with an accuracy not yet comparable with that of reactions induced by protons and neutrons. Models are needed to implement satisfactory event generators. The intranuclear cascade model for hadron interactions in the intermediate energy range has been used successfully for over 20 years. However some deficiencies are well known, in particular, the backward particle emission and the emission at very small angles is not satisfactory. Improvements based on modern physical concepts which have already shown promising results in some recent code developments can help solving most known problems. Also fragmentation models are necessary to improve residual nuclei predictions.

Several participants expressed their wish for more friendly user interfaces, tools to set up and debug geometries, techniques for automatic biasing. All such suggestions were aiming at making the use of Monte Carlo codes more reliable and easier to operate by specialists with a limited experience. In this same spirit, a suggestion was made to provide guidance against common errors which could lead to gross mistakes in the calculated results.

In order to improve the basic physical data used by code developers, it was suggested that recent compilations be made available in computer-readable form such as those published by Cullen et al., (LLNL) on photon and electron interactions. Several participants indicated that there appears to be hardly any effort on code development for high energy codes when compared with low energy codes; participants have stressed that further code development is necessary to achieve better accuracy in shielding calculations. Finally, the importance of semi-empirical shielding codes was stressed. These are mainly based on the concepts of source term and attenuation length, and often allow a quick and conservative estimate of shield effectiveness. The existing ones should be extended and refined to cover wider ranges of energies and shielding thicknesses, and the development of new ones, especially for forward shielding, should be encouraged. A special issue was raised about the quality control of computer programs. It was suggested that a theoretical analysis be made about models and experimental data, aiming at identifying common features and differences among various codes, so that the cause of discrepancies in the results could be traced.

e. Other requests

Various other proposals were brought forward during the workshop. Anthropomorphic phantom geometries and composition should be standardized and made available to all. Drs Roussin and Sartori agreed to provide this information through RSIC and the NEA Data Bank.

The shielding community is concerned about some potential difficulties faced in applying the recent recommendations of ICRP Publication 60 to high energies and would encourage the ICRP and ICRU to remove present inconsistencies in quality factors and weighting factors. It was pointed out that the ambient dose equivalent as an operational quantity may not be always suitable in high-energy accelerator environments and a dose-quantity appropriate for shield calculation was recommended. Other questions which were debated were: which area is relevant for dose measurement (or for scoring in the case of Monte Carlo calculations) when the irradiation takes place in a narrow beam? which scenarios should be assumed for accidental beam losses?

Finally, a "blind" intercomparison of unfolding codes was proposed, similar to those which are being sponsored by EURADOS for low-energy neutron spectra.

5. Recommendations and agreed actions

The discussion led to the proposal of a number of concrete actions, which can be accomplished with a relatively small effort in the short term and which would have immediate beneficial impact on improving range and quality of data and modeling computer codes (persons or organisations having accepted to carry out the actions are given in parentheses).

- collect and make available anthropomorphic phantom geometries including material compositions as used in Monte Carlo radiation transport codes (RSIC, NEADB, PTB, GSF);

- collect and make available existing data on:

  * thin target measurements (p, n, pi, HI) (A. Ferrari, L. Waters, E. Sartori),
  * thick target measurements (T. Nakamura),
  * deep penetration measurements (T. Nakamura),
  * photonuclear data (A. Fasso`, W.R. Nelson, R.W. Roussin, Y. Kikuchi);

- Contact ICRP and ICRU about dosimetry issues (R. Thomas);

- agree on definitions of attenuation length and source term parameters (aH, H0) (H. Dinter, G. Stevenson, T. Nakamura);

- establish regular exchanges of relevant publications among participants;

- set up an electronic network listserver for exchange of communications (W. R. Nelson, R. Donahue);

Other actions were agreed upon that will require larger efforts and coordination:

- courses on intermediate energy transport codes to ensure correct understanding of their models and their correct use;

- experiments-measurements:

  1. at LANL, USA:

  * pi+ and pi- projectiles double differential pion cross sections in the exit channel double differential proton/neutron cross sections in the exit channel,

  * proton/neutron projectiles double differential proton cross sections in the exit channel high resolution measurements in the forward direction double differential pion production some of these data sets are already available, but a systematic study should be carried out to identify and then obtain those which are missing or incomplete,

  2. at TIARA and other facilities in Japan:

  * excitation functions of activation detectors (C-11, Bi),

  * monoenergetic calibration of active instruments;

- follow-up meeting in 18 months to monitor progress on the different actions, to discuss and exchange ideas in code development and validation, decide further actions to speed-up progress. (Tentative date and place, October 1995, in Nice, France, in connection with the SARE meeting).

Nucleur Science

Proceedings of the Fifth Meeting of the Task Force on

Shielding Aspects of Accelerators, Targets and Irradiation Facilities

Paris, France
18-21 July 2000

Jointly organised by

OECD Nuclear Energy Agency (NEA)
CNRS – Institut de physique nucléaire d'Orsay (IPNO/IN2P3)
Radiation Safety Information Computational Centre (RSICC)
Shielding Working Group of the Reactor Physics Committee of Japan

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

EXECUTIVE SUMMARY

Scope

The expert group deals with multiple aspects related to radiation safety, activation and shielding modelling and design of accelerator systems including electron, proton and ion accelerators, spallation sources and the following type of facilities: synchrotron radiation facilities, transmutation sources, accelerator-driven systems, free electron lasers, high power targets and dumps.

Objectives

The main objectives of the SATIF meetings are:

- To promote the exchange of information among scientists in this particular field.
- To identify areas in which international co-operation could be fruitful.
- To carry on a programme of work in order to achieve progress in specific priority areas.
- To encourage free access to computer codes sources and cross-section and integral experiments data, and making them available at information centres.

Background and past achievements

The first SATIF meeting (SATIF-1) took place in Arlington, Texas (USA) on 29-30 April 1994, the second meeting (SATIF-2) was held on 12-13 October 1995 at CERN (European Laboratory for Particles Physics) in Geneva, Switzerland, the third meeting took place on 12-13 May 1997 at Tohoku University (Sendai, Japan) and the fourth meeting was held in Knoxville, Tennessee (USA) on 17-18 September 1998.

As a consequence of the success of these conferences, the seventh meeting of the NEA Nuclear Science Committee, held on 29-30 May 1996, approved the establishment of a specific task force on shielding aspects of accelerators, targets and irradiation facilities. Consequently, the SATIF specialists meetings became regular meetings of this task force. Following the fourth meeting it was decided to organise SATIF meetings every two years.

It is generally recognised that the four SATIF meetings preceding SATIF-5 have fostered considerable and significant co-operative actions and efforts at the international level, in areas such as:

- *Basic data*: New measurements, compilation of existing neutron, proton, light ion and pion cross-section data in the intermediate energy range above a few dozens of MeV, forward bremsstrahlung yields from thick targets at energies above 100 MeV, photoproduction data (namely photonuclear cross-sections and photonuclear yields and angular distributions for all common elements at all energies), photo-pion yields and angular distributions at energies above 200 MeV, isotope production data, etc.

- *Nuclear models and computer codes in the intermediate energy range*: Code validation, intercomparison of codes, comparison between experimental data and predictions from existing computer codes implementing nuclear models.

- *Shielding experiments*: Measurements of forward and lateral attenuation of iron and concrete for proton and ion accelerators up to a few tens of GeV and as deep as possible, i.e. at least 5-6 meters, measurement of forward and lateral attenuation at electron accelerators.

- *Benchmark data*: Organisation of new benchmark exercises, compilation of existing benchmark data sets, etc.

- *Anthropomorphic computational models*: Compilation of existing models, phantom geometry and material compositions, evaluation of effective and organ doses.

- *Dose conversion coefficients for "high-energy" radiation*: Evaluation of fluence-to-effective dose conversion coefficients for high-energy radiation.

The last four SATIF meetings were held in conjunction with SARE (Simulating Accelerator Radiation Environment) meetings. The two meetings are complementary in their subject matter and the participants in both meetings are experts coming from different fields of science and technology. SATIF was originally designed as a forum of discussion and exchange of information in order to identify areas in which international co-operation is needed or needs to be strengthened. In the past, special attention has been paid to:

- The availability and compilation of experimental data for different applications.

- The organisation of international benchmark exercises.

- The availability of computer codes and data libraries for the use of the scientific community involved in various aspects related to accelerator shielding and applications.

- Identifying areas in which international co-operation can contribute to solve existing problems.

The presentations made at the successive SATIF meetings can generally be categorised according to the following topics:

- Data.

- Benchmarks.

- Computer codes and models.

- Facilities.

- Shielding techniques.

- Conversion coefficients.

- Code intercomparisons.

- Status of codes.

The fifth meeting – SATIF-5

The fifth meeting of the SATIF task force (SATIF-5) took place in Paris, France, at the OECD headquarters in the Château de la Muette, from 18-21 July 2000, and was jointly organised by:

- OECD Nuclear Energy Agency.

- Institut de Physique Nucléaire d'Orsay (IPNO).

- Radiation Safety Information Computational Centre (RSICC).

- Shielding Working Group of the Reactor Physics Committee of Japan.

Fifty-five specialists attended the meeting, among them physicists, engineers and technicians from laboratories, institutes, universities and industries in Belgium (Univ. Liège), France (CEA, GANIL, IN2P3), Germany (DESY, KFZ – Jülich, Hahn-Meitner Institute – Berlin, Univ. Hannover), Italy (INFN, ENEA), Japan (CYRIC, JAERI, KEK, RIKEN, Universities of Kyoto and Tohoku, Mitsubishi and Hitachi Corporations), USA (LANL, RSICC, SLAC, Georgia Institute of Technology), the Russian Federation (ITEP), Israel (Soreq Nuclear Data Centre), as well as representatives from international organisations (CERN, ESRF and OECD/NEA). The detailed list of participants is provided at the end of this publication.

The SATIF-5 meeting was preceded by the Workshop on Models and Codes for Spallation Neutron Sources, imbedded in the SARE-5 meeting, and organised on the same premises (please refer to Appendix 3 for a short summary of the workshop).

The SATIF-5 meeting was organised in seven sessions, each addressing different issues:

- *Session 1*: Proton and Ion Accelerators.

- *Session 2*: Electron Accelerators and Photon Sources.

- *Session 3*: High Intensity Medium Energy Accelerators.

- *Session 4*: Shielding Benchmark Calculations and Results.

- *Session 5*: Dosimetry and Dose Calculations.

- *Session 6*: Additional Topics.

- *Session 7*: Discussions and Future Actions.

A detailed agenda of the SATIF-5 meeting is provided in Appendix 1. Thirty-two papers were presented during the first six (topical) sessions. Highlights from the presentations performed and subjects discussed are as follows:

- Experimental data (reaction rates, residual product nuclei yield and neutron spectra) for 0.1-2.6 GeV protons impinging on different targets (Al, Mg, Na, Pb, W, Hg). This data is useful for future high-power proton accelerators. Status:
  - Data analysis still in progress.
  - Further measurements are planned.
  - Discrepancies between codes and measurements need to be reconciled.
  - Programme needs support.
- Neutron attenuation length and deep penetration experiments and benchmarks. Status:
  - Good progress has been accomplished.
  - Uncertainties on neutron attenuation lengths (for protons incident on concrete and iron) need to be resolved.
  - Need to understand differences in codes.
  - Extend neutron dose attenuation to tens of GeV to confirm asymptotic value.
- FLUKA calculations on hadron yields from high-energy electrons around thick targets and dose attenuation in concrete and resulting parameterisation is useful for electron accelerator shielding.
- Beam loss scenarios for storage rings should be realistic and include Monte Carlo simulations and beam optics.
- Experimental measurements of neutron production from deuterons (up to 200 MeV) incident on Be, C and U targets show some discrepancies with calculations.
- Determination of high fission yields for future RNB facilities.
- Calculations and data presented for activation of soil, ground water, air, targets and cooling water. Status:
  - These data are relevant for personnel radiation safety and environmental impact.
  - In general there is less activation data available for electron machines than proton machines.
- Calculations for radiation damage to electronic components is important for future high-power machines.

- Benchmarking neutron dosimetry in simple phantoms:

  - Results indicate large discrepancies between codes.

  - Code experts need to resolve these differences.

  - Need for experiments on N and C targets to help reconcile differences.

- Completed collection of experimental data of neutron spectra and yield from thin and thick target bombardment with heavy ions up to 800 MeV/nucleon. Status:

  - This data is useful for benchmarking of future Monte Carlo codes that will deal with heavy ion transport (space research application, medical application, etc.).

- Several papers on dosimetry confirm that H*(10) is not always the best estimator of effective dose for both broad and narrow beams:

  - Comparisons were made between experiments and Monte Carlo calculations.

- Improvements of low-energy photon transport (keV) in EGS4 were verified with measurements between 20-40 keV. Status:

  - This data is very useful for synchrotron radiation facilities.

- Assessment of induced activity in accelerator structures is important for decommissioning efforts.

- Specific examples of application of Monte Carlo techniques in complex problems such as Atlas background and n_TOF experiments.

- Non-accelerator applications. They included:

  - Tokamak shielding aspects.

  - Neutron fluxes of high flux reactor.

- Computer codes for accelerator shielding design and modelling. Status:

  - Several of the major experts on intranuclear reactions (INC, evaporation, fissions) attended the meeting; however, the absence of experts on internuclear transport calculations was strongly felt.

  - Graphical interfaces between FLUKA and Autocad for geometry plotting and particle tracking appear promising to FLUKA users.

  - Duct-III code would facilitate design of ducts and labyrinths and therefore should be made available.

  - Developments in codes should include:

    ⇒ Electron and photon transport (with polarisation) down to 0.1 keV (for light sources).

    ⇒ Reflectivity and refractivity of mirrors (for light sources).

⇒ Time dependence of radiation fields (for light sources).

⇒ Ion transport.

⇒ Residual nuclei decay mode for direct calculation of radiation exposure.

Discussion, proposals, conclusions

An extensive discussion took place during Session VII, with the following pre-established objectives:

- To review the progress achieved since the SATIF-4 meeting.
- To monitor the status of the agreed actions (on experiments, benchmark organisation, compilation of basic data, codes and methods) undertaken since then.
- To identify and initiate new co-operative actions.
- To improve common understanding of problems that have technical and safety significance.
- To review the current organisation of the SATIF meetings and to discuss the organisation of future meetings.
- To review the scope, objectives and deliverables of SATIF, in order to adjust them to the new needs expressed in the Member countries.
- To prepare and discuss a work programme for the next two years, which will be proposed for approval by the NSC together with the revised scope and objectives.

Follow-up of action items from SATIF-4

Progress was monitored on the following actions, decided at SATIF-4 (or earlier meetings):

- The BEEP benchmark (electron/photon transport benchmark, group chaired by A. Bielajew):
  - A paper reporting on low-energy photon results conducted at Japan in the framework of BEEP was presented at SATIF-5 by H. Hirayama.
  - A progress report by A. Bielajew is in preparation.
- Conversion coefficients, anthropomorphic computational models (group chaired by N. Yoshizawa):
  - Excellent progress has been obtained, four papers were presented during SATIF-5.
- Attenuation length (extension to other codes and to higher energies, group chaired by H. Hirayama):
  - Excellent progress has been achieved, three papers were presented during SATIF-5.

- Ground activation (work conducted at CERN):
  - A paper by H. Vincke was presented at SATIF-5 reporting on the results obtained so far.
- Deep penetration problems – different approaches (work by G. Stevenson and J. Bull).
  - No status report was presented.
- Compilation of photonuclear cross-sections (work by A Fassò):
  - No status report was presented.

Organisation of benchmark and intercomparison exercises

Results were presented on:

- The intercomparison of neutron transmission benchmark analysis for iron and concrete in TIARA and on the intercomparison of the medium-energy neutron attenuation in these materials.
- The Benchmark Calculation with a Simple Phantom for Neutron Dosimetry.

It was decided to continue the collaborative work already undertaken, namely on:

- Conversion coefficients, anthropomorphic computational models (N. Yoshizawa).
- Attenuation length (H. Hirayama).

New benchmarks were proposed, discussed and accepted, as follows:

- Deep penetration shielding benchmarks (proposed by T. Nakamura):
  - *ISIS experiment*
800 MeV – protons, 90°
Materials: Concrete, iron
Determination of λ values, neutron spectrum (Bonner ball, C- and Bi-activation)
  - *LANSCE/WNR experiment*
800 MeV – protons, 90°
Materials: Iron
Determination of λ values
  - *HIMAC experiment* (proceeding now)
400 MeV/nucleon – C on Cu target, 0°
Materials: Neutron spectrum (NE-213, self TOF, Bi-activation) in concrete (2 m), iron (1 m).
- CERN experiment (proposed by M. Silari):
  - High energy mixed proton/pion beam on thick Cu target, complex shielding structure, FLUKA predictions and neutron spectral measurements.

- Activation cross-sections of neutrons (proposed by T. Nakamura – follow up by E. Menapace and S. Rokni):
  - Collection of data.
  - Data library above threshold especially for light nuclei in air, water and soil. Check for:
    - ⇒ LANL (what data is available?).
    - ⇒ MENDL (place it into information centres).
    - ⇒ Measurement.
- Residual nuclei production cross-section and reaction rates for high-energy (0.04-2.6 GeV) protons (proposed by Yu. Titarenko, V. Batyaev, *et. al*.):
  - Experimental data from ITEP Moscow (Titarenko).
  - LANL calculations (Mashnik, Prael).
- Heavy ions (F. Clapier):
  - Neutron production from:
    - ⇒ Thick target (Data collection and compilation – HIMAC, Cecil, Heilbronn).
    - ⇒ Thin target (Cecil, RIKEN, HIMAC).

Follow-up of agreed actions

It was recognised that follow-up of agreed actions needs to become more effective. The follow-up should be made by the NEA Secretariat together with the co-ordinators assigned for specific activities or topics. In particular benchmarks should be distributed officially through the OECD/NEA to ensure an official status and strengthen participation. The setting up of specific listserver and web pages has been proposed as a tool to accomplish this.

Listserver and web pages

The following proposal for a listserver was submitted and accepted by the SATIF-5 participants:

- Address: satif@nea.fr.
- Members: all SATIF participants.
- Characteristics: Moderated (focussed, pertinent, of general interest to SATIF);web page with searchable archive of messages to be used to facilitate communication and follow-up actions

Further development of the web pages already existing has been discussed, in order to provide information on:

- Scope and objectives, deliverables.
- Membership and organisation.
- Next meeting and other relevant meetings.
- List of relevant publications or links to them.
- Summary records/actions.
- Downloading of benchmark specifications.
- Links to relevant web sites.
- Open questions/answers via notebook.

Computer codes and data libraries for shielding design and modelling

With regard to the state-of-the-art computer codes and data libraries available for use by scientists in the field of radiation shielding, an exhaustive and updated list of computer codes, data libraries and databases has been produced which is included in these proceedings. This compilation issued by RSICC in collaboration with the NEA Data Bank is a valuable reference for the community of users.

Among other actions decided upon at the discussion session were:

- To pursue the collection of experimental data sets available.
- To continue the activities on data compilations, giving particular emphasis to data availability for the user community.
- To further develop the activities on intercomparison exercises, between modelling methods (e.g. computer codes) available and experimental data.
- To encourage free access to computer codes sources and cross-section and integral experiments data, and making them available at information centres.

Future meetings of the SATIF task force

Concerning the organisation of future SATIF meetings, it was agreed by the majority of the SATIF participants that:

- Future SATIF meetings will typically last three days. They should contain, besides presentations of progress in work carried out at different research institution relevant to the scope of SATIF, specific sessions related to agreed collaborative work. During these it should be clarified, what has been achieved, what is in progress, what needs emerge for further work.

- A specific topical workshop addressing an issue of particular interest is organised in connection or embedded in SATIF meetings. The organisation of such topicals is under the responsibility of the Chair.

The next meeting (SATIF-6) is scheduled for September 2002 at SLAC, Stanford, CA, USA. The meeting will be held if possible in connection with the ANS RP&S Division Topical to be held in September 2002 in Santa Fe, NM, USA. A topical meeting embedded in SATIF-6, the topic of which is synchrotron radiation and free electron laser (FEL) light sources, has been proposed.

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Nuclear Science ISBN

Sixth Meeting of the Task Force on

Shielding Aspects of Accelerators, Targets and Irradiation Facilities

10-12 April 2002
Stanford Linear Accelerator Center (SLAC)
Menlo Park, CA, USA

Jointly organised by

Organisation of Economic Co-operation and Development
Stanford Linear Accelerator Center (SLAC)
Radiation Safety Information Computational Center (RSICC)
Shielding Working Group of the Reactor Physics Committee of Japan

NEA

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

EXECUTIVE SUMMARY

Scope

The Expert Group on Shielding of Accelerators, Targets and Irradiation Facilities (SATIF) deals with multiple aspects related to the modelling and design of accelerator shielding systems including electron accelerators, proton accelerators, ion accelerators, spallation sources and several different types of facilities, such as synchrotron radiation facilities, very-high-energy radiation facilities, accelerator production of tritium and free electron lasers.

Objectives

Objectives of the SATIF-6 meeting include:

- to promote the exchange of information among scientists in this particular field;
- to identify areas in which international co-operation could be fruitful;
- to carry on a programme of work in order to achieve progress in specific priority areas;

Deliverables

Deliverables emerging from this meeting include:

- assessment of needs in experimental data for the validation of models and codes;
- organisation of shielding experiments;
- collection and compilation of experimental data sets;
- assessment of models, computer codes, parametrisations and techniques available for accelerator shielding design purposes;
- validation of computer codes and models available to perform particle transport simulation;
- organisation of international benchmark and intercomparison exercises;
- organisation of workshops and co-organisation of conferences relevant in the area of its scope and computing radiation dosimetry (e.g. QUADOS);
- publication of workshop proceedings;
- editing of an "Accelerator Shielding Handbook";
- maintenance of SATIF listserver and archive of technical discussion between members.

SATIF-6 workshop

Introduction

The sixth SATIF workshop was hosted by the Stanford Linear Accelerator Center (SLAC), Menlo Park, California, USA. The objectives were to present and assess achievements on agreed actions agreed upon at the previous meeting held in Paris in 2000, and to discuss and recommend actions where a strong need is identified for further work in theoretical model development, experimental work and benchmarking for model validation.

The workshop was opened and the participants welcomed by the General Chair Sayed Rokni (SLAC Radiation Physics Group). He also called to mind the passing away of Professor Kazuo Shin of Kyoto University. This is a great loss to the SATIF group; Professor Shin contributed much to the success of the SATIF activities. It was agreed that the proceedings of SATIF-6 would be dedicated to him. The Chair then noted that Professor Nakamura was accompanied by five of his students, and commented that this is an effective means of transmitting know-how to the younger generation.

Professor Paterson, Associated Director for the Technical Division of SLAC also welcomed the participants to SLAC. He presented a brief history of SLAC, including the construction, 40 years ago, of what was at the time the world's largest linear accelerator. He continued in this vein, mentioning the SPEAR rings, the PEP-I and PEP-II double rings, the linear collider SLC, the establishment of a BIO-X satellite for structural molecular biology and finally the work being carried out on the Next Linear Collider. He then emphasised the importance of international collaboration in this area and at SLAC in particular.

Enrico Sartori welcomed participants on behalf of the OECD/NEA and thanked SLAC for hosting this workshop.

The workshop was attended by about 50 participants from 10 different countries, representing 26 organisations. Thirty-three (33) presentations were made, organised into six topical sessions:

- source term and related data – proton and ion accelerators and spallation source;
- measurements and calculations of induced radioactivity;
- benchmarking – calculations and results;
- dose and related issues;
- status of computer codes, cross-sections and shielding data libraries;
- shielding in medical accelerator applications (special topic).

The workshop was concluded with sessions on follow-up of past SATIF agreements and actions, and discussion/summary and future actions.

Specific actions agreed upon are:

- Collection of the different data produced on dose conversion coefficients, store them in comparative tables and make them available internationally through the NEA Data Bank, along with the descriptions of codes and methods used. This should help to resolve the remaining discrepancies.

- All authors of the major computer codes for accelerator shielding problems should be invited to the next SATIF meeting to present the latest features of codes, to discuss further needed developments and share new physics models and developments.

- The know-how and experience gathered by the SATIF group over recent years should be synthesised into a handbook – “Accelerator Shielding Handbook” – for the benefit of an increasingly larger community of accelerator shielders. No current handbook exists on this subject and, a strong need for it being expressed, its production was agreed upon. The editors of the handbook were designated among those SATIF members having editing experience. This should be prepared over a period of two years and be available in draft form for the next SATIF workshop. The chapters will cover: physics basics for accelerator shielding, facilities and their shielding and dosimetry approaches, simple fast methods for estimating orders of magnitude, existing state-of-the-art transport codes (MC and deterministic), data for accelerator shielding and experimental benchmark data.

- Sharing of modules for translating geometries for different radiation transport codes. This will reduce efforts in benchmarking and ensure that input to codes is coherent among different users.

- At the special session on shielding in medical accelerator applications it was concluded that medical accelerator physicists greatly benefit from SATIF activities, and as some of the medical-accelerator-related activities are equally of interest to SATIF, it was recommended that benchmarks of common interest to the two communities be carried out, in particular benchmarking of simplified methods that are more widely used in the medical area; standardisation of mazes for developing analytical tools was recommended. A general need for increased intercommunication between these fields was identified.

- Much progress was achieved as concerns the intercomparison of medium-energy neutron attenuation in iron and concrete. However, participants should provide further results in order to resolve discrepancies found for iron and the study should be extended up to 100 GeV to enable improved formulation of attenuation length trends at high energies. Also, results of appropriate experiments need to be selected to benchmark and verify the calculations and models.

- Newly developed codes for hadron transport, transport in complex ducts and cascades of particles have been developed. These should be acquired by the code centres for sharing among the community of experts.

- Additional (γ,n) data for accelerator shielding applications need to be collected and made available. Neutron shields are becoming increasingly important for electron accelerators as they increase in energy and power.

- The group has expressed interest in contributing to the EU Quality Assurance for Numerical Dosimetry (QUADOS) initiative.

The mandate of this expert group has been extended until 2005. As this group meets only every two years, a period judged as required for a consistent progress to be reported, it will seek a further extension of the mandate during the 2005 NSC meeting. In view of the number of large accelerator facilities in planning and under construction within the OECD area, the need for extended and improved databases, methods and codes in accelerator and target shielding is growing. Over the years, the radiation shielding community has benefited from the co-operation which takes place under the aegis of SATIF, and the group has established itself as the international forum for addressing priority issues in this area. SATIF will contribute shared research results to emerging priority areas.

The seventh NSC meeting on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-7) will be will be hosted by ITN, Portugal from 17-18 May 2004 in connection with the ICRS10 and RPS-2004 conferences. The group organising these series of meetings should prepare a new draft mandate proposal for discussion at the NSC bureau meeting and subsequent decision at the next NSC meeting in June 2003.

Sponsors

This event was jointly organised by the:

- OECD Nuclear Energy Agency;
- Stanford Linear Accelerator Center (SLAC);
- Radiation Safety Information Computational Center (RSICC);
- Shielding Working Group of the Reactor Physics Committee of Japan.

Scientific Committee

The members of the Scientific Committee of SATIF-6 were:

A. Fassò (CERN)	E. Sartori (OECD/NEA, Secretary)
H. Hirayama (KEK)	M. Silari (CERN)
B. Kirk (RSICC)	G. Stevenson (CERN)
N. Mokhov (FNAL)	P. Vaz (ITN)
T. Nakamura (U. Tohoku, Vice Chair)	L. Waters (LANL)
S. Rokni (SLAC, Chair)	

Executive Committee

The members of the Executive Committee, in charge of preparing the Technical Programme for SATIF-6 and submitting it to the Scientific Committee, were:

B. Kirk (RSICC)	E. Sartori (OECD/NEA, Secretary)
T. Nakamura (U. Tohoku, Vice Chair)	G. Stevenson (CERN)
S. Rokni (SLAC, Chair)	P. Vaz (ITN)

Nuclear Science

Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF 7

Proceedings of the Seventh Meeting held at
Instituto Tecnológico e Nuclear (ITN)
Sacavém, Portugal
17-18 May 2004

Jointly organised by

Organisation of Economic Co-operation and Development
Instituto Tecnológico e Nuclear (ITN)
Radiation Safety Information Computational Center (RSICC)
The Division of Radiation Science and Technology of Atomic Energy Society of Japan

NEA No. 6005

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

EXECUTIVE SUMMARY

Scope

The Expert Group on Shielding of Accelerators, Targets and Irradiation Facilities (SATIF) deals with multiple aspects related to the modelling and design of accelerator shielding systems including electron accelerators, proton accelerators, ion accelerators, spallation sources and several different types of facilities, such as synchrotron radiation facilities, transmutation sources including accelerator driven systems, very-high-energy radiation facilities, free electron lasers, high-power targets and dumps.

Objectives

Objectives of the SATIF-7 meeting include:

- to promote the exchange of information among scientists in this particular field;
- to identify areas in which international co-operation could be fruitful;
- to carry on a programme of work in order to achieve progress in specific priority areas.

Deliverables

Deliverables emerging from the SATIF-7 meeting include:

- assessment of needs in experimental data for the validation of models and codes;
- organisation of shielding experiments;
- collection and compilation of experimental data sets;
- assessment of models, computer codes, parametrisations and techniques available for accelerator shielding design purposes;
- validation of computer codes and models available to perform particle transport simulation;
- organisation of international benchmark and intercomparison exercises;
- organisation of workshops and co-organisation of conferences relevant in the area of its scope and computing radiation dosimetry;
- publication of workshop proceedings;
- editing of an “Accelerator Shielding Handbook”;
- maintenance of the SATIF listserver and archive of technical discussion between members.

SATIF-7 workshop

Summary

The seventh SATIF workshop was hosted by the Instituto Tecnológico e Nuclear (ITN), of Sacavém, Lisbon, Portugal. The objectives were to present and assess achievements on actions agreed upon at the previous meeting held at Stanford, California in 2002, and to discuss and recommend actions where a strong need is identified for further work in theoretical model development, experimental work and benchmarking for model validation.

The workshop was opened by Professor Manuel Leite de Almeida, Vice President of ITN, who welcomed the participants along with the General Chair, Pedro Vaz (ITN). He reminded participants of the history of SATIF and that the occasion marked the 10th anniversary of the first SATIF meeting, which was held at Arlington, TX, and chaired by Dr. Shun-ichi Tanaka, now Vice President of JAERI.

Enrico Sartori welcomed participants on behalf of the OECD/NEA and thanked ITN for hosting this workshop.

The workshop was attended by 36 participants from 9 countries, representing 24 organisations. Twenty-five (25) presentations were made, organised into five topical sessions:

- source term and related data – electron, proton and ion accelerators and spallation source;
- measurements and calculations of induced radioactivity and activation data;
- benchmark experiments and calculations;
- dose and related issues;
- status of computer codes, cross-sections and shielding data libraries.

The abstracts of the presentations from this proceeding are accessible via Internet at the following address: http://www.nea.fr/html/science/meetings/SATIF-7/satif7-programme.html.

The complete set of presentations was indexed and made available to participants on CD-ROM. The workshop proceedings are being edited and published in hard copy by the OECD. Details about the programme and its participants are provided in the Annex to the Executive Summary and the List of Participants.

The workshop was concluded with sessions on follow-up of past SATIF agreements and actions, and discussion/summary and future actions.

Concerning future directions, the following topics were proposed for discussion.

- The visibility of the SATIF group activities needs to be enhanced through:
  - a book on “State-of-the-art on Accelerator Shielding”;
  - publication in archival journals.

- New applications should be targeted, such as:
  - medical radiation applications;
  - dosimetry-related calculations for different applications;
  - shielding of transmutation facilities;
  - applications involving high-energy radiations.
- Increased interaction with other groups should be implemented via:
  - QUADOS-like initiatives (quality assurance and benchmarking);
  - EURADOS (dosimetry).

During Sessions VI and VII, which were concerned with follow-up, future actions and recommendations, Pedro Vaz, co-ordinator of the NEA/NSC activities in Radiation Shielding and Dosimetry, reported on the scheduled in-depth discussion that will tackle the subject with emphasis on accelerators at the next NSC meeting (10 June 2004).

The mandate of this expert group had been extended in 2003 through 2005. As this group meets only every two years, a period judged appropriate for consistent progress, and as the mandate expires before the next meeting, a discussion as to justification for continuing the SATIF activities was initiated.

Aspects for future studies were then discussed by all participants, the most important ones being:

1. Activation and dose rate estimations for facility maintenance planning are requested. It is particularly crucial if the targets are changed to identify "hot spots" and how to prevent them.

2. Dismantling of facilities requires estimation of remanent dose for dose management in order that the waste can be declared free from radiation. Lack of such capability may lead to very expensive solutions.

3. Relevant data on activation and corresponding evaluation were presented in several papers of SATIF-7 (e.g. induced radioactivity and remanent doses at CERN, production of radioactive isotopes at GT, an important/comprehensive set of experiments carried out within the ISTC programme in the Russian Federation by ITEP, and the HINDAS project, which has produced large sets of data at GSI, Darmstadt). These data contribute to waste disposal and hazard classification of accelerators. The SINBAD database should be expanded to include such compilations as EXFOR; however, this database does not seem to be an adequate format. In addition, more basic data on mass distribution and spallation products are needed and should be integrated into the databases.

4. The activities of SATIF can provide reliable, evaluated data and guidance for model selection; however, there should be strong support for making such data available. These experimental data should be presented at the SATIF meetings.

5. The group does not just meet and hold workshops, it also co-ordinates analysis and proposes action items (e.g. the collaboration on attenuation length up to 10 GeV for which codes now agree). Consensus on certain parameters, reached though independent but co-ordinated work, is of high value.

6. Comparison between codes creates a challenge for code developers to show which ones perform better. This creates important insight for users and code developers.

7. For the energy region where it becomes difficult to distinguish phenomena such as fission and spallation, additional development of models is needed as the discrepancies are still very high. SATIF should devote a certain amount of effort to resolve such issues by proposing experiments that help in choosing the right model.

8. In accelerator shield design, simple codes are often used. This tends to lead to overdesign. With today's state-of-the-art methods only a few safety factors need to be applied.

9. Experimental databases and benchmarking are key elements for building confidence in utilized data and codes; SATIF encourages objective comparison and facilitates access to needed information. Official endorsement of benchmarks by NEA/NSC is essential.

10. The discussions and exchange of views at SATIF relative to mechanisms that are not well-understood provide new ideas for designing experiments that lead to solution of problems.

11. The provision of a gamma beam line for nuclear physics and applications at the AURORA facility were reported. It was noted that there is a lack of photonuclear data available for light elements and that those available involve a limited range and poor quality. Data for the production of *d*, *t* and alphas with their spectra are required. Relevant work on photonuclear data is going to be presented and published by A. Fassó at the International Conference on Nuclear Data for Science and Technology (ND-2004) in September 2004 at Santa Fe, NM, USA. This work could form the basis for identifying the need for experiments to be carried out at this new facility. The availability of such a facility would be most welcome.

12. Concerning computer programs, it is essential that all responsible developers of the relevant codes contribute to the discussion and share their model. The developers should also generate a table describing the quality (good and bad aspects) of their features. This should be presented and discussed by authors at SATIF-8. A session should be devoted to "event generators" in order to facilitate common ways of solving problems. The release of standard routines and tools for geometry conversion from one code input to another should be strongly encouraged to minimise benchmarking efforts and cost.

13. A very valuable contribution is the "Heavy Ion Handbook", presented at SATIF-7. Preparation of additional specialised handbooks should be encouraged.

14. At SATIF-6 it was agreed that the know-how and experience gathered by the SATIF group over recent years should be synthesised into an "Accelerator Shielding Handbook" for the benefit of an increasingly large community of accelerator shielders. Since no current handbook exists on this subject and a strong need for it has been expressed, its production was agreed upon. The importance of such a work was underlined during SATIF-7 and stronger co-ordination of the effort is required. The editors of the handbook were designated among SATIF members with editing experience and time to realise the project. Those chosen include: Pedro Vaz and Nikolai Mokhov (co-ordinators and authors); Takashi Nakamura, Stepan Mashnik, Phillip Ferguson and Franz Gallmeier (authors); and others who will confirm their availability. The handbook should be prepared over the next two years and be available in draft form for the next SATIF workshop. The chapters will cover physics basics for accelerator shielding, facilities and their shielding and dosimetry approaches, simple fast methods for estimating orders of magnitude, existing state-of-the-art transport codes (MC and deterministic), data for accelerator shielding and experimental benchmark data.

It was noted that many of the actions agreed on in previous meetings have been carried out to the benefit of participants and the shielding community in general.

Members concluded that in view of the number of large accelerator facilities in planning or under construction within the OECD area, there is a growing need for extended and improved databases, methods and codes on accelerator and target shielding. The present scope and objectives of SATIF define well and represent current needs in this field as well as the deliverables (e.g. experimental benchmarks, adequate computer codes and code comparison reports, preparation of special handbooks, etc.). SATIF will be a major contribution to progress in this area.

Over the past 10 years, the radiation shielding community has benefited from the co-operation that takes place under the aegis of SATIF and the group has established itself as the international forum for addressing priority issues in this area. SATIF will further contribute by sharing its research results on emerging priority areas; the members recommend that SATIF's mandate be extended for a period of two years until 2007.

B. Kirk presented the Technical Group in Computational Medical Physics (TGCoMP), recently set-up within ANS for the promotion of advancement of computational tools, experimental data and enabling technologies, which are applicable to problems in medical and health physics. The group has a multidisciplinary approach (nuclear engineering, medical physics and health physics) to the studies of radiation effects on human and animal life. The applications include computational benchmarks on phantoms and detectors, large-scale optimisation and deterministic/stochastic approaches to radiation therapy problems. This area is separate from the other two ANS divisions – Isotopes and Radiation, Biology and Medicine. She presented their proposed future activities. From the subsequent discussion, it was clear that these activities are of interest to SATIF, who agreed to co-operate with this group.

H-S. Lee introduced the Pohang Accelerator Laboratory (PAL) of the Republic of Korea, which is operated by the Pohang University of Science and Technology (POSTECH). PAL has a third generation light source (PLS) 160 m long with a 2.5 GeV S-band PLS linac. He briefly described the plans for construction of future facilities. Interest in accelerator radiation research is increasing in Korea and efforts are made to encourage young students to work in the field of nuclear science and accelerator radiation. PAL offers to host the NSC meeting on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-8) from 22-24 May 2006, in conjunction with the Synchrotron Radiation Instrumentation Conference that will be held at Gyeongju the following week. Members of SATIF welcomed the offer because of the opportunity for discussion with the experts at PAL.

Sponsors

This event was jointly organised by the following:

- OECD Nuclear Energy Agency;
- Instituto Tecnológico e Nuclear (ITN);
- Radiation Safety Information Computational Center (RSICC);
- Division of Radiation Science and Technology of the Atomic Energy Society of Japan.

Scientific Committee

The members of the Scientific Committee of SATIF-7 were:

T. Gabriel (ORNL)	T. Nakamura (U. Tohoku, Vice-chair)
H. Hirayama (KEK)	S. Rokni (SLAC)
B. Kirk (RSICC)	E. Sartori (OECD/NEA, Secretary)
A. Leuschner (DESY)	M. Silari (CERN)
N. Mokhov (FNAL)	P. Vaz (ITN, Chair)

Executive Committee

The members of the Executive Committee in charge of preparing the Technical Programme for SATIF-7 and submitting it to the Scientific Committee were:

B. Kirk (RSICC)	M. Silari (CERN)
T. Nakamura (U. Tohoku, Vice-chair)	E. Sartori (OECD/NEA, Secretary)
S. Rokni (SLAC)	P. Vaz (ITN, Chair)

Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-8

Proceedings of the 8th Meeting

22-24 May 2006
Pohang Accelerator Laboratory (PAL)
Nam-Gu Pohang, Gyongbuk
Republic of Korea

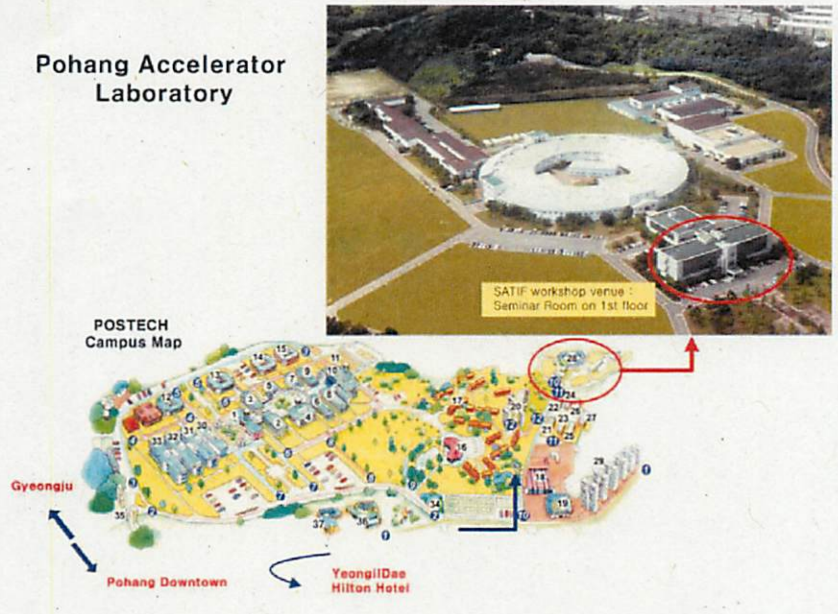
NUCLEAR ENERGY AGENCY
Organisation for Economic Co-operation and Development

Executive summary

The OECD/NEA Expert Group on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF) meets every two years when it organises a Workshop in places where world-class facilities are operated, alternating between North America, Europe and the Far East. During these workshops progress and results form an agreed programme of work are presented and common actions and research initiatives promoted and started with the aim of achieving progress and enhancing international co-operation in this area of research.

The eighth SATIF workshop took place from 22-24 May 2006 and was hosted by the Pohang Accelerator Laboratory (PAL) POSTECH, Republic of Korea (see figure). The local organiser and Chair of the workshop was Dr. Hee-Seock Lee, from the Radiation Safety Division of PAL. It was attended by 48 specialists in radiation protection, radiation shielding and radiation dosimetry from 9 countries representing 27 different organisations active in this field (see *Annex 1: List of participants*).

Figure 1: SATIF-8 workshop venue and facility visited



The main topics discussed at SATIF-8 were:

- source term and related topics;
- dosimetry and related issues;
- shielding at high energy accelerator;
- induced radioactivity and activation data;
- benchmarking – calculations and results;
- status of computer codes, cross-sections and shielding data libraries;
- shielding in medical and industrial accelerator application.

The detailed programme is provided in Annex 2.

The SATIF technical and scientific activities are organised around the major categories of accelerator shielding/facilities/proton and ion accelerators, electron accelerators, photon and neutron sources. Shielding aspects related to accelerator facilities are of multidisciplinary nature and address cross-cutting issues. They imply the utilisation of state-of-the-art computer codes and modelling techniques.

Forty papers were submitted for presentation including results from benchmark studies and status of relevant computer codes, results from measurements such as thick target yields, intercomparison of the medium energy neutron attenuation in iron and concrete, measurement of high energy neutron spectra behind shields in facilities, measurements and benchmark simulations of photoneutron yields from targets, nuclear data relevant to the radiological safety for 100 MeV proton linac. The *Handbook on Secondary Particle Production and Transport by High-energy Heavy Ions* was also presented.

Further benchmarks are proposed.

One of the strong components of the specialists' group activities is benchmarking, in most cases with experimental data in support of computations. Such benchmarks and the results obtained were instrumental for the identification of the needs in modelling methodologies in non-conventional energy domains, such as the intermediate energy range (few hundreds of MeV), typical of emerging and innovative technological applications such as accelerator driven systems (ADS), spallation neutron sources and other high power target applications attracting the attention of different scientific communities.

Over the last decade, the activities and results obtained by the SATIF group have paved the way to major developments in computer codes and to the assessment of nuclear data needs. This is documented in the proceedings of the various SATIF meetings, as the present one.

Dosimetry- and shielding-related activities deserve special mention: ultimately for the benefit of radiation protection, such activities are associated with the utilisation of particle accelerators and radiation sources in different domains, from basic research up to medical applications and are another major domain of the SATIF activities. In this respect, the discussions held during SATIF-8 led to following statement by the specialists' group:

- Dosimetry-related activities are of cornerstone importance for the operation of existing facilities, as well as for the design of new and innovative facilities currently in project phase, associated with the operation of high intensity particle accelerators, high power targets.
- Developments and findings resulting from these activities are of course applicable to any other type of non-accelerator facilities (nuclear power plants, space applications, aircrew dosimetry, industrial applications of radiations, intrusive detection techniques, etc.).
- The SATIF group should strengthen its involvement in ongoing dosimetry-related activities of other groups at the international level (*e.g.* EURADOS – European Radiation Dosimetry Group, ANS/CMPWG – Computational Medical Physics Working Group, etc.), in order to contribute to fostering major achievements and developments, to exchange scientific results and to jointly promote initiatives (conferences, workshops, education and training, technical documents and reports, etc.). Such involvement should be endorsed by the Nuclear Science Committee.

A series of benchmarks were proposed to be started over the next two years:

1) Production yields of the radionuclides induced from various targets in concrete shield at the 500-MeV neutron irradiation facility of KENS by H. Matsumura (KEK), N. Nakao (KEK), K. Masumoto (KEK), K. Oishi (Shimizu Co.), M. Kawai (KEK), T. Aze (U. Tokyo), A. Toyoda(KEK), M. Numajiri (KEK), K. Takahashi (KEK), M. Fujimura (Nihon U.), Q. Wang (IHEP), K. Bessho (KEK), T. Sanami (KEK).
2) Thick target yield (TTY) at 0° by 250 and 350 MeV protons at the Research Center of Nuclear Physics (RCNP) cyclotron by Y. Iwamoto (JAEA).
3) AGS spallation target experiment by H. Nakashima and ASTE collaboration team.
4) Benchmarks on photoneutron spectrum, differential yields and angular distribution from targets irradiated by 2 GeV electrons based on measurements carried out at PAL by H.S. Lee.

5) Heavy ion benchmark based on data from HIMAC by K. Niita.

6) Proposal for a ADS and high power accelerator facilities benchmark by P. Vaz (ITN).

7) Revisiting the *Inter-comparison of the Neutron Attenuation in Iron and Concrete (7)* report results from improved modelling – experimental data for resolving discrepancy, by Hideo Hirayama (KEK). N. Mokhov will suggest a list of published lambda measurements and an experiment with 120 GeV p into a beam dump

8) Computational medical physics benchmark(s), by B.L. Kirk (RSICC); benchmarks are being set up; this will be reported on at SATIF-9.

9) SHARE benchmark exercise (for modellers and code developers) by S. Leray (CEA): to be defined; this will be reported on at SATIF-9.

Benchmarks are open to model/code developers and code users. Code users are recommended to show their results to code authors, in particular in case of large discrepancies compared with experimental results, to ensure that the code is used with competence, and the appropriate model features or parameters are used.

The first five benchmarks were recommended for inclusion into the Shielding and Dosimetry Experiments Database (SINBAD).

The main objectives of the SATIF workshops were revisited and approved as follows:

- promote the exchange of information among experts in the field of accelerator shielding and related topics,
- identify areas where international co-operation can be fruitful;
- carry on a programme of work in order to achieve progress in specific priority areas.

The deliverables:

- assessment of needs in experimental data for the validation of models and codes;
- organisation of shielding experiments;
- collection and compilation of experimental data sets;
- assessment of models, computer codes, parametrisations and techniques available for accelerator shielding design purposes;
- validation of computer codes and models available to perform particle transport simulation and organisation of international benchmark and intercomparison exercises;
- organisation of workshops and co-organisation of conferences relevant in the area of its scope and computing radiation dosimetry;
- publication of workshop proceedings; and editing of an "Accelerator Shielding Handbook".

It was agreed to hold the ninth workshop in connection with the joint 11th International Conference of Radiation Shielding and Radiation Protection (ICRS11 & RPS-2008), to be held probably at the SNS Facility in Oak Ridge, TN, USA. Progress in benchmarks and results from experiments, code and database developments will be presented.

The new Executive/Scientific Committee for SATIF-9 was elected as follows: Ph. Ferguson (ORNL) (next Chair), H. Hirayama (KEK), B. Kirk (RSICC), H.S. Lee (PAL, current Chair), A. Leuschner (DESY), N. Mokhov (FNAL), T. Nakamura (U. Tohoku), S. Rokni (SLAC), E. Sartori (OECD/NEA), M. Silari (CERN), P. Vaz (ITN).

To summarise, SATIF activities have contributed for more than a decade to enhancing the role NEA is playing in promoting international co-operation in scientific areas related to nuclear energy (at large), radiation physics and the application of ionising radiations in different fields of science and technology. Such actions are in line with the NEA Programme of Work and the main lines of activity set out in the NEA Strategic Plan.

Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-9

Proceedings of the 9th Meeting

21-23 April 2008
Spallation Neutron Source
Oak Ridge National Laboratory
Oak Ridge, TN USA

NUCLEAR ENERGY AGENCY
Organisation for Economic Co-operation and Development

Executive summary

The OECD/NEA Expert Group on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF) meets every two years, and organises its workshops in places where world-class facilities are operated, alternating between North America, Europe and the Far East. During these workshops progress and results form an agreed programme of work are presented and common actions and research initiatives promoted and undertaken with the aim of achieving progress and enhancing international co-operation in this area of research.

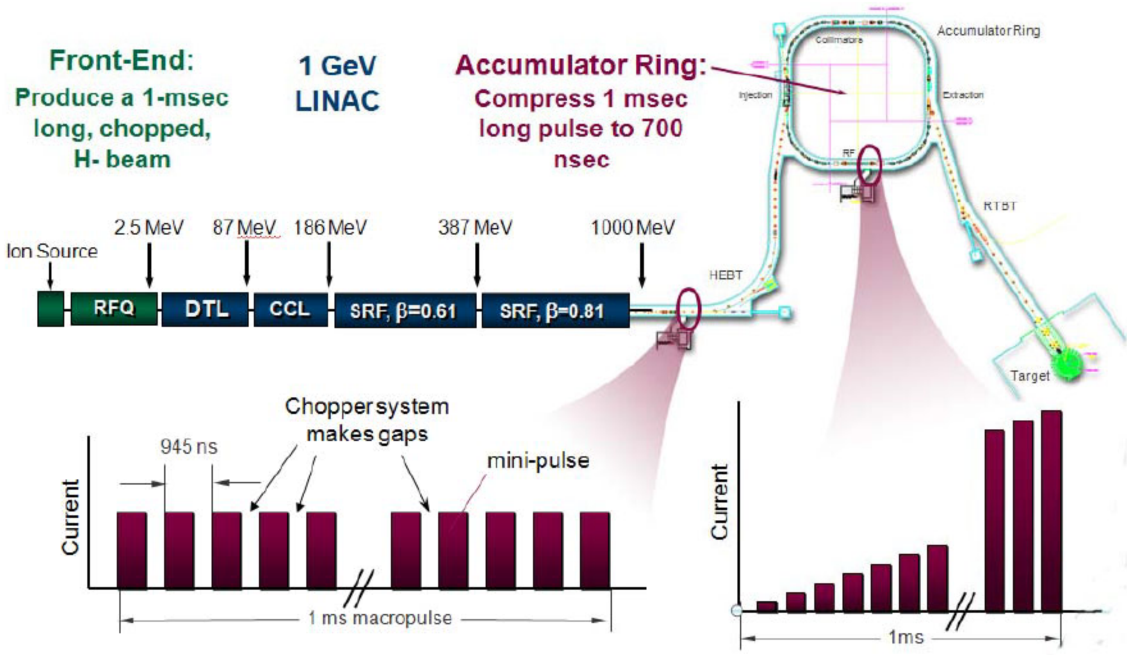
The ninth SATIF workshop took place on 21-23 April 2008 and was hosted by the Spallation Neutron Source (SNS) (see Figures 1 and 2), Oak Ridge National Laboratory in the United States. The local organiser and Chair of the workshop was Dr. Phil Ferguson from the SNS. It was attended by 35 specialists in radiation protection, radiation shielding and radiation dosimetry from 10 countries representing 20 different organisations active in this field (see Annex 1: List of participants).

The objectives of SATIF-9 are as follows:

- To promote the exchange of information among experts in the field of accelerator shielding and related topics.
- To identify areas where international co-operation can be fruitful. Recommend actions with strong need for international work on theoretical models, experimental work and benchmarking.
- To carry on a programme of work in order to achieve progress in specific priority areas.
- To present and assess achievements on actions agreed upon previously.

Figure 1: SATIF-9 workshop venue and facility visited

Figure 2: Spallation Neutron Source (SNS)



Thirty presentations followed by discussions were made, organised into six topical sessions:

1) source terms and related topics;
2) measurements and calculations of induced radioactivity and activation data;
3) shielding in medical and industrial accelerator applications;
4) benchmarking – calculations and results;
5) dose and related issues;
6) status of computer codes, cross-sections and shielding data libraries.

The detailed programme is provided in Annex 2.

Future directions for the expert group discussed and agreed upon include the following actions:

- Enhance visibility of work:
  - state-of-the-art handbook(s);
  - publications in archival journals.
- Target new applications:
  - medical radiation applications;
  - dosimetry-related calculations for different applications (industrial, material/tissue damage, irradiations of specimens, radiation fields in and around irradiation facilities);
  - shielding of transmutation and high-power accelerator facilities.
- Increase interaction with other groups (*e.g.*):
  - CONRAD activities (quality assurance and benchmarking, monitoring in workplace, review of HE facilities, carbon beams for therapy, etc.);
  - Computation Medical Physics Working Group (ANS);
  - close co-operation with joint PSI/ORNL ARIA activity.

- Training courses/tutorials (good codes and competent users).
- Enhance effectiveness:
  - form sub-groups on topics of common interest – project-oriented;
  - exchange via videoconferencing;
  - make use of SATIF forum via *satif@nea.fr* Q/A.

The important aspects of the work were identified as follows:

- Activation and dose rates estimation for facility maintenance planning is requested and it is particularly crucial if the targets are changed, to identify "hot spots" and how to prevent them
- Dismantling of facilities requires estimation of remnant dose for dose management, for the characterisation of waste to be able to declare it free from radiation. Lack of such a capability may lead to very expensive solutions. Relevant data on activation and their evaluation contributing to waste disposal and hazard classification of accelerators. The SINBAD database should be expanded to include such compilations, in particular, as EXFOR does not seem to be an adequate format for it. More basic data on mass distributions and spallation products are also needed and should be integrated in the databases.
- Shield designs of high-power accelerator facilities require best-estimate/state-of-the art methods to reduce the cost of facilities.
- The activities of SATIF can provide reliable evaluated data and guidance for model selection; strong support and stimulation for making data available should be provided, and such experimental data should be presented at the SATIF meetings.
- The group does not just meet and hold workshops, it co-ordinates analysis, proposes action items; examples are the collaboration on attenuation length up to 10 GeV. The consensus for certain parameters, reached though independent but co-ordinated work, is of high value.
- Code comparisons present a challenge for code developers and lead to valuable insight for users and code developers.
- For the energy region where it becomes difficult to distinguish phenomena such as fission and spallation, requirements exist for additional development of models as the discrepancies are still very high. SATIF should devote efforts to resolving such issues by proposing experiments that help choosing the right model.
- In accelerator shield design simple codes are still used quite often. This normally leads to overdesign. With today's state-of-the-art methods only few safety factors need to be applied
- Experimental databases and benchmarking are key elements for building confidence in data and codes used; this is an essential activity of SATIF that enforces objective comparison and facilitates access to the information needed. It is felt that official endorsement of benchmarks by NEA NSC WPRS is essential.
- The discussions and exchange of views at SATIF relative to mechanisms that are not well understood provide new ideas for design experiments that lead to problem-solving.
- It was noted that there is lack of photonuclear data available for light elements and those available are for a limited range and often of poor quality. Data for production of d, t and alphas with their spectra are required (work by Fassò and available facilities for such measurements).
- Concerning computer programs it is essential that all responsible developers of the relevant codes contribute to the discussion and share their models; they should also generate a table describing the quality (good or bad) of their features. This should be presented and discussed by authors at SATIF-10. A session should also be devoted to "event generators" to facilitate common ways of solving problems. Release of standard routines and of tools for geometry conversion from one code input to others, to minimise benchmarking efforts and cost should be strongly encouraged.

The know-how and experience amassed by the SATIF group over recent years will be synthesised into an "Accelerator Shielding Handbook", for the benefit of an increasingly large community of accelerator shielders. No current handbook exists on this subject and, a strong need for it being expressed, its production was agreed upon. The editors of the handbook were designated among those SATIF members having editing experience: P. Vaz and Nikolai Mokhov and a number of co-ordinators and authors (*e.g.* T. Nakamura, S. Mashnik, P. Ferguson, F. Gallmeier, A. Fassò, M. Silari, W. Dittrich, L. Waters, etc.) as well as others who confirmed their availability. The agreed upon structure of the handbook is provided in Annex 3.

The following chapters have been drafted thus far:

- W. Dittrich:
  - 2.3 Radiological standards and limits, legal dose
  - 2.5 Practical aspects
  - 3.6 Environmental impact

Comments: Explain that legal dose limits are in practice never approached: (F. Gallemeier will provide examples). As to environmental impacts, contamination should be included in particular as concerns facilities in support of fusion reactors (Ph. Joyer will contribute issues relevant to fusion).

- T. Nakamura:
  - 7.1 Thick target yields
  - 7.2 Shielding experiments
  - 11.4 Heavy ions

Comments: Provide feedback to T. Nakamura.

Actions specific to the shielding handbook were discussed, and include the following:

- Editors will contact co-ordinators to verify structure of handbook and confirm contributors.
- Verify co-ordinator/authors for Chapter 2 (R. Thomas, H. Menzel, A. Fassò). If not available, verify if M. Pelliccioni would be available.
- Verify whether Y. Titarenko would be willing to contribute parts of the text.
- Chapter co-ordinators will contact authors in the near future to provide instructions and monitor progress on a regular basis with the aim of having drafts of most chapters/sections by March/April 2009.
- Arrange meeting of editors and chapter co-ordinators in March/April 2009 to discuss draft chapters and ensure coherence of presentation, identification of gaps, etc. (E. Sartori).
- Add handbook to the NEA publication schedule for 2010/11.

The benchmark and related activities were discussed, proposals made and several choices made during SATIF-8 confirmed and complemented with new ones. The following is a summary of items discussed and deemed of importance. Preservation of evaluated experiments in the SINBAD database was recommended:

1) Production yields of the radionuclides induced from various targets in concrete shield at the 500-MeV neutron irradiation facility of KENS by H. Matsumura (KEK), N. Nakao (KEK), K. Masumoto (KEK), K. Oishi (Shimizu Co.), M. Kawai (KEK), T. Aze (U.Tokyo), A. Toyoda (KEK), M. Numajiri (KEK), K. Takahashi (KEK), M. Fujimura (Nihon U.), Q. Wang (IHEP), K. Bessho (KEK), T. Sanami (KEK).
2) Thick target yield (TTY) at 0 degree by 250 and 350 MeV protons at the Research Center of Nuclear Physics (RCNP) cyclotron by Y. Iwamoto (JAEA).
3) AGS Spallation Target Experiment by H. Nakashima and the ASTE collaboration team.
4) Benchmarks on photon-neutron spectrum, differential yields, and angular distribution from targets irradiated by 2 GeV electrons based on measurements carried out at PAL by H-S. Lee.

5) Heavy ion benchmark based on data from HIMAC by K. Niita.

6) Proposal for a ADS and high power accelerator facilities benchmark, by P. Vaz (ITN).

7) Benchmark experiments using 140-392 MeV p-Li quasi monoenergetic neutrons at RCNP (T. Nakamura).

8) Propose priority targets for ITEP-ISTC project with p up to 2.6 GeV (Cr, Ni and Zr-4 + others) (P. Ferguson).

9) Investigate possible release of material assay data for low activation concrete (K. Kimura).

10) Possible general release of BRIEFF, FLUKA and PHITS computer codes.

11) Upgrade models for TOF experiments and undertake a quality review of accelerator shielding benchmarks in SINBAD.

12) Revise/submit additional solutions for inter-comparison of the "Neutron Attenuation in Iron and Concrete (7)" report results from improved modelling/experimental data for resolving discrepancy, by Hideo Hirayama (KEK) (N.V. Mokhov will suggest a list of published lambda measurements; results on an experiment with 120 GeV p into a beam dump will be available by SATIF-10).

13) Contact should be made with G. Gualdrini and S. Agosteo for sharing results from the EURADOS benchmark activities (E. Sartori).

14) Make MCNP input for inter-comparison of the medium-energy neutron attenuation in iron and concrete available (F. Maekawa).

15) Computational Medical Physics Benchmark(s), report progress on database of Dosimetry Benchmarks for Radiation Transport at SATIF-10.

16) SHARE benchmark exercise (for modellers and code developers) by S. Leray (CEA) now organised within IAEA: proposed reporting at SATIF-10.

17) There is a need for releasing data for production of d, t, and alphas with their spectra. The collection by A. Fassò would be a good source for it and its general release would be useful.

It was agreed to hold the tenth workshop at CERN, Geneva on 2-4 June 2010. Executive Group members from Japan will investigate the possibility of hosting SATIF-11 in 2012 in Japan.

The new Executive/Scientific Committee for SATIF-10 was elected as follows: M. Brugger (CERN), Ph. Ferguson (ORNL, current Chair), A. Ferrari (CERN), H. Hirayama (KEK), B.L. Kirk (RSICC), H-S. Lee (PAL), N.V. Mokhov (FNAL), G. Muhrer (LANL), T. Nakamura (U. Tohoku), H. Nakashima (JAEA), S. Roesler (CERN), S. Rokni (SLAC), M. Silari (CERN, new Chair), P. Vaz (ITN), M. Wohlmuther (PSI).

To summarise, SATIF activities have contributed for over a decade to enhancing the role NEA plays in promoting international co-operation in scientific areas related to nuclear energy (at large), radiation physics and the application of ionising radiations in different fields of science and technology. They are in line with the NEA Programme of Work and the main areas of activity set out in the current NEA Strategic Plan.

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Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-10

10th Workshop Proceedings

Hosted by the
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Geneva, Switzerland
2-4 June 2010

NEA No. 6898

NUCLEAR ENERGY AGENCY
Organisation for Economic Co-operation and Development

Executive summary

The tenth SATIF workshop (SATIF-10) took place at CERN, Geneva (Switzerland) on 2-4 June 2010. This was the second time that SATIF was hosted by CERN, after SATIF-2 in October 1995. The workshop was chaired by Marco Silari and was the most attended meeting of the series, with 65 participants from 34 institutions and 14 countries.

The SATIF community welcomed Jim Gulliford, the NEA representative replacing Enrico Sartori who retired last year. SATIF forms part of the activities of the newly formed Expert Group on Radiation Transport and Shielding (EGRTS) which reports to the Nuclear Science Working Party on Scientific Issues of Reactor Systems (WPRS). The EGRTS also co-ordinates maintenance and development of the SINBAD database of Reactor Shielding, Fusion Neutronics and Accelerator Shielding benchmark experiments. More information on the activities of the WPRS can be found at: *http://home.nea.fr/science/wprs/index.html*.

The objectives of the SATIF meetings are:

- to promote the exchange of information amongst experts in the field of accelerator shielding and related topics;
- to identify areas where international co-operation can be fruitful, and recommend actions with strong need for international work on theoretical models, experimental work and benchmarking;
- to carry on a programme of work in order to achieve progress in specific priority areas;
- to present and assess achievements on actions agreed upon previously.

The SATIF-10 programme was organised in six sessions. Each session was opened by an invited talk to provide a review of the session topic, followed by contributed presentations. At the end of each session half an hour was allocated for general discussion. The meeting closed with a two-hour discussion session to provide a summary of the meeting and revise the topics where future actions are needed. Interesting presentations, productive discussions and constructive dialogue characterised all six sessions, and numbered to a total of 44 talks (6 invited and 38 contributed):

1) source term and related topics (1 invited + 8 contributions);
2) induced radioactivity (1 + 10);
3) benchmarking (1 + 7);
4) dosimetry (1 + 2);
5) medical and industrial accelerators (1 + 5);
6) present status of codes and code libraries (1 + 4).

There was also a one-hour session devoted to discussing the opportunity of setting up a network amongst the radiation protection groups of major accelerator laboratories in order to ease the exchange of information on topics of common interest like training, procedures, shielding assessments, instrumentation development and calibration, and so on.

Session 1 on source terms and related topics was opened by T. Nakamura, who gave an excellent overview of experimental data (until 2008) on neutron distributions and spallation products from thick and thin targets for p, d, He and HI beams (MeV to GeV). These data are an invaluable asset for the community and should possibly be included in SINBAD if/when digitised. For the first time in a SATIF meeting, discussion was started on what level of agreement between data and simulations should be regarded as satisfactory. A very interesting set of results on radiation fields induced by 243 and 390 MeV quasi-monoenergetic neutrons was presented, which is another good candidate for inclusion into SINBAD.

Systematic studies of thick target yields (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 were undertaken within the Japan-Fermilab JASMIN collaboration, again certainly of interest for inclusion in SINBAD when the analysis is finished. A talk was presented on considerations of dark current-induced radiation in superconducting RF cavities and shielding around. An interesting sensitivity analysis was presented of effects of cryogenic moderator, reflector, decoupler and temperature on radiation field at ESS. Other contributions discussed shielding and activation study for a high-intensity laser facility and neutron yield and nuclear transmutation at a photo-neutron source.

Megawatt beams were again a hot topic at the meeting. A 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 approaches. 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. The JASMIN, BLIP (BNL) and HiRadMat (CERN) activities are excellent examples. Joint efforts with material experts are needed.

Session 2 on induced radioactivity was opened by a review talk by F. Gallmeier, who discussed the pros and cons of the two possible approaches: all-in-one, *i.e.* direct prediction by plugging in activation modules into transport codes solving for the radionuclide build-up and decay on-line on a per-event basis, versus modular, *i.e.* sampling fluxes and radionuclides in transport analysis and feeding the information into external activation codes. He stressed the need for realistic simulations to avoid unnecessary costs. His talk was followed by presentations discussing the use of Monte Carlo codes for generic activation studies, for both proton and ion accelerators, to predict the variation of ambient dose equivalent rate as a function of material irradiated and of cooling time. The activation properties of an element are an important factor to be taken into account in the choice of a material for any given application (*e.g.* beam dump). A conclusion drawn for ions is that the radionuclide inventory does not depend on the projectile species and that the induced activity decreases with increasing ion mass and with decreasing energy. A number of talks described various ongoing activation studies for present and future facilities such as SPES in Legnaro (Italy), CLIC, n_TOF, EURISOL and Beta Beams. The importance of benchmarking code predictions versus experimental data was underlined.

The proposal was made to create a database of reaction cross-sections:

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

with focus on:

- calculation of radioactive inventory for transport, handling and waste;
- ground and sump water activation;
- air activation;
- cooling water activation.

Session 3 on benchmarking was introduced by a review by P. Sala, who stressed that computing tools for accelerator radiation shielding are faced with new challenges from the present and next generation of particle accelerators. The Japan-Fermilab JASMIN collaboration has carried out experimental studies with the aim of benchmarking simulation codes and studying irradiation effects for upgrade and design of new high-energy accelerator facilities. Neutron production and propagation are reasonably well understood by most codes (with some caveats). Deep penetration is surprisingly well predicted but further benchmarks are welcome. There have been huge steps forward in the last ten years on residual nuclei predictions, but still a lot of work is needed: new data and comparisons are welcome for both thin and thick targets, with particular emphasis on special cases (*e.g.* production of rare isotopes through (α,x) reactions by secondary α particles). Light (composite) charged particle production is a big challenge, which could also be relevant for radiation protection applications. There are not too many data available at medium/high energies for photonuclear reactions, so that new data are welcome.

As for code benchmarking for heavy ions, there are many experiments on neutron production (mostly by Japanese groups), but there is still a room for improvements in codes (*e.g.* forward angles) and almost no data are available above 1 GeV/A. Projectile fragmentation is a very important issue for particle therapy and not only: both experimental data and benchmarking are welcome (the FIRST experiment at GSI should provide data in the near future). A lot of interesting data came from GSI/FAIR, with also some unexpected challenges (*e.g.* range calculations). Radionuclide production distributions are of great interest. In general all sort of data for heavy ions are welcome, but perhaps there is a need to establish priorities.

The role of Λ hyperons in thick shielding calculations was discussed. Recent results by the PHITS code showed that their effect can be substantial, while there is no such evidence from the mature codes, FLUKA, MARS and GEANT, where this particle is always taken into account. Although a deeper look should be taken at this issue, it seems unlikely that Λ hyperons with their $c\tau$ = 7.89 cm and an inelastic cross-section comparable with that for nucleons and pions would become a driver in hadronic cascade development. Some discussion was devoted to calculation of scintillator efficiencies for high-energy neutrons, and to biasing (*i.e.* variance reduction techniques). It was stressed that there is no chance to make meaningful calculations for specific studies (*e.g.* deep penetration in shields) without biasing.

For the first time at a SATIF meeting, the issue of DPA in radiation damage to materials and electronics was specifically discussed. This is a very important problem for present and future projects. There is unfortunately a very complex physics background, which together with the impossibility of direct measurements generates different and confusing results. The practical implementation as well as the calculation 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. The idea was presented to plan a future SATIF session (or even a dedicated workshop) where every code presents how its DPA is computed and where to compare results on simple cases.

Session 4 on dosimetry was short as compared to previous SATIF meetings. The session was introduced by a comprehensive review by T. Sato of recent dosimetric studies, both computational (comparison of fluence-to-dose conversion coefficient, updated w_R and w_T, authorised voxel phantoms, neutron dose estimates) and experimental (JASMIN and KEK experiments, neutron measurements and the challenge of measuring in pulsed fields). A talk provided comprehensive FLUKA calculations of the radiation levels (prompt dose rate in service caverns and on the surface) around the ATLAS detector in the LHC. The session closed with an interesting discussion on dose, its definitions and "ingredients", phantoms and their description correlated with computer power and detectors.

Session 5 on medical and industrial accelerators was mostly devoted to particle therapy accelerators. It was opened by a review by G. Fehrenbacher on radiation protection issues at particle therapy facilities. There are a growing number of proton and ^{12}C ion medical accelerators, essentially synchrotrons and cyclotrons employing passive and active beam shaping systems in conjunction with fixed beams and isocentric gantries. The main radiation source at these machines is neutrons, for which source terms (neutron energy distributions) are needed (experimental data and Monte Carlo predictions). A peculiarity of these facilities is that many radiation sources are present, in the accelerator and treatment rooms, patient included. Various approaches are used to radiation shielding, both Monte Carlo and analytical using attenuation curves. Shielding materials employed at these facilities are concrete, combined low-Z + high-Z materials, and a sandwich technology recently introduced, which allows saving time and construction costs. Activation issues are present in the accelerator, energy degrader, beam transport and passive beam shaping system. In particular, cyclotron systems using an energy degrader and passive scattering techniques implicate higher activation and radiation exposure of personnel working on activated components in contrast to synchrotron based facilities. More shielding data are generally needed for light-ion facilities, as the available experimental data are essentially from measurements at HIMAC. Improvements are desirable, in particular for the lowest angles (0°-15°). There is also room for improvement in models.

Although most of the focus at the session on medical accelerator shielding (introduced for the first time at SATIF-6) has always been on proton accelerators, one presentation was on seismic base-isolation structure for a conventional electron linac, where alternative solutions to pure shielding have to be found to reduce costs. Calculations validated by measurements were presented to predict dose rates due to radiation scattered and streaming underneath the treatment room, taking into account multiple beams due to rotating gantry.

Finally, high-current, low-energy accelerators for novel applications such as material testing in strong neutron field, as well as a high-intensity laser facility and photo-neutron source presented in Session 1, pose new challenges (*e.g.* the dump must withstand high particle current and becomes a very intense neutron source) requiring novel shielding solutions.

Session 6 on the present status of codes and code libraries started with a comprehensive review by B. Kirk of nuclear computational information, followed by talks on modern activation-transmutation systems, on the impressive performance of the improved INCL4 and ABLA models, on radiation protection and safety issues in IFMIF, and on a "physics list" in Geant4 where the user defines 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 users. A debate followed, as this offer by the code seems appropriate for expert HEP users, whereas for radiation protection calculations it seems much safer not to let the user "play" with models but rather to provide a set of "defaults" adapted to the problem.

In summary, the main questions raised at the meeting were:

- 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, dose conversion coefficients at E > 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 are needed?

  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.

- Shall SATIF help in pursuing the organisation of RP network amongst the accelerator laboratories?

- Shall we have a dedicated DPA session at SATIF-11?

The publication of the Accelerator Shielding Handbook was also discussed. The handbook was first proposed at SATIF-8 and since then some contributions have been provided, but much still has to be written. It has been agreed to look for a person who has sufficient available time to solicit the missing contributions to the various chapters and take up on the editing work.

Jim Gulliford (NEA), Nikolai Mokhov (Fermilab), Marco Silari (CERN)

Nuclear Science

Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-11 Workshop Proceedings

Tsukuba, Japan

11-13 September 2012

Hosted by the

High-energy Accelerator Research Organisation (KEK)

NEA No. 7157

NUCLEAR ENERGY AGENCY

Organisation for Economic Co-operation and Development

Executive Summary

The 11th workshop on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-11) took place at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan on 11-13 September 2012, following the 12th International Conference on Radiation Shielding (ICRS12), which was held in Nara, Japan the previous week. The workshop was chaired by Syuichi Ban and was attended by 36 participants representing 21 organisations located in 8 countries.

Support for the SATIF workshop is now part of the mandated activity of the Expert Group on Radiation Transport and Shielding (EGRTS, chaired by R. Grove from ORNL) of the Working Party on Scientific Issues of Reactor Systems (WPRS) of the OECD/NEA Nuclear Science Committee (NSC). The EGRTS also co-ordinates maintenance and development of the SINBAD database of Reactor Shielding, Fusion Neutronics and Accelerator Shielding benchmark experiments. The SATIF internet forum has been reactivated and will be used to distribute information to members. An overview of WPRS activities can be found at: *www.oecd-nea.org/science/wprs/index.html*.

The main objectives of the SATIF workshops are to:

- promote the exchange of information among experts in the field of accelerator shielding and in other related areas;
- identify areas where international co-operation could be fruitful;
- identify a programme of work in order to achieve progress in specific priority areas.

SATIF-11 is sponsored by the OECD/NEA and its Nuclear Science Committee (NSC) and co-sponsored by the Technical Divisions of Radiation Science and Technology of the Atomic Energy Society of Japan (AESJ) and the Radiation Safety Information Computational Center (RSICC). The meeting consisted of five technical sessions and a wrap-up session summarising achievements and defining further work for the next two years. The highlight of the meeting was a trip to the J-PARC facility at the Tokai site, which included visits to the Materials and Life Science Experimental Facility (MLF), the neutrino beam line and Hadron Hall. The facility is very impressive and the participants noted in particular the facility's astonishingly quick recovery from the earthquake.

The five technical sessions were as follows:

- Session 1: Induced radioactivity;
- Session 2: Present status of codes and data libraries;
- Session 3: Dosimetry, medical and industrial accelerators;
- Session 4: Benchmarking code/code and code/experimental data;
- Session 5: Source term and related themes.

The first session, during which five presentations were made, was dedicated to activation data, predictions of radioactive nuclides, and predictions of residual dose rates. The session was chaired by Heinz Vincke from the European Organization for Nuclear Research (CERN).

The second session was dedicated to recent developments in simulation codes, data for accelerator shielding, and integral experiments databases. Five presentations were made during this session, which was chaired by Nikolai Mokhov (Fermilab). At the end of the session, participants commented that, while damage can be measured, Displacement per Atom (DPA) cannot, and therefore validation of DPA against experiments cannot be carried out directly. It was also noted that quantitative confidence bounds cannot be attached to results for high energy simulations. Uncertainty analysis due to different models is therefore "next to impossible," and only comparisons of a qualitative nature can be proposed in practice.

During the third session, issues related to calculation of dosimetric quantities, shielding, secondary dose to patients, and dose delivery were explored, with Syuichi Ban (KEK) acting as chair of the session. Three presentations were made during this session. The chair added some comments for future studies, noting that there are many medical electron linear accelerators. Beam energies were mainly at E=10, 15, and 18 MeV, and the amount of activity in the air and water was small and difficult to measure. Some benchmark studies were carried out, but the components of these accelerators are not well known; nor are the actual beam energy or energy spreads during the operations because medical staff generally have no interest in these issues. This is an important problem and further studies, including experiments and benchmarks, are needed.

The fourth session was dedicated to thick-target yield experiments, shielding and deep penetration, neutron spectra-experiments and calculation, energy deposition, and high-energy reference fields. Four presentations were given, with the session chaired by Hiroshi Nakashima, Japan Atomic Energy Agency (JAEA).

The fifth session focused on hadron production, electron-photon production, photo-neutron production, radioactive ion production, and spallation neutron sources. Six presentations were given, with Hideo Hirayama (KEK) chairing the session. It was noted during this session that code inter-comparison activities within SATIF are crucial, especially for the growing number of heavy-ion facilities.

The main outcomes of the meeting were summarised during the last session where areas of co-operation for the next two years and actions required to achieve progress in the different research areas were identified. Several comments and suggestions were made by participants, and by N.V. Mokhov in particular, and are included herein. In many talks, a systematic underestimation of code-computed results compared to experimental results was revealed with the underestimation factors ranging from 2 to 10. It was recommended that the authors perform further analyses to better understand the reasons for the underestimations and inform the community on their findings. Without a safety factor, regulatory limits may otherwise be exceeded.

Hideo Hirayama proposed a computational benchmark to compare code performance for neutron production by high-energy protons. In a previous benchmark for medium energy neutron attenuation in iron and concrete, large discrepancies among the codes were found. The new proposal would use incident proton energies of 1, 3, 10, 50, and 100 GeV. The materials would be C, Al, Cu and W with target dimensions of 1 interaction length and 1 cm in diameter. The angular neutron spectrum would be examined at various angles and compared to determine the differences resulting from the code and model used. A detailed specification for the computational benchmark will be prepared as well. Some participants suggested making comparisons against experiments, since unpublished data from SATURNE exists that could be included in SINBAD. Thick target experiments from CERN and a 50 GeV experiment at Protvino are additional candidates. It was agreed that comparison against experiments could be part of a second benchmark phase, but the proposed computational benchmark is appropriate for the first phase. In the meantime, Hideo Hirayama asked for comments from participants on the proposed computational benchmark.

It was suggested that the NEA Secretariat arrange for the OECD-NEA Expert Group on Radiation Transport and Shielding (EGRTS) to discuss the different tasks agreed upon at the SATIF-11 workshop. It was also suggested that the NEA SATIF listserver be used for this purpose. New experimental data, to be compiled, evaluated and reviewed for the SINBAD database, should be identified and collected by EGRTS and the NEA Secretariat.

It was suggested that the next SATIF meeting (SATIF-12, also celebrating the 20^{th} anniversary of the first meeting held in Arlington, Texas in 1994) would be held in 2014 in the USA, following the tradition of rotating the venue between America, Europe and Asia. The suggested venue is Fermilab in Batavia, Illinois; the tentative date would be Spring or Autumn 2014, depending upon the dates of the RPSD Topical meeting. It was suggested that SATIF-12 not be held in conjunction with the RPSD Topical. N. V. Mokhov of Fermilab agreed to explore this possibility of holding the meeting at this time, and indicated that final confirmation would be provided well in advance of the next meeting. Participants thanked the General Chair, Syuichi Ban, and KEK for hosting SATIF-11 and for their kind hospitality. The chair adjourned the meeting.

The members of the Scientific Committee of SATIF-11 were: S. Ban (KEK, the general chairman of SATIF-11), M. Brugger (CERN), R. Grove (ORNL), J. Gulliford (OECD/NEA), H. Hirayama (KEK), H.S. Lee (PAL), N. Mokhov (Fermilab), G. Muhrer (LANL), T. Nakamura (U. Tohoku), H. Nakashima (JAEA), S. Roesler (CERN), S. Rokni (SLAC), M. Silari (CERN), T. Valentine (ORNL), and P. Vaz (ITN).

The members of the Local Organising Committee were: S. Ban (KEK), H. Hirayama (KEK), K. Masumoto (KEK), S. Sasaki (KEK), T. Sanami (KEK), H. Iwase (KEK), H. Nakamura (KEK), N. Toyoshima (KEK), and H. Nakashima (JAEA).

Nuclear Science

Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-12
Twelfth Workshop Proceedings

Hosted by the
Fermi National Accelerator Laboratory (FNAL)
Batavia, Illinois, US
28-30 April 2014

NUCLEAR ENERGY AGENCY
Organisation for Economic Co-operation and Development

Executive summary

The twelfth SATIF workshop (SATIF-12) took place at the Fermi National Accelerator Laboratory (FNAL), Batavia, US on 28-30 April 2014. The workshop was chaired by N. Mokhov and was attended by 65 participants representing 29 organisations of 10 countries.

Support for the SATIF workshop is now part of the mandated activity of the Expert Group on Radiation Transport and Shielding (EGRTS, chaired by R. Grove from ORNL) of the Working Party on Scientific Issues of Reactor Systems (WPRS) of the NEA Nuclear Science Committee (NSC). The EGRTS also co-ordinates maintenance and development of the Shielding Integral Benchmark Archive and Database (SINBAD) of Reactor Shielding, Fusion Neutronics and Accelerator Shielding benchmark experiments.

More information on the activities of the WPRS can be found at: http://www.oecd-nea.org/science/wprs/index.html.

The main objectives of the SATIF Workshops are to:

- promote the exchange of information among experts in the field of accelerator shielding and related topics;
- identify areas where international co-operation can be fruitful;
- undertake a programme of work in order to achieve progress in specific priority areas.

SATIF-12 is sponsored by the NEA and its Nuclear Science Committee (NSC) and co-sponsored by the Office of Science of the US Department of Energy and FNAL. The workshop consisted of 7 technical sessions (including a poster session) and a wrap up session summarising achievements and defining further work for the next two years. The highlight of the workshop was a tour to the Fermilab ASTA and PXIE Facilities, Tevatron A/E sector and D0 detector, Pbar Rings, the Neutron Therapy Facility and a face-to-face meeting with the Fermilab radiation experts.

There were 7 technical sessions:

- Source Term and Related Topics
- Induced Radioactivity
- Radiation Shielding
- Medical Accelerators
- Status of Codes and Data Bases
- Code Benchmarking and Inter-comparison
- Poster Session

The first session was chaired by H. S. Lee (POSTECH) and focused on source term and related topics. Six presentations were made, including introductions on the installation of new facilities and discussions on evaluations related to radiation protection as well as techniques being employed in the development of new detectors. As more facilities are being made available for external users around the world, the participants recognised that more information, such as beam availability and field property of the relevant facility, needs to be easily accessible for external users to help identify the facilities which would most suit the needs. There has been growing interest in utilising new types of radiation sources in evaluations for radiation protection purposes to reflect the latest trend in high power lasers. Estimation of environmental effect due to radioactive material released from the Hadron Experimental Facility of J-PARC was also reported.

The second session was chaired by H. Nakashima (JAEA) and S. Rokni (SLAC) and targeted induced radioactivity. The session contained eleven presentations. The main themes of discussions consisted of issues associated with estimation and evaluation of residual activity (and cool down) and handling and storage of activated materials (e.g. leaching of tritium from shielding and soil with or without ground water, different scenario studies for temporary storage, etc.) from the viewpoint of radiation protection. Estimation of residual activity requires a vast accumulation of measured data with various irradiation conditions (particle, energy), various atomic composition, and chemical types as well as analyses. Extensive measurements, benchmarking of models and codes enable optimisation in many applications, such as in designing nuclide inventory in accelerators or designing target chambers. On the other hand, the recent trend of increase in the power or the use of heavy ions is bringing new challenges in shielding and radiation protection and further development in modelling and validation is needed for improved accuracy in analyses to meet the requirements.

The third session was chaired by H. Hirayama (KEK) and V. Vylet (TJNAF) and focused on radiation shielding of different types of facilities including spallation neutron sources, radioactive ion beams, heavy-ion accelerators, and electron accelerators. There were ten presentations in the session. Monte Carlo calculations (together with empirical models) are now extensively utilised in shielding analyses and designs, especially in upgrading the existing facilities and designing new facilities (with high energy and luminosity, heavy ions). However, they require not only large computation power, but also considerable man-power for preparations. Recent advances in the development of a tool drew a lot of interests on the part of the participants as it saves substantial amounts of analyst time as well as achieving well-converged solutions in substantially less computer time. Also, it was suggested that users should not rely on such powerful tools without understanding the physics of the subject. The participants also shared risks associated with the use of powerful Monte Carlo programmes, such as the risk of being over-confident with the calculated results and overlooking the complexity of the problem in simulations.

The fourth session was chaired by V. Mares (HZM) and focused on medical accelerators. The session contained four presentations. Today, most radiation therapies are performed using with high-energy X-rays due to cost and availability. However, different technologies are being developed to improve the efficacy of radiotherapy treatments and ultimately the overall quality of life of the patients. In this session, the success and challenges of such technologies were presented including neutron therapy and various particle beam radiation therapies (protons and ions). It was discussed and agreed that a simulation bridge between physical processes and biological processes is needed.

The fifth session was chaired by A. Ferrari (CERN) and the status of codes and databases was discussed. There were four presentations in the session. The participants showed interest in potential contribution to the activities of NEA Expert Group on Radiation Transport and Shielding. For example, accelerator benchmarks (e.g. on deuteron beam experiments) and contribution to review the current SINBAD benchmarks may be made available for the Shielding Integral Benchmark Archive and Database (SINBAD) supported by the SATIF experts. The latest developments of the FLUKA and MARS codes were presented. Some requests were made for inclusion in the future SATIF workshops of presentations on developments of other Monte-Carlo particle transport simulation codes, which were not presented this time (e.g. PHITS, MCNP) and of discussions on safety factors applied in design and licensing of facilities.

The sixth session was chaired by R. Grove (ORNL) and focused on code benchmarking and inter-comparison exercises. The session contained four presentations. Extensive benchmarking and inter-comparisons were presented for the codes FLUKA, GEANT4, MARS15 and PHITS and phenomena. The results on the inter-comparison proposed at the last workshop (SATIF-11) revealed some unexpected discrepancies among results from different codes (in the energy range of 10-100GeV and with increasing angle) and indicated that further comparisons and analyses were needed for the next workshop (possibly, comparison with experimental measurements).

For the first time in the history of SATIF, a poster session was held, due to the high number of submitted contributions that could not be accommodated in the oral session. The session attracted 11 contributions from ESS (2), HZDR (2), Fermilab (4), FRIB (1), JLab (1), and KEK (1) in the topics of radiation protection (7), design of instrumentation (3), and code development (1).

The last session was dedicated to summarising the workshop, identifying areas of co-operation for the next two years, identifying actions required in order to achieve desired progress in the different research areas and monitoring the progress achieved in actions decided in past workshops. Several comments and suggestions were made by the participants and by N. Mokhov and P. Vaz in particular. Some participants showed interest and were encouraged to participate in NEA EGRTS activities and in particular, to participate in the compilation of new experimental data and review of SINBAD.

There were on-going investigations on possible causes of the systematic underestimation or overestimation of code-computed results compared with experimental results (by factors ranging up to a factor of 10 in some cases). The participants agreed on the need to perform further analyses to better understand the reasons for the underestimations and inform the community on their findings. This need was also supported by the outcome results of the computational benchmark proposed by H. Hirayama at SATIF-11. The results from the benchmark indicated a further need to compare total cross-sections used by each code as well as compare total neutron fluence, and total energy fluence emitted from the target. Furthermore, comparison with experimental measurements seemed essential.

Discussions were undertaken on the available computational methods to perform radiation damage assessment and to compute displacement per atom (dpa), helium production, etc. The need to validate models currently used for dpa calculation, using measurements already identified at the SATIF-11 meeting, was re-stated. Suggestions for topics to be addressed in the future SATIF workshops included discussions on state-of-the-art of radiation transport in molecular dynamics and multi-scale modelling.

It was suggested that the next SATIF workshop (SATIF-13) be held in 2016 in Europe following the tradition of rotating the venue between America, Europe and Asia. Anna Ferrari (HZDR) presented that Helmholtz-Zentrum Dresden-Rossendorf is ready to organise SATIF-13 with the support of the Technische Universität Dresden in Dresden, Germany. A technical tour to ELBE (Electron Linac for beams with high Brilliance and low Emittance) may be arranged. A. Ferrari agreed to explore details of the potential arrangements. An interest in hosting SATIF-13 was also expressed by P. Ortego (SEA) at the fourth EGRTS meeting of WPRS held in February 2014 at the NEA. Final confirmation will be provided well in advance of the next meeting. Participants thanked the General Chairman N. Mokhov and FNAL for hosting SATIF-12, for the outstanding scientific programme, for the friendly atmosphere that contributed to foster intense scientific discussion and for their kind hospitality. The Chairman adjourned the meeting.

The members of the Scientific Committee of SATIF-12 were:

S. Ban (KEK), M. Brugger (CERN), R. Grove (ORNL), J. Gulliford (NEA), H. Hirayama (KEK), G. Hughes (LANL), B. Kirk (honorary), H.S. Lee (PAL), S. Mashnik (LANL), N. Mokhov (the general chairman of SATIF-12, FNAL), G. Muhrer (ESS), T. Nakamura (honorary), H. Nakashima (JAEA), S. Roesler (CERN), S. Rokni (SLAC), E. Sartori (honorary), M. Silari (CERN), T. Valentine (ORNL), P. Vaz (IST), and A. Yamaji (NEA).

The members of the Local Organising Committee (from FNAL) were:

M. Bruce, D. Cossairt, N. Mokhov, V. Pronskikh, I. Rakhno, C. Sazama, K. Vaziri, and S. Weber.

Foreword

The transport of radiation through shielding materials is a major consideration in the safety design studies of nuclear power plants, and the modelling techniques used may be applied to many other types of scientific and technological facilities. Accelerator and irradiation facilities represent a key capability in R&D, medical and industrial infrastructures and can be used in a wide range of scientific, medical and industrial applications. Intermediate-energy ion accelerators, for example, are now used not only in fundamental and applied research, but also for therapy as part of cancer treatment.

While the energy of the incident particles on the shielding of these facilities may be much higher than that in nuclear power plants, much of the physics associated with the behaviour of the secondary particles produced is similar, as are the computer modelling techniques used to quantify key safety design parameters, such as radiation dose and activation levels. Clear synergies exist, therefore, with other technical work being carried out by the Nuclear Energy Agency (NEA), and its Nuclear Science Committee (NSC) continues to sponsor activities in this domain.

One of these activities concerns "Shielding Aspects of Accelerators, Targets and Irradiation Facilities" (SATIF). A series of workshops have been held over the last 20 years: SATIF-1 was held on 28-29 April 1994 in Arlington, Texas; SATIF-2 on 12-13 October 1995 at CERN in Geneva, Switzerland; SATIF-3 on 12-13 May 1997 at Tohoku University in Sendai, Japan; SATIF-4 on 17-18 September 1998 in Knoxville, Tennessee; SATIF-5 on 17-21 July 2000 at the NEA in Paris, France; SATIF-6 on 10-12 April 2002 at the SLAC National Accelerator Laboratory[*], Menlo Park, California; SATIF-7 on 17-18 May 2004 at ITN, Sacavem, Portugal; SATIF-8 on 22-24 May 2006 at the Pohang Accelerator Laboratory in Pohang, Korea; SATIF-9 on 21-23 April 2008 at Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee; SATIF-10 on 2-4 June 2010 at CERN in Geneva, Switzerland; SATIF-11 on 11-13 September 2012 at the High-energy Accelerator Research Organisation (KEK) in Tsukuba, Japan; SATIF-12 on 28-30 April 2014 at Fermi National Accelerator Laboratory (FNAL) in Batavia, Illinois.

The 13th workshop on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-13) took place in Dresden, Germany and was jointly organised by the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the Expert Group on Radiation Transport and Shielding (EGRTS) of the Working Party on Scientific Issues of Reactor Systems (WPRS) of the NEA.

The workshop was sponsored by HZDR and co-sponsored by the NEA and its NSC. The current proceedings provide a summary of the discussions, decisions and conclusions as well as the text of the presentations made at the thirteenth workshop.

[*] *The "Stanford Linear Accelerator Center (SLAC)" at that time.*

Executive summary

The 13th Workshop on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-13) took place at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany on 10-12 October 2016. The workshop was chaired by Anna Ferrari (HZDR) and was attended by 71 participants representing 32 organisations of 11 countries.

Support for the SATIF workshop is now part of the mandated activity of the Expert Group on Radiation Transport and Shielding (EGRTS, chaired by R. Grove from ORNL) of the Working Party on Scientific Issues of Reactor Systems (WPRS) of the NEA Nuclear Science Committee (NSC). The EGRTS also co-ordinates maintenance and development of the Shielding Integral Benchmark Archive and Database (SINBAD) of reactor shielding, fusion neutronics and accelerator shielding benchmark experiments[1].

The main objectives of the SATIF workshops are to:

- promote the exchange of information among experts in the field of accelerator shielding and related topics;
- identify areas where international co-operation can be fruitful;
- undertake a programme of work in order to achieve progress in specific priority areas.

SATIF-13 was sponsored by HZDR and co-sponsored by the NEA and its NSC. The workshop consisted of seven technical sessions and one poster session, and a wrap-up session summarising achievements and defining further work for the next two years. Highlights of the workshop were a presentation on "HZDR Laser-Plasma Research Program" by T. Cowan (Director Institute of Radiation Physics, HZDR) and a tour to the HZDR ELBE (Electron Linac for beams with high Brilliance and low Emittance).

The seven technical sessions were as follows:

- Session I: Source terms and related topics
- Session II: Induced radioactivity
- Session III: Radiation shielding and dosimetry
- Session IV: Laser-plasma interaction and acceleration
- Session V: Medical accelerators
- Session VI: Status of codes and data libraries
- Session VII: Code benchmarking and intercomparison

1. More information on the activities of the NEA/WPRS can be found at: www.oecd-nea.org/science/wprs/.

The detailed programme is provided in Annex 1, and most of the presentations can be found at: www.hzdr.de/SATIF13.

The first session was chaired by H. Hirayama (KEK) and focused on source terms and related topics. Four presentations were made in the session, including estimation of source term to environment from the target station and discussions related to neutron production rates with protons below 20 MeV, 50 MeV/nU and high energy electrons. From the comparisons of neutron production rates between measurements and calculations with Monte Carlo codes, factor 2 or more differences were presented in some conditions. Source term is one of the most important parameter for shielding calculations. It is desire to obtain more experimental results and to perform the benchmarking studies for neutron production by various particles.

The second session was chaired by D. Kiselev (PSI) and S. Roesler (CERN) and targeted induced radioactivity. The session contained seven presentations. Radiological characterisation of irradiated material is imperative not only for disposal but also for free release, i.e. avoiding waste. While measurements are preferable, they are often not straight forward to perform. In order to complement measurements, calculations are of high importance because they can be performed well in advance of dismantling campaigns and they allow radiological characterisation of components that are either inaccessible before dismantling or too radioactive for direct measurements. At the same time, the predictable power of calculations may be affected by uncertain irradiation histories and material compositions. The following needs for future developments or considerations were suggested:

- Integration of radiological characterisation into design and operation:
  - recording of history of components and tracking after dismantling;
  - comprehensive dose-rate measurements and recording over entire life time;
  - recording of beam losses over accelerator life time;
  - placement of material samples representative of actual components;
  - assessment and record of elemental composition including trace elements relevant for waste disposal;
  - optimisation of design for future dismantling;
  - assessment of nuclide inventory as soon as possible.
- Instrumentation to allow efficient measurements:
  - mobile instrumentation;
  - 4pi counter;
  - instrumentation allowing direct measurements of beta emitters without need for radiochemical methods.
- Calculation methods/tools:
  - Assessments for radioactive waste where irradiation history is not available.
  - Efficient assessments for contribution of trace elements to nuclide inventory.
  - Parametrisation of Monte Carlo studies in order to avoid repeating full-scale Monte Carlo calculations in case of design changes or for assessments of the activation of sub-components.
  - Scaling factors from measurable to total radiotoxicity and from external dose rates to nuclide inventory.
  - Benchmarks, especially for beta emitters.

The third session was chaired by T. Sanami (KEK), H.-S. Lee (PAL) and A. Leuschner (DESY) and focused on radiation shielding and dosimetry of different types of facilities including major spallation neutron sources, heavy-ion accelerators and electron accelerators. There were 12 presentations in the session:

- Two from ISIS and SNS described the analysis of neutron production from new high power proton targets and the design of targets and peripherals.
- MARS 15 code was applied for shielding studies for ESS and ILC and the dark current was estimated in detail.
- Six practical studies based on commissioning or measurement results were presented for electron, proton and heavy-ion facilities with two shielding design reports of FRIB.
- Shielding designs using Monte Carlo code touch very deep item like delicate structure of accelerator and the data-based design showed more credit.

The fourth session was chaired by J. Bauer (SLAC) and focused on laser-plasma interaction and acceleration, which is an important emerging field with peculiar shielding problems. The session contained four presentations about the issues faced by the laser facilities at ELI, SLAC, and the European XFEL (there were also poster presentations about ELI, Spring-8/SACLA, and HZDR)**.**

A major point of study is the source term. Depending on the type of target, a different source term applies, and these source terms depend on many parameters and uncertainties, some of which are difficult to control. Similarly, the measurements of the resulting dose are highly dependent on these parameters and the exact conditions during the shots. For solid targets, a new source term was presented that is based on particle in cell (PIC) calculations, which use the basic Maxwell equations to step through the laser-target interactions in space and time. Further studies and measurements are expected from several laboratories.

The fifth session was chaired by M. Silari (CERN) and focused on medical accelerators. The session contained three presentations on very different topics, two linked to hadron therapy and one to radionuclide production. The first talk discussed neutron measurements and dosimetry at hadron therapy accelerators, addressing specific issues namely the pulsed nature of the neutron field and the very low radiation level outside shielding. The latter may pose regulatory monitoring problems because of the need to discriminate the neutron signal from natural background. Issues of neutron dosimetry with medical accelerators are also linked to medical dosimetry presented in the third session. The second talk discussed secondary neutron dose to the proton therapy patient, which – with up to a few mSv of stray dose per therapy Gy – may lead to a few percent lifetime excess cancer risk. Various approaches can be adopted to mitigate the problem, from shielding the nozzle or the patient, to replacement of nozzle material or a combination of the two. The third talk discussed the recent “discovery” of the production of tritium via the $^{18}O(p,t)^{16}O$ reaction in ^{18}O-enriched water target. Although tritium is never present in the final radiopharmaceutical to be injected in the patient, it may pose regulatory issues for licensing/import/export of non-irradiated and irradiated ^{18}O-enriched water.

The sixth session was chaired by N. Mokhov (FNAL) and the status of codes and data libraries was discussed. There were four presentations in the session:

- The fist talk introduced some of the FLUKA’s new features (improvements/ new features related to the large hadron collider (LHC) and future high energy projects, new features in electromagnetic dissociation, fully correlated pointwise neutron cross-sections for a few selected isotopes, improved ion-ion nuclear models for medical applications).
- The second talk introduced new data of electron-photon-relaxation for MCNP6 and plans for verification and validation testing of the data.
- The third talk introduced new features of the latest version of Geant4 and results of shielding benchmarks for the latest Geant4.
- The fourth talk introduced the FLUKA Line Builder (a CERN tool to generate FLUKA geometry from set of elements).

The seventh session was chaired by H.G. Hughes (LANL) and Alfredo Ferrari (CERN), and focused on code benchmarking and inter-comparison exercises. The session contained nine presentations. Four were code benchmarking exercises:

- Simulations using FLUKA in LHC;
- FLUKA/photon and neutron dose rates around thick targets irradiated with GeV electrons;
- PHITS/neutron attenuation in iron and concrete during shielding experiments at proton accelerator facilities (TIARA/RCNP/AGS);
- FLUKA/Bi and Al activations around a Cu target irradiated with GeV protons.

Five were code inter-comparison exercises:

- Geant4, PHITS, MCNPX, MARS/fluence, energy fluence, spectra, angular integral energy fluence of neutrons from Al/Cu/Au targets irradiated with 1/10/100 GeV protons;
- FLUKA, MARS, Geant4/muon fluence and absorbed dose after massive iron shielding induced by GeV electrons;
- Geant4, FLUKA, MCNP/photo-nuclear production from targets irradiated with MeV electrons/photons;
- FLUKA, PHITS, MCNPX, MARS/various cases of neutron yield, neutron attenuation, and activation for designing large accelerator facilities;
- Geant4, FLUKA, MCNPX/Po production in Pb irradiated with MeV protons.

A poster session was held as had been held previously at SATIF-12, due to the high number of submitted contributions that could not be accommodated in the oral sessions. The session attracted 21 contributions from CNAO (1), CNSC (1), ELI Beamlines (1), ESS (2), Fujita Corp. (1), Hanyang Univ. (1), HZDR (10), KAERI (2), RIKEN (1), and TUV SUD Nucl. Tech. (1) in the topics of source terms and related topics (1), induced radioactivity (3), radiation shielding and dosimetry (3), laser-plasma interaction and acceleration (4), code benchmarking and inter-comparison exercises (3), and presentations of facilities (7).

Related to one of the contributions, “Standardisation of concrete for radiation shielding” was orally presented in order to discuss possible collaboration works on the topic at the end of the seventh session.

The last session was chaired by R. Grove and was dedicated to summarising the workshop, identifying areas of co-operation for the next two years, identifying actions required in order to achieve desired progress in the different research areas, and monitoring the progress achieved in actions decided in past workshops.

Following a comprehensive summary of the sessions 1-7 by N. Mokhov, H. Hirayama emphasised that, in addition to presentations of various research works, the SATIF community has to organise “tasks” suitable for the main SATIF objectives:

- Organise working groups.
- Work together as an international collaboration.
- Present the results obtained by the collaborations at the SATIF meeting in order to improve the knowledge in the field of “Shielding aspects of Accelerators, Target and Irradiation Facilities”.

H. Hirayama introduced the following as ongoing/new tasks (the new are underlined):

- exchange information about “Status of codes and data libraries”;
- intercomparison of particle production:
  - particle production (currently, neutron production by high-energy protons) from targets; **add neutron production by 2-20 MeV protons (including low-Z materials) and by Giant-resonant photons;**
  - contribution of the results by code developers and code users;
  - difference between codes for simple problems;
- intercomparison and benchmark for muon fluence and absorbed dose in shielding irradiated by electron beams;
- neutron production cross-sections for low-energy protons;
- standard concrete for radiation shielding.

H. Hirayama also mentioned the importance of SINBAD for Verification and Validation of various radiation transport codes. A review of the status of SINBAD at the next SATIF meeting (SATIF-14) was requested.

Highlights from the poster session were briefly introduced by Anna Ferrari. The participants agreed that the poster session was useful for the SATIF Workshop.

In the discussion, several comments and suggestions were made by the participants. Extensions of regions of the participants (Asia and America, especially), the workshop format (3 days to 3.5/4 days), and sessions to nuclear-data evaluation were proposed. E. Sartori (honorary member of the SATIF Scientific Committee) reminded the participants about several historical points, especially that the SATIF workshop is a system of information exchange for the main objectives, different from ordinary international conferences. E. Sartori hoped that more contributions to the “SATIF tasks” would be made by the participants.

It was suggested that SATIF-14 be held in 2018 in Asia following the tradition of rotating the venue between America, Europe and Asia. On behalf of Korea Multipurpose Accelerator Complex (KOMAC) and Pohang Accelerator Laboratory (PAL), H.-S. Lee presented a proposal for the next SATIF-14 in 2018. KOMAC and PAL are considering organising SATIF-14 in Pohang or Gyeongju, Korea. Dates and venue will be fixed and provided well in advance of the next meeting.

Participants thanked the General Chair Anna Ferrari and HZDR for hosting SATIF-13, for the outstanding scientific programme, for the friendly atmosphere that contributed to foster intense scientific discussion and for their kind hospitality. The Chair adjourned the meeting.

After the workshop, the technical tour to the HZDR ELBE facility was arranged. Participants in the tour had a chance to visit the facilities in ELBE and have face-to-face meetings with the HZDR radiation experts.

The members of the Scientific Committee of SATIF-13 were: S. Ban (High Energy Accelerator Research Organization – KEK, Japan), F. Cerutti (CERN), Anna Ferrari (the general chair of SATIF-13, HZDR), R. Grove (ORNL), J. Gulliford (NEA, France), H. Hirayama (KEK), G. Hughes (LANL), B. Kirk (honorary), H.-S. Lee (PAL), N. Mokhov (FNAL), G. Muhrer (ESS), Y. Nakahara (NEA, France), T. Nakamura (honorary), H. Nakashima (JAEA), S. Roesler (CERN), S. Rokni (SLAC), E. Sartori (honorary), M. Silari (CERN), T. Valentine (ORNL), and P. Vaz (IST).

The members of the local organising committee (from HZDR) were: A. Ferrari, S. Müller, U. Schramm, R. Schwengner, and A. Varga.

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NUCLEAR ENERGY AGENCY
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Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-14

Proceedings of the Fourteenth Workshop, 30 October-2 November 2018, Gyeongju, Korea

Please note that this document is available in PDF format only.

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Executive summary

The 14th workshop on Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-14) took place at Hilton Gyeongju in Gyeongju, Korea on 30 October – 2 November 2018. The workshop was chaired by Y.S. Min (KOMAC) and H.S. Lee (PAL) and was attended by 64 participants representing 30 organisations from 10 countries.

Support for the SATIF workshop is now part of the mandated activity of the Expert Group on Radiation Transport and Shielding (EGRTS, chaired by R. Grove from ORNL) of the Working Party on Scientific Issues of Reactor Systems (WPRS) of the Nuclear Energy Agency (NEA) Nuclear Science Committee (NSC). The EGRTS also co-ordinates maintenance and development of the Shielding Integral Benchmark Archive and Database (SINBAD) of reactor shielding, fusion neutronics and accelerator shielding benchmark experiments.

The main objectives of the SATIF workshops are to:

- promote the exchange of information among experts in the field of accelerator shielding and related topics;
- identify areas where international co-operation can be fruitful;
- undertake a programme of work in order to achieve progress in specific priority areas.

SATIF-14 was sponsored by KOMAC and PAL and co-sponsored by the NEA and its NSC. The workshop consisted of six technical sessions and one poster session, and a wrap-up session summarising achievements and defining further work for the next two years. The highlight of the workshop was a trip to the high power proton linac and utilising facilities at KOMAC and Pohang Light Souce II (PLS-II) and PAL X-ray Free Electron Laser (PALXFEL). Those facilities are very impressive. The workshop participants also enjoyed exploring ancient capital city, Gyeongju, and a local fish market.

The six technical sessions were as follows:

Session I: Source terms and related topics

Session II: Radiation shielding and dosimetry

Session III: Beam-plasma and laser-plasma interactions and acceleration

Session IV: Code status and medical and industrial accelerators

Session V: Induced radioactivity

Session VI: Code benchmarking and intercomparison

The first session was chaired by H. Nakashima (JAEA) and focused on source term and related topics. Three presentations were made, including various sources of highly-intensive protons, dark current of long linac and photoneutrons. The latter two subjects were not supported by sufficient experimental data until now.

The second session was chaired by I. Popova (ORNL), S. Rokni (SLAC) and V. Mares (Helmholtz Munchen) and was dedicated to shielding and dosimetry. The session contained 13 presentations. CERN CHARM & CSBF mixed field facility where about 150 configurations are available is useful for shielding study and dosimetry of high-energy radiation. Fundamental measurements of Bi(p, xn) radionuclide yields and benchmarking contributes to improve the code development. Such an experimental study is recommended to be performed by SATIF community members. Reflecting the recent trend, the presentations of shielding studies of heavy ion accelerators and high power accelerators became more interesting.

The third session was chaired by R. Qui (Tsinghua Univ.) and targeted beam-plasma and laser-plasma interactions. This topic was introduced to shielding group recently. Three presentations gave experimental results, dose estimation and application method of shielding design.

The fourth session was chaired by H. Iwase (KEK) and focused on code status and medical, industrial accelerators. Three presentations introduced shielding and activation issues of the latest and important types of medical accelerator: particle therapy, BNCT and PET cyclotron. The decommissioning of PET cyclotrons became a big issue because of the number of operating machines in the world; the process is somewhat different from the decommissioning of high-energy accelerators. Also, a new functional idea of uncertainty in PHITS calculations was presented.

The fifth session was chaired by A. Ferrari (Helmholtz Dresden) and targeted induced activity. The session contained five presentations. Wider application of ActWiz II was introduced. A Japanese group lead by K. Kimura presented impressive studies of a "standard" concrete model. A possible collaboration with other countries and facilities was suggested.

The sixth session was chaired by V. Vylet (Jefferson Lab); eight presentations were dedicated to code benchmarking and intercomparison. One of the primary objectives of SATIF meetings has been de facto simulation code benchmarking. Several experimental results gave sufficient results for the code developers and for the entire SATIF community. Serial study of code comparison lead by H. Hirayama revealed the strengths and limitations of each code used by SATIF community members.

Following the previous meeting, a poster session was held, due to the high number of submitted contributions in the oral session. It helped to keep sufficient time for oral presentations and to make detailed discussions possible during the poster presentations. The session attracted nine contributions in the topics of shielding analysis (5), concrete composition (1), benchmarking (1), new calculation module (1) and facility status (1).

The session highlights were summarised during the last session by N. Mokhov and H. Hirayama. The objectives and activities of the SATIF community were emphasised: the idea is to co-ordinate analysis and propose action items, not just to hold workshops. During the last two decades, every SATIF meeting has highlighted the dedicated, well-thought experimental studies, benchmarking simulation results against the data, simulation code intercomparison and those results and future plans on the code developments. It was also suggested to add the following items from the objectives of SATIF workshop:

- information necessary to improve the shielding design, such as new or improved data;

- requests of new functionalities to code developers needed for the improvement of shielding design, such as a survey of the participants or a task force created by the time of the next SATIF workshop;
- In particular, the same requests for the "standard" concrete.

Practical action items related to the above were proposed. Gathering the appropriate information will be useful for future activities of the SATIF workshops.

The NEA Secretariat representative, S. Tsuda, explained how the NEA Nuclear Science Committee (NSC) supports SATIF-related activities, and the role of SATIF. With the impressive status of the upgrading plan of SINBAD (Shielding Integral Benchmark Archive and Database), which evaluates the present data and performs the technical review, it is suggested that all SATIF colleagues join the plan.

It was suggested that the next SATIF workshop (SATIF-15) be held in 2020 in the United States following the tradition of rotating the venue between America, Europe and Asia. Dali Georgobiani, on behalf of the Facility for Rare Isotope Beams (FRIB), Michigan State University (MSU), presented a proposal for the SATIF-15 that was planned to take place in 2020. The workshop will take place at FRIB (MSU campus). *Due to the COVID-19 pandemic, the date of SATIF-15 was tentatively moved to September 2022.*

The members of the Scientific Committee of SATIF-14 were: S. Ban (KEK), F. Cerutti (CERN), A. Ferrari (HZDR), R. Grove (ORNL), J. Gulliford (NEA), H. Hirayama (KEK), G. Hughes (LANL), B. Kirk (honorary), H.-S. Lee (the general co-chairman of SATIF-14, PAL), N. Mokhov (FNAL), G. Muhrer (ESS), T. Nakamura (honorary), H. Nakashima (JAEA), S. Roesler (CERN), S. Rokni (SLAC), M. Silari (CERN), S. Tsuda (NEA), T. Valentine (ORNL), and P. Vaz (IST).

The members of the Local Organising Committee were: N.S. Jung (PAL), M.H. Kim (PAL), H.-S. Lee (PAL), Y.S. Min (the general co-chairman of SATIF-14, KOMAC), and S.G. Park (KOMAC). All members of PAL Radiation Safety Team contributed for the friendly atmosphere and intense scientific discussions.

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SATIF-15: 15th workshop on Shielding aspects of Accelerators, Targets, and Irradiation Facilities (SATIF)

SATIF-15 Workshop participants. Photo: courtesy of the Facility for Rare Isotope Beams (FRIB)

Introduction

The 15th Workshop on Shielding aspects of Accelerators, Targets, and Irradiation Facilities (SATIF-15) took place at the Facility for Rare Isotope Beams (FRIB) at Michigan State University on 20-23 September 2022. The workshop was chaired by Dali Georgobiani (Fermi National Accelerator Laboratory, USA) as Chair of the Scientific Programme Committee and Thomas Ginter (FRIB, USA) as Chair of the Local Organizing Committee. The workshop was sponsored by FRIB and co-sponsored by the NEA.

Support for the SATIF workshops is now part of the mandated activity of the Expert Group on Radiation Transport and Shielding

(EGPRS) of the Working Party on Scientific Issues of Reactor Systems (WPRS) of the NEA Nuclear Science Committee (NSC). The EGPRS also co-ordinates maintenance and development of the Shielding Integral Benchmark Archive and Database (SINBAD) of reactor shielding, fusion neutronics and accelerator shielding benchmark experiments.

There was an unforeseen 2-year delay of the workshop due to the COVID-19 pandemic. Furthermore, to accommodate the participants who were unable to travel, and to protect the workshop from cancellation due to a feasible pandemic surge, the workshop was carried out in a hybrid format. There were 130 registered participants. 43 of them were registered for in-person participation; the actual number of in-person participants was 35. There were 40 registered talks, 28 of them in-person, and 14 posters. 2 oral presenters and 2 poster presenters could not make it to the workshop for personal reasons.

SATIF-15 Workshop Sessions

The workshop consisted of eight technical sessions and one poster session, and a summary session where the status of the SATIF community and its efforts was summarised, and future actions were proposed. The workshop participants had also the opportunity to tour the Facility for Rare Isotope Beams.

Overall, there was a very impressive array of presentations, showcasing great achievements with respect to various new and emerging code modules, reviews of radiation environments at diverse facilities, as well as continuing research (such as standard concrete studies or intercomparison of particle production). Experts and developers of four major Monte-Carlo radiation transport codes – FLUKA, MARS, MCNP, and PHITS – presented the code advances, new features, and modules. Several talks featured state-of-the-art methods, such as Machine Learning implementations.

- ***Session 1: Facility Reports / Shielding & Dosimetry*** ***(***5 talks: 4 in-person, 1 remote):
  The session was chaired by Anna Ferrari (HZDR). The session

featured the host facility radiation analysis presentation by Tom Ginter (FRIB), as well as overview of shielding analyses at the ESS, ORNL, and LANL facilities.

- **Session 2: Code Status, Advances, & Model Converters** *(*5 talks: 4 remote, 1 in-person):
  The session was chaired by Hideo Hirayama (KEK). The highlights of the session were the presentations of two of the major Monte-Carlo codes, the Fermilab-based MARS code and the two separately maintained versions of the FLUKA code.
- ***Session 3: Code Status, Advances, and Model Converters [continuation]*** *(*5 talks: 3 in-person, 2 remote):
  The session was chaired by Francesco Cerutti (CERN). The session started with the presentation on recent updates and benchmarking of another major Monte-Carlo radiation code, PHITS. Several talks were devoted to new updates to the existing numerical techniques, and their applications at various facilities.
- **Session 4: Code Benchmarking & Intercomparison** (6 talks: 6 in-person):
  The session was remotely chaired by Nikolai Mokhov (FNAL). Juan Zamora (FRIB) discussed ML scaling models within the FRIB radiation analysis framework. Code intercomparison and benchmarking via a simple model analysis or accelerator shielding applications were also showcased by the presenters. Hideo Hirayama (KEK) presented the latest iteration in the series on the intercomparison of particle production, the effort that he leads with participation from the major Monte-Carlo code experts. The SINBAD task force presentation was delivered by Oliver Buss (NEA).
- **Session 5: Code Benchmarking & Intercomparison (continuation) / Induced Radioactivity & Decommissioning** (6 talks: 6 in-person):
  The session was remotely chaired by Mikhail Kostin (JLAB). Talks on code benchmarking continued with contributions from PAL and CERN. CERN and STFC colleagues also contributed to the discussion of decommissioning issues at accelerator facilities, while decommissioning of nuclear power plants was stud-

ied by a colleague from HZDR.

- **Session 6: Shielding & Dosimetry** (6 talks: 3 in-person, 3 remote):
  The session was chaired by Hee-Seock Lee (PAL). More talks from CERN described radiation analysis of the existing facilities and their upgrades. Kenichi Kimura (Fujita Corp) presented a talk on the concrete composition for radiation shielding, while Hiroshi Iwase (KEK) discussed the importance of water and iron content in concrete for neutron shielding applications. The BNL ARI-SXN beamline radiation shielding analysis was presented by Ricardo Augusto. Federico Chiarelli (INFN) delivered a talk on skyshine.
- ***Session 7: Source Terms / Medical Accelerators*** ***(***3 talks: 1 in-person, 2 remote):
  The session was chaired by Oliver Buss (NEA). Hee-Seock Lee (PAL/POSTECH) discussed photon-neutron emission for low-energy photons; the KEK team (Kenta Sugihara) discussed the application of a time-of-flight method to measure neutron production yields. A medical application talk (Gonzalo Fernandez, UP Madrid), devoted to new delivery methods in proton therapy at Compact Proton Therapy Centers, was not delivered because of technical problems.
  Session 7 also included two talks with the proposals for the next SATIF workshop: a proposal from GANIL and LPC Caen presented by Manssour Fadil, and another proposal from Frascati National Laboratories (INFN-LNF) presented by Raffaella Donghia.
- **Poster Session** (12 posters):
  Session 7 was followed by the Poster Session that was organized due to a high number of submitted contributions. The virtual poster session was set up in Gather Town to enable simultaneous participation by in-person and remote participants. Out of 14 registered posters, 12 were presented and discussed in lively virtual conversations.
- ***Session 8: Radiation Damage / High Intensity Laser Facilities / Techniques & Applications*** (5 talks: 1 remote, 4 in-person):
  The session was chaired by Reg Ronningen (FRIB, retired). This

session featured radiation damage analysis (Yosuke Iwamoto, JAEA), laser facility advancements from HZDR and ELI Beamlines, and discussions of new methods for plugging penetrations (Ralf Buckermann, Framatome). The session was concluded by Yasuhito Sakaki (KEK) with a discussion of atmospheric-like neutrons and muons at the ILC beam dumps.

- ***Concluding Session: Summary, Future Actions, SATIF-16***:
The summary session was chaired by Dali Georgobiani (FNAL); she also summarized workshop highlights, spoke about future actions, and delivered closing comments. Oliver Buss (NEA) presented information pertaining to workshop proceedings preparation, logistics, and timeline. The summary session is where future activities of the SATIF community, including various proposed collaborations, can be discussed. The participants are always welcome to propose further needs and tasks aligned with the SATIF framiework.

Workshop Conclusions

The workshop resulted in the following major conclusions:

- Discussion surrounding the advancements and utilization of major radiation transport codes stands as a cornerstone within SATIF. SATIF-15 has shown significant progress in code intercomparison and benchmarking, pivotal for ensuring accuracy and reliability..
- SATIF-15 featured radiation environment assessments for emerging, new, and upgraded facilities employing novel techniques.
- The participation of heavy ion facilities like the FRIB as host of SATIF-15 has introduced intriguing new issues into the discourse, underscoring the evolving nature of the field.
- The observation of few proposed talks on medical accelerators or material damage perhaps suggests the need to re-attract experts from this field into the SATIF community. The few talks covering the emerging field of laser facilities was less unexpected.

- A disconnect between the code developers and the experts performing code benchmarking and intercomparison was observed and emphasizes the importance of cohesive collaboration. Efforts to reconcile differences in code results, particularly in comparison to experimental data, are crucial and differences in the underlying physics models should be investigated. The commendable work by the PHITS team exemplifies this, continuously refining its physics models based on rigorous code-to-experiment evaluations.

Throughout the workshop, the objectives and activities of the SATIF community were emphasised. Traditionally, the meeting highlighted the importance of simulation code intercomparison, benchmarking simulation results with experimental data, gathering such data as a result of dedicated and organized experimental studies, as well as current results and achievements and future plans on code development. As with earlier SATIF community gatherings, code developers received requests to add new features to the codes in order to improve code application to shielding design and other implementations.

Future of SATIF

Following the tradition of rotating the SATIF workshop venue between America, Europe and Asia, the next SATIF workshop (SATIF-16) will take place in Europe. INFN-LNF in Frascati, Italy, was selected as the site for SATIF-16 based on a vote of the SOC (6 for INFN-LNF, 4 for GANIL, 1 neutral, 5 not respoding). It is scheduled for May 28-31, 2024.

When?

20 - 23 September 2022

Facility for Rare Isotope Beams at Michigan State University, East Lansing, Michigan (USA)