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The SPES project at the INFN - Laboratori Nazionali di Legnaro

Gianfranco PRETE
INFN Laboratori Nazionali di Legnaro, Legnaro, Padova, Italy

The SPES Radioactive Ion Beam (RIB) facility is in the construction phase at INFN-LNL.
It is based on a dual exit high current Cyclotron, with proton beam energy 35-70 MeV and 0.2-0.5 mA, used as proton driver to supply an ISOL system with an UCx Direct Target able to sustain a power of 10 kW. The second exit will be used for applied physics: radioisotope production for medicine and neutrons for material study.
The ISOL system will produce neutron-rich radioactive ions by proton induced fission in the UCx target. The expected fission rate in the target is in the order of 10^{13} fissions per second. The exotic isotopes will be re-accelerated by the ALPI superconducting LINAC at energies of 10 AMeV and higher, for masses in the region of A=130 amu, with an expected rate on the secondary target of $10^7 – 10^9$ pps.
The SPES project has the aim to provide high intensity and high-quality beams of neutron-rich nuclei as well as to develop an interdisciplinary research center based on the cyclotron proton beam. The status of the project will be presented.

Topics : High power beams.

BINP accelerator based neutron source

Sergey TASKAEV
Budker Institute of Nuclear Physics, Novosibirsk, Russia

A source of epithermal neutrons for BNCT is proposed and created basing on the tandem accelerator with vacuum insulation and a lithium target.
Accelerator is characterized by the rapid acceleration of charged particles. High-voltage strength of vacuum gaps, the dark current behavior, beam focusing, acceleration and striping are studied. Stationary proton beam with an energy of 2 MeV and a current of 1 mA is obtained. The beam is highly monochromatic in energy - ± 0.1 %.
Neutron generating target for BNCT is proposed, developed and experimentally investigated. The target is a thin disc intensively cooled, coated with thin layer of lithium on the side of the proton beam. Target is cooled with water, earlier with liquid gallium. V, Ta, alfa-Fe were defined to be the material most resistant to blistering. Problem of target activation by radioactive isotope Be-7 was solved by developing a protective subsurface container for holding and temporary storage of activated targets designed as a long steel cup with a lead cover immersed in the ground.
It is proved that the Beam Shaping Assembly which includes filters of MgF_2, Al and Ti, allows us to keep directionality of neutron flux due to kinematic collimation at 1.915-2 MeV protons, and to use the near threshold mode attractive due to low activation. The Beam Shaping Assembly at 2.3-2.5 MeV protons allows forming orthogonal neutron beam providing high quality of the beam for BNCT and bringing a new opportunity to direct a neutron beam at any angle and to irradiate the patient from all sides.
Neutron generation is realized, and experimentally measured: the neutron flux through 7Be activation and activation of NaI scintillator of gamma-ray spectrometer, neutron spectrum by BDT and BD100R bubble detectors and TOF technique using innovative technical solutions generating short pulses of neutron radiation, the spatial distribution of neutron dose with dosimeter-radiometer.
Tandem accelerator with vacuum insulation with specialized targets can generate monochromatic neutrons for calibration of dark matter detector, the fast neutrons for fast neutron therapy and for dating rocks, monochromatic gamma rays with energy 478 keV, resonance 9.17 MeV gamma rays for the development of techniques prompt detection of explosives and narcotics, alpha particles to explore promising neutronless thermonuclear reaction $^{11}B(p,alfa)^2alfa$ and positrons in the reaction $^{19}F(p,alfa)^{16}O$.

Topics : Target Cooling ; BNCT

Accelerator based Epithermal Neutron Source for BNCT using Thin Layered Solid Lithium Target

Ryo FUJII[1], Yoshio IMAHORI[1], Masaru NAKAMURA[1], Jun ITAMI[2], Yoshihisa ABE[2], Hirofumi SEKI[3], Tetsuya ISHIDA[4], Nobuaki OZOE[5], Kenichi FUKUDA[5], Shigeo SHIOTA[6], Hidaka FURUYA[7]
[1] *Cancer Intelligence Care Systems, Inc., Japan*
[2] *National Cancer Center, Japan*
[3] *AccSys Technology, Inc. , Japan*
[4] *Moriya Cutlery Laboratory, Ltd. , Japan*
[5] *Shimane Institute for Industrial Technology, Japan*
[6] *Tanaka Kikinzoku Kogyo K.K. , Japan*
[7] *Nippon light metal Co., Ltd. , Japan*

By using a nuclear reactor, boron neutron capture therapy (BNCT) has been studied basically and clinically so far, and has provided many results in the basic and clinical research.
BNCT is a different approach to therapy from the existing radiotherapy, having a new concept. It is expected as the new radiotherapy for cancer treatment. BNCT is a therapy which destroys cancer cells by using alpha particle and lithium ion which are secondarily produced from the nuclear reaction of proton and boron 10.
BNCT needs epithermal neutron in addition to boron compound. The nuclear reactor has been used as the epithermal neutron source until now. But it is impossible for BNCT to provide cancer treatment to many patients if a nuclear reactor is used, which can't be served close by the patients. Therefore, the development of epithermal neutron source using an accelerator is proceeded all over the world.
There are various types of epithermal neutron sources using an accelerator. We have developed the epithermal neutron source using thin layered solid lithium as the target for neutron production.
The advantage of lithium target is to produce low energy neutron by using low energy proton beam. Therefore, moderator for generating epithermal neutron can be very compact, space-saving. As the energy of proton is low, downsizing of moderator is also possible. Therefore, our accelerator based on neutron source is the best system as an in-hospital epithermal neutron source.
We selected the RFQ linac as a proton beam accelerator which has 2.5 MeV of proton energy and 20 mA of beam current. The accelerated proton beam is bended downward at a 90-degree angle, and delivered to the treatment room under the accelerator room, then irradiated to the lithium target.
The lithium target is conically-shaped and aims at heat dispersion by increasing irradiation surface area. The laminar structure of the lithium target has a blistering countermeasure layer under the lithium layer. Copper is used as a basement for lithium target. These layers are made thinner to the minimum necessary to heighten the heat removal efficiency. We set up the system which enables automatic reproduction of lithium deposited to the target without removing the target. And thus, we can keep the condition of lithium always good.
Neutron produced by the nuclear reaction of proton and lithium is moderated to epithermal neutron through a moderator. We estimated this sintered magnesium fluoride as a moderator and found that it has the optimum characteristics of epithermal neutron for BNCT.
This system was installed into the National Cancer Center (NCC) based on a joint research between NCC and us. It is supposed to be forwarded to the clinical application.

Topics : BNCT

High-Power Proton Irradiation and Neutron Production with a Free Surface Liquid-Lithium Target

HALFON, Shlomi [1,] Michael PAUL[2], Alexander ARENSHTAM [3], Danny KIJEL[3], Leo WEISSMAN[3], Dan BERKOVITS[3], Yosef EISEN[3], Ilan ELIYAHU[3] ; Gitai FEINBERG[1], Arik KREISEL[3], Israel MARDOR[3] , Guy SHIMEL[3] ; Asher SHOR[3] ; Ido SILVERMAN[3], Moshe TESSLER[2]
[1]*Hebrew University of Jerusalem and Soreq NRC, Jerusalem, Israel*
[2]*The Hebrew University of Jerusalem, Jerusalem, Israel*
[3]*Soreq NRC, Jerusalem, Israel*

A free surface liquid-lithium jet target was bombarded for the first time with a high-intensity (~1.91 MeV, 1.3 mA, 2.5 kW) continuous-wave proton beam at Soreq Applied Research Accelerator Facility (SARAF). The apparatus, operating at a base temperature of ~200°C and a lithium flow velocity of ~2.5 m/s, experienced no significant change in temperature or vacuum. The experiments demonstrated the capability the Liquid Lithium Target (LiLiT) to dissipate extremely high ion beam power densities (>0.5 MW/cm^3) and constitute an intense source of epithermal neutrons produced by the $^7Li(p,n)^7Be$ reaction. The LiLiT device will be used to demonstrate the feasibility of accelerator-based Boron Neutron Capture Therapy (BNCT) with a lithium target, for research in stellar and Big-Bang nucleosynthesis and for Accelerator Driven Systems (ADS) material cross section measurements.

The liquid-lithium loop of LiLiT generates a stable lithium jet at high velocities (up to 7 m/s) on a concave supporting wall, with free surface toward the incident proton beam. The liquid-lithium jet acts both as a neutron-producing target and as a beam dump, by removing with the flow the thermal power deposited by high-intensity proton beams (up to 10 kW).

With a proton beam irradiation of ~1.91 MeV energy, just above the $^7Li(p,n)$ threshold of 1.880 keV, neutrons were continuously detected with a fission-chamber detector positioned at 0° with respect to the proton beam, while the intensity of the proton beam on the lithium target was monitored using the yield of gamma rays, dominated by the inelastic $^7Li(p,p'g)$ reaction. Gold activation targets positioned in the forward direction show that the average neutron intensity during the experiment was ~2×10^{10} n/s.

Topics : Target Cooling ; High Power Beams ; BNCT ; Applications.

ANEM: a rotating composite neutron production target for Single Event Effects Studies at the 70 MeV Cyclotron of LNL-INFN

Gabriela ACOSTA[1], Dario BISELLO[2], Juan ESPOSITO[3], Luigi FERRARI[3], Pierfrancesco MASTINU[3], Gianfranco PRETE[3], Luca SILVESTRIN[2], Jeffery WYSS[2]
[1]*Universidad Simon Bolivar, Caracas, Venezuela*
[2]*INFN Sezione di Padova, Padova, Italy*
[3]*INFN Laboratori Nazionali di Legnaro, Legnaro PD, Italy*

A fast neutron (E>1 MeV) irradiation facility at the SPES cyclotron at LNL is under study to investigate neutron-induced Single Event Effects (SEE) in state-of-the-art digital microelectronic components, devices and systems used in high-altitude avionics and, especially, in diverse and fast growing ground-based applications.

Here we describe the progress in designing the atmospheric-neutron emulator (ANEM), a rotating composite target, made of Be and a heavy material such as Pb, Ta or W, to produce fast neutrons in the accessible energy range (70 MeV cutoff) with a continuous energy spectrum similar to that of neutrons produced by cosmic rays at sea level (atmospheric neutrons). Of course the highest energy atmospheric neutrons have energies that reach up to a few GeV, but 66% of the neutrons with energies above 1 MeV are in the 1-70 MeV energy range. In addition there is an increased sensitivity of new digital devices to Single Event Upset induced by neutrons with energies below 10 MeV.

In ANEM, the 70MeV proton beam of the cyclotron will alternatively impinge on two circular sectors of different composition, thickness and areas; the effective neutron spectrum is composed by a weighted combination of the spectra coming from the two sectors. Thick heavy materials such as Pb, Ta or W well reproduce the lower (few MeV) energy part of the atmospheric neutron spectrum. Beryllium provides more high energy neutrons (up to the cyclotron energy) hence a Be sector is used to populate the high energy part of the spectrum where the fast neutron emission of the heavy material is too weak. By adjusting the ratio of the areas of the sectors, one can shape the effective neutron spectrum to be nearly atmospheric-like at a chosen test point. The proton beam is not stopped by the Be sector (to avoid damage such as blistering): the spent low energy protons that emerge are magnetically deflected towards a beam dump; a simpler option under investigation is to stop them in a thin Cu plate.

As a first goal, the ANEM target should be able to handle a 50 microA current of 70 MeV protons (3.5 kW), allowing one to deliver 6 m downstream a broad beam of fast neutrons with an atmospheric-like continuous energy spectrum with an integral flux F(1-70 MeV) = $3x10^7$ n/(cm^2s) that is $3x10^9$ more intense than the natural one at sea-level: a very competitive acceleration factor for SEE testing. We will describe in detail a realistic prototype that will soon be used to perform power dissipation studies of the water cooling system.

The SPES neutron irradiation facility may prove to be strategic for small/medium high-tech industries that develop devices and systems for various applications (information, automation, automotive, biomedical, homeland security, military,…). New products should be checked for un-expected sensitivity to lower energy neutrons in view of very expensive standard tests at higher neutron energy facilities imposed by international certification agencies.

Topics : Applications.

Neutron generators at JST "NIIEFA" for nuclear physics, detectors and neutron therapy

Dmitry SOLNYSHKOV[1]
[1]*JSC "NIIEFA", Saint-Petersburg, Russia*

The Efremov Institute has carried out a series of research and development projects in order to create generators capable of producing neutron fluxes of high intensity in continuous mode, but also capable of operating in pulse mode with a wide range of pulse frequency and repetition rate. Such generators allow develop highly effective detectors for radioactive materials, and can be used for explosives, drugs, and poisons detection.
Ongoing research are being carried out the for neutron radiation treatment of malignant tumors, which is associated primarily with the hope of introducing into clinical practice boron capture therapy, as well as combined photon-neutron therapy, which is one of the methods of treating tumors resistant to the photon radiation which account for about 30% of the total tumors.

Topics: BNCT ; Applications ; Others

Recent measurements using monoenergetic and thermal neutrons at the National Physical Laboratory

Catalin MATEI[1], N. HAWKES[1], N.j. ROBERTS[1], G.c TAYLOR[1], D.j. THOMAS[1],
[1]*National Physical Laboratory, Teddington, Middlesex, UK*

We present the experimental facilities for neutron studies at the National Physical Laboratory and our latest results aimed at improving neutron interaction data measurements. The facility is capable of producing well-characterized fast and thermal fields.

The NPL thermal pile consists of a large graphite moderator block within which fast neutrons are produced by bombarding two beryllium targets, located on either side of a central irradiation cavity, with deuterons from a 3.5 MV Van de Graaff accelerator. The NPL thermal pile is a unique facility capable of producing intense (3×10^{7} $cm^{-2}s^{-1}$) and well characterized thermal fields. Details of MCNP simulations of the thermal pile and methods of characterizing thermal fields will be presented.

In the fast neutron area advantage has been taken of our existing expertise in neutron metrology, particularly fluence measurements, to improve cross section measurements of interest to new generation power plants and fuel cycles. A recent sensitivity study performed by a working party of the Nuclear Energy Agency established a need for neutron interaction data uncertainties for ^{242}Pu of 3-5% as compared to current uncertainties of 20%. We used a Frisch-grid ionization chamber to measure the fission fragments produced by bombarding a very well characterized ^{242}Pu target with monoenergetic neutron beams. Results of the ^{242}Pu spontaneous fission half-life and the neutron induced fission cross section in the 1-2.5 MeV energy range will be presented.

Topics: Applications ; Others.

Construction Status of BNCT Facility Using an 8-MeV HIgh Power Proton Linac in Ibaraki, Japan

Hitoshi KOBAYASHI
KEK, High Energy Accelerator Research Organization, Japan

An accelerator-based BNCT (Boron Neutron Capture Therapy) facility is now under construction and the entire system including the patient treatment system will be installed in the Ibaraki Neutron Medical Research Center. An 8 MeV proton linac composed of 3 MeV RFQ and 5 MeV DTL is under construction. Designed output power is 80 kW. The moderator simulation shows that a neutron intensity of 4.66×10^9 n/cm^{2}s, with energy between 0.5 eV and 10 keV will be available . We are aiming at the construction of a "Hospital and Patient friendly" BNCT system which has very low residual radio-activity. A beryllium-based neutron production target which has three layers; beryllium, blistering mitigation material and heat-sink is under manufacturing. Heat conductivity of the three layers target shows 200 W/m·K.
Blistering is the most crucial issue for low beam energy BNCT. In order to make a detailed study of blistering phenomenon, an experimental setup for observation of the metal surface that have high sensitivity and high spatial resolution has been developed. Surface roughness due to the formation of blisters is detected by the change of reflectivity using a glancing incidence He-Ne laser beam. A polarized long distance microscope is used to be able to obtain images with high-sensitivity and high-spatial-resolution in real time while under the irradiation of a proton or H^- beam on the sample test materials. The system has successfully detected blistering surface dynamics. The first beam is expected in April, 2014.

Topics: BNCT Contribution.

Measurement of neutron yield by 62 MeV proton beam on a thick Beryllium target

Marco RIPANI[1], Giovanni RICCO[1], Mikhail OSIPENKO[1], Rosa ALBA[2]
[1] *INFN Sezione di Genova, Genova, Italy*
[2] *INFN Laboratori Nazionali del Sud, Catania, Italy*

A low-power prototype neutron amplifier, based on a 70 MeV high current proton cyclotron being installed at LNL for SPES experiment, was recently proposed within INFN-E strategic project. This prototype uses a thick Beryllium converter to produce a fast neutron spectrum feeding a sub-critical reactor core. To complete the design of such facility the new measurement of neutron yields from a thick Beryllium target was performed at LNS. This measurement used liquid scintillator detectors to identify produced neutrons by Pulse Shape Discrimination and Time of Flight technique to measure the neutron energy. ToF was measured with respect to cyclotron RF signal. To extend the covered energy range He_3 detector explored low energy neutrons. The obtained yields were normalized to the charge deposited by the proton beam on the metallic Beryllium target. These techniques allowed to achieve wide angular coverage from 0 to 150 degrees and to explore almost complete neutron energy interval. In this talk I will shortly describe the proposed neutron amplifier facility, while most of the attention will be given to present the obtained experimental data in comparison with Geant4, FLUKA and MCNP Monte Carlo simulations.

Topics: Applications.

Cyclotron Test site for high power proton beams

Luciano CALABRETTA, Alessandra CALANNA, Daniela CAMPO, Danilo RIFUGGIATO
INFN, Laboratori Nazionali del Sud, Catania, Italy

A small cyclotron with 800 mm pole radius, able to accelerate H_2^+ ion, ionized hydrogen molecule, up to the maximum energy of 7 MeV/A, is presented. This cyclotron is based on the design of central part of a bigger cyclotron already studied in the context of the DAEδALUS collaboration, experiments to investigate CP-violation in the neutrino sector, and IsoDAR experiment to search for sterile neutrinos.
At the same time this small cyclotron could be used also to deliver up to 10 mA proton beams at 7 MeV that is an energy and intensity useful to drive a BNCT facility.
This cyclotron test site has been designed by INFN-LNS team and will be realized in collaboration among Best Theratronics Limited (Ottawa,Can), INFN-LNS (Catania, Italy) and MIT (Boston USA).
Best Theratronics will build the cyclotron, LNS-INFN will perform the injection and acceleration test in Catania while the MIT-Boston will supply the high intensity ion source and the injection beam line.
One of the goals of the project is to check experimentally the acceleration of H_2^+ beams with current up to 5 mA. Of course, using this cyclotron, it will also be possible to accelerate He^{++} beams up to a maximum energy of 28 MeV (7 MeV/amu) and deuteron beam up to 14 MeV (7 MeV/amu).
The beam extraction of H_2^+ could be accomplished by stripper method or by electrostatic deflector. Indeed the cyclotron will be equipped with 4 RF cavities operate at a conservative maximum voltage of 70 kV. The energy gain per turn will be of 0.28 MeV/amu and the interturn separation at the extraction radius will be of 14 mm that is enough to achieve an extraction efficiency near 100%. The maximum beam power delivered for proton and for deuteron will be about 7 kW.
The Space charge effects during acceleration have been already simulated using the code OPAL and new simulation to investigate the space charge effects along the injection line and the early turns are in progress.
Details of the beam dynamics, construction drawings and planned test will be presented.

Topics: High Power Beams.

Reliable Injectors for High Power Accelerators

Santo GAMMINO[1], Giuseppe CASTRO[1], Lorenzo NERI[1], David MASCALI[1], Giuseppe TORRISI[1,2], Luigi Giuseppe CELONA[1], Claudia CALIRI[1], Carmen ALTANA[1]
[1]*INFN - Laboratori Nazionali del Sud, Catania, Italy*
[2]*Università Mediterranea di Reggio Calabria, Italy*

At INFN-LNS different sources have been developed since the end of Nineties for high power accelerators, operating in the range of 2.45-3.5 GHz according to the principle of "Microwave Discharge Ion Source" (MDIS). On the basis of a former prototype named TRIPS (TRasco Intense Proton Source), producing >60 mA of proton current (now moved to Legnaro), a permanent magnet version was built, named PM-TRIPS, working at lower voltage (40 kV instead of 80 kV) but soon dismantled and used as a tool for test, while the LEBT was coupled to the improved version of PM-TRIPS, named VIS (Versatile Ion Source), which has produced many tens of mA of proton and Helium beams, as well as H_2^+ beams. VIS is currently installed at Vancouver testbench of Best Company to produce H_2^+ beams for the ISODAR feasibility test. A new version of the plasma chamber has been designed in order to minimize the proton current with respect to the H_2^+ one, and the description of these efforts will be hereby given.

More recently, a new proton source has been designed for the European Spallation Source; the construction of the PS-ESS source and its LEBT is now ongoing and it will be described in this presentation. The Ion Source will be able to provide a proton beam current larger than 70 mA to the 3.6 MeV RFQ. Several innovative solutions have been implemented in the final design phase in order to cope with high-reliability/high-performance requirements of the ESS project. A flexible magnetic system will allow investigating alternative configurations for future ion current upgrade of the machine based on the formation of denser plasma. Innovative set-ups have been also explored for beam extraction, transport and chopping. The tests of some components have been carried out and they will be described; additional emphasis will be given to the ability to produce a low ripple, high stability proton beam, and to guarantee a high reliability of the source.

Topics: High Power Beams.

Hyperion Accelerator Technology for BNCT

Noah SMICK[1], William PARK[1]
[1]*GT Advanced Technologies 1 Industrial Drive, Danvers, U.S.*

^{7}Li(p,n) is the primary neutron producing reaction considered for use in accelerator-based Boron Neutron Capture Therapy (BNCT). One key component of a clinically viable neutron generator for this approach is an accelerator technology that is capable of producing at least 20-30 mA of protons at 2.5 MeV. In order for large-scale commercialization of the technology to be successful, the accelerator must be straightforward to manufacture, simple to operate, low-cost and highly reliable. GT Advanced Technologies' Hyperion 4 accelerator is well suited for this application. Initially developed for use in proton-induced exfoliation, the Hyperion 4 is a single-ended electrostatic accelerator designed to operate at 40-50 mA and 2.0 MeV. It can readily be adapted to meet the demands of BNCT. We present the major Hyperion 4 design features and the operating conditions achieved to date.

Topics: High Power Beams.

Neutron spectrometry from thermal to GeV with single-moderator instruments

Roberto BEDOGNI
INFN Laboratori Nazionali di Frascati, Roma, Italy

The NESCOFI@BTF project (2011-2013), supported by the Scientific Commission 5 of INFN, developed two new types of neutron spectrometer, called SP^2 (SPherical SPectrometer) and CYSP (CYlindircal SPectrometer). These spectrometers condense the performance of the Bonner Spheres in a single moderator, thus allowing the neutron spectrum to be determined in only one exposure. Whilst the SP^2 has spherical geometry and nearly isotropic response, the CYSP has cylindrical geometry and is intended to be used as a directional spectrometer. Suitable active thermal neutron detectors were developed and embedded in the final version of the devices. The resulting instruments can be used as real-time neutron spectrometers in neutron-producing facilities.

Topics: Applications.

High intensity accelerators for neutron production

Andrea PISENT
INFN Laboratori Nazionali di Legnaro, Legnaro, Padova, Italy

A new generation of accelerators are being developed for the production of intense fluxes of neutron for application that spans from the test of materials for future fusion reaction, new method for cancer treatment (BNCT), characterization or transmutation of nuclear wastes. The talk will be centered on recent developments of IFMIF EVEDA and MUNES projects.

Topics: High Power Beams; BNCT.

The European Spallation Source Accelerator

John WEISEND II
ESS, Lund, Sweden

The European Spallation Source (ESS), currently under construction in Lund, Sweden will be a world class neutron science center with a long pulse neutron source 30 times more intense than existing facilities. The linear accelerator driving this spallation source produces a 2 GeV, 5 MW proton beam. The accelerator starts with a normally conducting front end consisting of an ion source, LEBT, RFQ MEBT and DTL followed by 43 cryomodules, containing spoke, medium β elliptical and high β elliptical SRF cavities. The bulk of the accelerator is superconducting. Other features of the ESS accelerator are the reliance on in kind contributions from ESS member states and a commitment to sustainability. This talk provides an overview of the ESS accelerator and gives the status of the various accelerator components.

Topics: Others.

Targets for RIB Production

Daniel STRACENER
Oak Ridge National Laboratory, Oak Ridge, U.S.

For a number of years, the HRIBF at Oak Ridge National Laboratory has produced radioactive beams for nuclear physics experiments using low-energy light-ion beams. While some neutron-deficient beams were produced, the majority of the delivered beams were produced as fission fragments in uranium carbide targets using 50-MeV proton beams to induce fission of the uranium. Neutron-induced fission can also be used to produce radioactive nuclei and with great advantage in some cases, since the mass distribution of the fission fragments will be shifted to more neutron-rich nuclei than is achieved with proton-induced fission. This talk will present some of the experience gained with these uranium carbide targets and discuss some of the issues related to using neutrons to induce fission in an actinide target. One advantage to using neutron-induced fission is that the primary beam power can be deposited in a target that is independent from the RIB production target. This reduces the potential risk of damaging the RIB production target along the primary beam axis where the deposited power density is quite high. A disadvantage of using neutron-induced fission is the size of the RIB production target compared to the targets where direct proton irradiation is used. Release experiments have shown that the density of the uranium carbide target can affect the release time, which can greatly affect the yields of short-lived species. For a given density, the targets for neutron-induced fission will be significantly larger and this additional volume can also affect the release time. So, one must determine the optimum target density and volume for the desired production mechanism and beam species.

Topics: Applications.

Thin Beryllium target for Be(d,n)-driven BNCT

KREINER, Andres J.[1], María Eugenia CAPOULAT[1], Daniel M.MINSKY[1], Leonardo GAGETTI[1], Manuel SUAREZ ANZORENA[2], Mariela F. DEL GROSSO[3], Javier BERGUEIRO[2], Daniel CARTELLI[1], Matías BALDO[2], Walter CASTELL[2], Javier GOMEZ ASOIA[2], Javier PADULO[2], Juan Carlos SUAREZ SANDIN[2], Marcelo IGARZABAL[2], Julian ERHARDT[2], Daniel MERCURI[2], Alejandro A. VALDA[1], Mario E. DEBRAY[1], Hector SOMACAL[1], Maria S. HERRERA[1], Nicolas CANEPA[2], Nicolas REAL[2], Marcelo GUN[4], Hernan TACCA[4]

[1]*CNEA & UNSAM, Argentina*

[2]*CNEA, Argentina*

[3]*CNEA & CONICET, Argentina*

[4]*UBA, Argentina*

There is a strong international consensus that accelerator-based BNCT may change the history of BNCT due mainly to the possibility of in-hospital siting in contrast to reactor-based facilities. Hence, there is a quest for finding the "best" technological solution for such a facility. Decision criteria may be: simplicity, safety and lowest possible cost in order to promote widest possible dissemination.

In this context we have studied thoroughly the $^{9}Be(d,n)^{10}B$ reaction as a possible neutron source, which being exoergic, takes place already with a large cross section at relatively low energies, implying a significant advantage in terms of the required accelerator. For bombarding energies ranging from 1 to 1.5 MeV, the neutron spectrum produced by this reaction shows a strong contribution of neutrons of a few hundred keV. A thin target can maximize the benefit from that fact. The excellent mechanical and thermal properties of the target material plus the absence of induced radioactivity make of this reaction a better candidate for a neutron source concerning target engineering, cooling requirements and safety compared to the traditional $^{7}Li(d,n)^{7}Be$ reaction.

Extensive Monte-Carlo simulations aimed at assessing the deep-tumor, thin target, treatment capability of $^{9}Be(d,n)^{10}B$-based neutron sources were carried out. A comprehensive compilation of the existing data on double-differential cross-sections was made first, which allowed us to build realistic primary neutron field models. In addition, measurements of the double-differential neutron production were performed for some bombarding energies in the range of interest. A thorough investigation on the optimal combination of bombarding energy and target thickness was carried out. Our best-case result shows that it is possible to achieve dose performances comparable to clinical trials carried out with reactor-based sources and to a $^{7}Li(p,n)^{7}Be$-based neutron source.

In addition to the studies concerning the reaction and the beam shaping assembly we have done progress in the design and construction of the high power target.

To produce a suitable neutron beam, the Be target has to be hit by a deuteron beam of 1.4 MeV and 30 mA. Under such conditions, the target should be able to dissipate an energy density of up to 1 kW/cm^2 and preserve its mechanical properties and integrity for a sufficient length of time under irradiation and hydrogen damage conditions.

Surface treatments of different backing materials were made, like blasting and metal deposits, to favor the affinity between Beryllium and the substrate, and stable deposits were obtained. These deposits, made on different substrates, were characterized by means of different techniques including Electron Microscopy (SEM), roughness, thickness, etc. Microchannel system fluid dynamics and structural mechanics simulations in a turbulent flow circulation regime were made.

Finally progress will be shown in the development of ESQ accelerators.

Topics: BNCT.

Recent developments of the CERN-ISOLDE neutron spallation source

Thierry STORA
CERN, Geneva, Switzerland

The very first Isotope mass-separated online (ISOL) beam was produced sixty years ago with a deuteron beam impinging on a Beryllium target, and neutron induced fission reactions in a larger uranium dioxide target, connected via a cold transfer tube to an ion source. Neutron-rich krypton beams were then released. The concept of neutron conversion was later proposed by J. Nolen as a mean to use high particle beam powers for radioactive ion beam production. At CERN-ISOLDE, which is celebrating its 50st anniversary this year, a solid neutron converter has been developed and used for slightly more than 10 years, inducing fission reactions in a Uranium target. Recently, we have extended its use to produce ^{6}He via the ^{9}Be(n,alpha)^{6}He reaction for the beta-beams project. For the past few years, a conceptual design study took place, and a prototyping phase started to develop this concept towards reaching higher beam intensities and better beam quality. In addition, I will report on an ongoing collaboration with TRIUMF to develop a high power version that could accommodate several 10's kW incoming beam power.

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The Line for Fast Neutron Irradiation of Electronic Components for the European Spallation Source

Alberto MILOCCO[1], Stuart ANSELL[2], Luca ZANINI[3],Giuseppe GORINI[1]
[1]*Universita' di Milano-Bicocca, Milano, Italy*
[2]*Rutherford Appleton Labs-ISIS, Harwell Oxfor, United Kingdom*
[3]*ESS-Target Division, Lund, Sweden*

Europe is working towards the construction of a 5 MW, 2 GeV spallation neutron source, the European Spallation Source (ESS). The primary goal of the ESS neutronic effort has been to optimizing the thermal (<1 eV) and cold neutron (<50 meV) spectra in the beamlines devoted to condensed matter research. Nonetheless, fast neutron and/or proton spectra originating from the spallation process might be utilized parasitically without disturbing the beamlines' performance, by adding suitably designed irradiation ducts in the monolith to the target. This gives the possibility to do: a) fast neutron irradiation of spallation materials of interest to ESS, b) test irradiation of materials for fusion reactors [1], c) tests of microchips (as on ChipIr at ISIS [2]), d) irradiation of components for the nuclear industry or even e) production of radioisotopes.
This work describes the neutronic design of an irradiation line for test irradiation of electronic components. We built a detailed model of the ESS Target-Moderator-Reflector (TMR) system, the monolith and the bottom utility rooms where the flood room for chip testing might be installed. A parametric model was constructed using the ISIS's CombLayer geometry optimization system [3] and neutronics simulations were performed using MCNP(X). The calculated neutron fluxes are compared between 1 MeV and 2 GeV with a reference atmospheric spectrum based on the Qinetiq Atmospheric Radiation Model (QARM) [4] whilst the minimal modification to the beamline fluxes was calculated between 1 meV and 1 eV.
This work demonstrates the potential to broaden the industrial applicability of the ESS to electronic components irradiation with fast neutrons, without compromising the scientific performance of the ESS beamlines.

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[2] S. Ansell, 'A New Dedicated Neutron Facility for Accelerated SEE Testing at the ISIS Facility', 2009 IEEE international reliability physics symposium, vol. 1 and 2 pp 952-955, 2009
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Topics: High Power Beams ; Applications.

Electro-production at Frascati: is it worth it?

Paolo VALENTE[1], Bruno BUONOMO[2], Luca Gennaro FOGGETTA[2], Roberto BEDOGNI[2], Lina QUINTIERI[2],
[1]*INFN Sezione di Roma I, Roma, Italy*
[2]*INFN Laboratori Nazionali di Frascati, Roma, Italy*

The Frascati beam-test facility can drive the full DAFNE Linac beam, up to $2*10^{11}$ electrons/s, on a optimized tungsten target for neutron production ($6*10^5$ n/cm^{2}s at 1 m distance) in the MeV region. The interest for such a facility should be discussed in order to plan future activities and improvements of the source.

Topics: Others.

Perspectives on accelerator neutron production for BNCT

S Green[1], B.Phoenix[2], M. Scott[2]
[1]*University Hospital Birmingham, Birmingham, UK*
[2] *University of Birmingham, Birmingham, UK*

BNCT requires an intense neutron beam to allow patient treatments to be delivered in a clinically acceptable manner. This paper will begin by exploring the variables that determine what is considered as a clinically acceptable manner. These include delivered dose, boron compound kinetics, patient comfort and radiobiological aspects such as repair kinetics.
Achieving the required neutron beam intensity and beam quality with an accelerator neutron source is still a subject of research and a number of different approaches are being explored. These include the ^{7}Li(p, n) and ^{9}Be(p, n) reactions generating neutrons under proton bombardment with a range of incident proton energies. In the case of Li, both solid and liquid targets are being explored.
The characteristics of these two neutron source reactions will be discussed and the way these impact on moderator design will be outlined.

Topics: BNCT.

The development of a BNCT facility at Birmingham University using a solid lithium target

B.Phoenix[1], M. Scott[1], R. Edgecock[2], R. Bennett[3], S.Green[1]
[1] *University of Birmingham, Birmingham, UK*
2 University of Huddersfield, Huddersfield, UK
3 STFC, Rutherford Appleton Laboratory, UK

The accelerator based BNCT beam at the University of Birmingham is based around a solid thick lithium target cooled by heavy water. This system was designed to provide an appropriate neutron spectrum for clinical BNCT, avoid problems with hydrogen blistering of the lithium and remain simple enough to potentially implement in a hospital environment. The current submerged impinging jet cooling system has been in routine use for more than 10 years and has been tested up to currents of 1.5 mA at 2.8 MV proton energy.

Significant upgrades to Birmingham's Dynamitron accelerator are planned prior to commencing a clinical trial. These upgrades will result in an increase in maximum achievable beam current to at least 3mA. At these power levels the current cooling system would be unable to prevent the target melting; further development of the cooling system is therefore required.

Tests of a phase change coolant known as "binary ice" have been carried out using an induction heater to provide comparable power densities to the Dynamitron beam. Binary ice consists of a pump-able slurry of very fine ice crystals suspended in a mixture of water and a freezing point suppressant. This has seen widespread use in direct cooling of food products and in air conditioning heat exchangers. The experimental data shows no improvement over chilled water in the submerged jet system, with both systems exhibiting the same heat input to target temperature relation for a given flow rate.

A critical aspect of high energy lithium target systems is the choice of lithium backing and the methodology used for bonding lithium onto the backing. Birmingham's system uses a copper backing because of its excellent thermal properties. A series of empirical measurements has been used to develop a stable bonding technique. Measurements are on-going to prove that this method is stable even in conditions where the lithium surface is molten for extended periods of time.

Topics: BNCT.

Imaging-guided BNCT applications: from physics to biology and medicine

Laura Evangelista[1,2]
[1]Istituto Oncologico Veneto, Padova, Italy, [2]INFN - LNL, Legnaro, Italy

Boron neutron capture therapy (BNCT) is a biologically-targeted radiotherapy that can selectively hit the tumour cells, saving the surrounding normal tissue. The basic requirements for a successful BNCT treatment are firstly that the boron-containing compound/material has to be delivered to the neoplastic tissue, and secondly the amount of boron atoms concentrated inside/around the cancer cells must be sufficient for an optimal therapeutic response. The irradiation of tissue or organ with therapeutic doses of thermal neutrons can lead to a selective, complete ablation of the malignant lesion. Specific carriers have been developed for BNCT: para-borophenylalanine (BPA), represents one of them and the most employed in clinical trials to preferentially deliver boron to the malignancy. Positron emission tomography (PET) is considered one of the most useful tool for molecular imaging both in clinical and preclinical research for in vivo assessing of biochemical and pharmacological processes. For the in vivo examination of pharmacokinetic, accumulation and metabolism characteristics of L-B-BPA, a positron-labeled boronophenylalanine analogue, L-18F-10BPA was proposed and its pharmaco-properties were non-invasively evaluated by PET imaging.
Here the status of BNCT in clinical applications, boron carrier and boron imaging with PET, PET-guided BNCT and other studied and employed tracers for PET in order to optimize BNCT will be presented.

Topics: BNCT.

The high power target for LENOS Project at Laboratori Nazionali di Legnaro of INFN

Pierfrancesco MASTINU[1], Fabiana GRAMEGNA[1], Guido MARTIN HERNANDEZ[2], Gianfranco PRETE[1], Antonio Javier PRAENA RODRIGUEZ3

[1]INFN Laboratori Nazionali di Legnaro, Legnaro PD, Italy
[2]CEADEN (CUBA)
[3]CNA, Sevilla, Spain

LENOS (Legnaro NeutrOn Source) project at the Laboratori Nazionali di Legnaro of INFN (Italy) is a neutron irradiation facility for nuclear astrophysics studies and data validation for energy and non-energy applications. It is based on a high current low energy RFQ. The facility, will use the 5 MeV, 50 mA proton beam of RFQ under test at LNL to produce an unprecedented neutron flux, precisely shaped to a Maxwell- Boltzmann energy distribution. The beam power is 250 kW in CW, so a new and challenging high specific power heat sink has been developed for this application. In particular, since the neutron producing target is made by lithium, a low melting point material (180°C) with low thermal conductibility an heat sink have to keep the surface temperature not higher than 150 C.
In order to dissipate 3 kW/cm^2 keeping the surface temperature well below 150 degree a micro channel heat sink, cooled with liquid metal has been designed and realized. In this talk, we will present the working principle, the FEM calculations and the preliminary results of the high power test of the micro channel water cooled target .

Topics: Target Cooling ; Applications.