Project Description

a*. *Instrument Location:

- Idaho Accelerator Center, 1500 Alvin Ricken Dr, Pocatello, ID 83201

Instrument type:

- Instrument Code: MRI-39 (Engineering Testbeds).

b. Research Activities to be Enabled

Linear electron accelerators can and do address many of the world's challenges, including environmental problems, cancer treatment, energy, industry and national security. Many accelerator applications require high-intensity and high-power beams to allow significant exposure within an acceptable irradiation time. We are proposing to design and develop a multi-purpose facility for investigations of gamma and neutron activation to serve as three individual end-stations that span a range of applications: 1) a fission-spectrum neutron source for material irradiation, 2) thermal neutron source for neutron activation analysis and 3) bremsstrahlung gamma source, mostly for photon activation analysis. The first two variants of the testbed will exploit the photo-production of neutrons using a high power target. The last one will use bremsstrahlung photons from a thick tungsten radiator.

The end-station will be designed to operate at up to 40 MeV electron beam energies and at a power of 10 kW. This accelerator energy and power level is within the capabilities of an accelerator under construction at the Idaho Accelerator Center. The fast neutron source is intended to irradiate small samples with a fission-spectrum flux of 10^{14} n/cm^2*sec. The fission-like energy distribution is similar to the unmoderated neutron spectrum produced by fuels in the reactor. Full or partial moderation of the spectrum enables the source to mock-up any spectrum found in the reactor. Samples will be placed in cavities of the desired neuron flux. Post-irradiation and in-situ observation and testing of the samples is essential for the different areas of science and engineering.

The thermal neutron source will have several purposes. First, it will be used as a testbed for low energetic neutron damage. This kind of tool would be complementary for electronics sensitivity investigations and studies of radiation-resistant bacteria and microorganisms. However, its much more important application would be the neutron activation analysis. The neutron activation analysis (NAA) capability is intended to determine elemental composition of solid, liquid or gaseous samples with minimal preparation. NAA detection limits vary depending on the neutron flux and on the element under investigation [1]. Typically, high Z elements have a larger neutron capture cross-section and are more likely to be activated. Note, that not all the elements can be detected with this technique. This technique is quite established and has numerous applications in different areas of science, art and engineering; however we will significantly extend it and compliment it by the photon activation analysis.

The photon activation analysis (PAA) is also intended to determine elemental composition of solid, liquid or gaseous samples with no or minimal preparation [2]. The PAA technique is very similar to the NAA: it is non-destructive, sensitive, and requires minimal (if any) sample preparation. However, for particular elements PAA can be more sensitive than NAA. Another PAA advantage is that the size and the mass of the sample can be much greater as photons can penetrate deeper into a medium. A matrix of users for this testbed with the interchangeable end stations would be extremely broad. Environmental science and engineering, elemental analysis of astromaterials, studies of radiation damage of materials and electronics sensitivity to radiation fields, radiobiology, forensic anthropology, archeology, antiquities authentication and testing and verification of artifacts, food irradiation, enhancing gemstone optical properties by irradiation – this is just a short list of possible applications. We have established collaboration with scientists from different areas (letters are attached) who are in need for such a tool and would like to use once it's build an in operation. Below are the detailed descriptions of several such collaborations; the summary of different research activities to be enabled using the proposed testbed is shown in Table 1.

Elemental analysis: NAA and PAA are complimentary and can be done together for elemental analysis of different samples. There are numerous areas of applications where non-destructive elemental analysis at very low (ppb) level is essential.

One of such applications is environmental science which traditionally involves analyzing air, water and soil samples. The sensitivity of PAA allows the analysis of small trace quantities of elements; many elements of environmental relevance can be detected in the nanogram level. This is of particular importance in the analysis of air particulate; usually total amounts of only a few milligrams or less collected on air dust filters are available for analytical investigations. The multi-step analytical procedure used in treating samples chemically is complicated. Moreover, due to the expected small masses of the "dust particles" (10 to 100 μgram) collected on filters, such a chemical treatment can easily lead to significant contamination levels. Radio-analytical techniques and, in particular, activation analysis methods offer a far cleaner alternative. Activation methods require minimal sample preparation and provide sufficient sensitivity for detecting the vast majority of the elements throughout the periodic table. While NAA has historically been by far the more standard technique, we propose to employ the PAA technique of to activate dust particles with 30-40 MeV photons. This technique can also be applied for the characterization of large amounts of inhomogeneous material, for example biological material, soil samples and electronic waste [3, 4, 5]. However, facilities for generation of large volume bremsstrahlung fields must be available in these cases. This method can also be used during the non-destructive analytical study of bulky objects if sampling and other invasive operations are not allowed [6].

Another important application is archeological research, in particular, chemical characterization of stone and other raw materials, analyses of ancient residues, pigments, and other organics, elemental and isotopic analysis. This now broad field, often referred to as Archaeological Chemistry, or even more broadly as archaeometry, is so integral to art, archaeology, and museum curation that little modern archaeological research is done without it [7, 8, 9, 10]. For over 50 years NAA has been central to many of these analyses because of the proliferation of research reactors at academic institutions, because it had high precision for elemental analysis, and because it was an obvious area of interdisciplinary research. The long history of NAA in archaeology has withstood multiple challenges to find itself still considered the benchmark for provenience studies [11, 12, 13].

But with the increasing importance of non-destructive testing, and especially in museum curation and in the study of the material remains of indigenous peoples in the arctic and elsewhere, new, completely non-destructive techniques are necessary. The lack of dedicated photon activation analysis facilities in the US, the reduction in the number of nuclear facilities, and the increasing need for completely non-destructive whole-artifact analysis, positions the Idaho Accelerator Center to take the lead in archaeological, museum, and materials photon activation analysis.

One more application of elemental analysis would be studying astromaterials, which is crucial for understanding of the huge number of interstellar processes, such as element formation, grain condensation, formation and evolution of organics, accretion history, etc. Eventually, answering these questions would lead to better understanding of the solar system and our own planet formation and evolution. PAA and NAA can help non-destructively studying bulks of the different samples: from microscopic dust grains recovered form comets and asteroids to large samples of meteorites, Moon and Mars rocks. For example, models to explain the overall formation and evolution of the Moon are greatly dependent on geochemical signatures of lunar materials. Literally thousands of analyses of major and trace elements have contributed to this effort, however, the signature of many key elements and/or elemental ratios need to be enhanced in order to evaluate these models. Specifically, the ratios of key incompatible trace elements such as Nb/Ta, Zr/Hf, and Cs/Rb, which are difficult to fractionate during geological processes, are important for determining source regions and planetary differentiation processes. The lunar rock analytical databases still lack key elements, for which the non-destructive technique was not available or the technique used were not robust (see LPI site for lunar samples – http://www.lpi.usra.edu/lunar/samples/). PAA and NAA would compliment existing database and provide a much broader understanding of processes involved in the evolution of the Moon. PAA would also help decipher one of the leading problems – the content of volatile elements in lunar soils, rocks and volcanic glasses [14, 15, 16]. The volatile content of the Moon (water and various gases, and the signature elements that exhibit volatile behaviors (e.g. C, N, F, Cl, As, Sb, Bi, I, Tl, Pb, etc) need to be better characterized. Similar cases can be made for samples of meteorites, interstellar dust, cometary debris and other astromaterials.

Isotope Production: Note that the same reactions that enable PAA also enable isotope production in copious quantities. For one example, ^{67}Cu production via the ^{68}Zn(γ, p) reaction produces carrier-free species is more straightforward to separate because the daughter is chemically different. The proposed device could produce nationally significant quantities off such research isotopes for a number of species. In particular, for ^{67}Cu, a cancer therapy isotope that is approved for human trials research, the proposed device could supply 100% of the national need. For the separation of photo-neutron reaction products from the target, other procedures which we have preliminarily investigated, are required and will be the subject of future proposals.

The most interesting nuclei for these investigations are: ^{67}Cu,^{149}Pm, ^{177}Lu, ^{90}Y, ^{111}In and ^{131}Ba/^{131}Cs because they span a wide range of masses, a spectrum of post-irradiation separation challenges, and are either used or of very high interest for bio-medical research and applications.

Radiobiology: It has been well documented that in mammalian systems, radiation quality has an impact on Relative Biological Effectiveness (RBE) [17, 18]. Overall survival, as well as more subtle cellular changes, is dependent on the type of dose, because quality influences the extent and form of damage within the cell. There exist relatively few radiation sources for such comparative experiments, which are generally dependent on availability of a reactor or specialized accelerator. These types of experiments are generally carried out on mammalian cells where total dose delivered, and dose delivery rates, are extremely low. In radiation microbiology, where doses delivered, and by extension the dose delivery rates, are 10 to 100 times higher, such sources are virtually non-existent [19].

In contrast to mammalian systems, virtually all reported experiments on microbial species such as the extremely radiation resistant bacterium *Deinococcus radiodurans*, have been performed with gamma or electrons [20]. Thus, the effect of radiation quality on survival, including induction of repair systems, is largely unknown in such high dose systems.
The device described in this proposal will allow investigation in to this relatively unknown field of effects of radiation quality on highly resistant microbes. This will be very useful for extremophile research and associated questions in astrobiology. Given the short doubling time of microbial organisms and the extreme tolerance of some species to ionizing radiation, delivery of high doses in a short period of time is highly desirable. In addition the potential to investigate effect of radiation quality is unique. In short, the one-stop shopping potential of this device is very attractive. The combination of sources available in one location will streamline further

research and facilitate collaborations with other universities and research centers already using the electron beam delivery for investigation of resistance in microbes.

The facilities at the Idaho Accelerator Center are already optimized for high dose delivery of electrons and photons for investigation of survival mechanisms in extremely radiation resistant microbes. The addition of a comparable neutron delivery system and gamma delivery system will make this multi-use facility unique in the country by providing these multiple sources in one location.

Electronics sensitivity to radiation: Since the 1990s, research has revealed that Single Event Effects (SEEs) including Single Event Upsets (SEUs) and Single Event Latchup (SEL) can impact the reliability of microelectronics both in space and on the ground [21, 22]. Criteria have been developed to measure and report SEEs [23] and incorporated into Standards (JEDEC Standard JESD89). The most important contributor to SEEs at commercial aircraft altitudes to ground level is neutrons generated from interaction of cosmic rays with the atmosphere. The neutron spectrum is a continuum ranging from thermal energies to near the energy of the incident rays (see Figure 1).

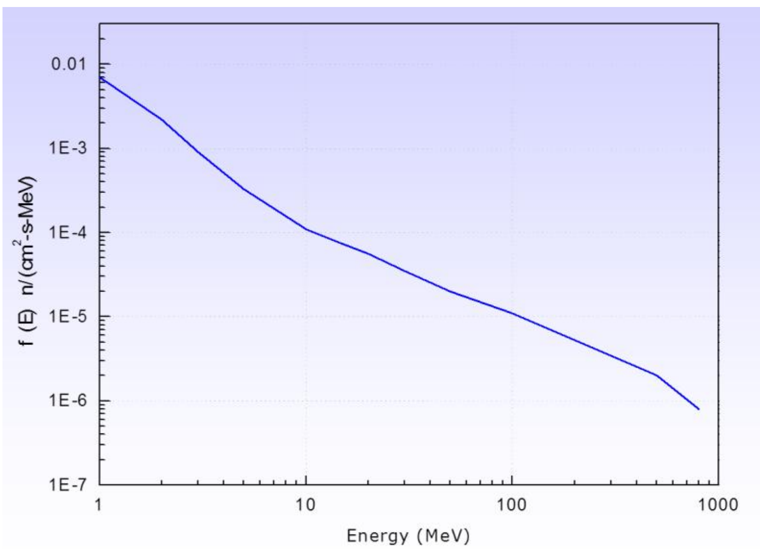

Figure 1. Atmospheric neutron energy spectrum.

Commonly, neutron induced SEEs are studied at high energy proton accelerators such as TRIUMF and LANSCE using spallation. These accelerators are expensive to run and often scheduled well in advanced. Work has been done showing that the cross sections of various SEEs can vary greatly depending upon the device, the type of effect (SEU vs SEL for example) and the energy of the neutron [24]. Some devices are highly susceptible to thermal through mid-energy neutrons [25] and it is valuable to investigate these phenomena at a lower cost at an appropriate facility. The neutron source proposed for the IAC would provide a high flux for research of SEE at an energy range spanning from thermal to approximately 40 MeV enabling additional research and testing of this important reliability degradation mechanism.

Radiation-induced damage to materials: We propose a low-cost intense source of fast fission-spectrum neutrons for irradiation of materials of interest to the advanced fuel cycle. The source is based on the photo production of neutrons with a 40 MeV electron beam with a power of up to 10 kW. This accelerator energy and power level is within the capabilities of the accelerator now being commissioned at the Idaho Accelerator Center. The source is intended to irradiate small mm-scale samples with a fission-spectrum flux of 10^{14} n/cm^2*sec. Fluxes greater than 10^{13}

n/cm^2*sec can be achieved for larger, cm-scale specimens. The source would be on a dedicated accelerator beam line and serve as a user facility for ISU, INL and other university and national laboratory researchers as well as private sector users in need of fast neutrons.

A standard parameter measuring the radiation damage from ions and neutrons in materials is the displacement per atom (DPA). It is an integral characteristic that depends on the material response (displaced atoms) and the radiation (type, fluence and spectrum) to which the material was exposed. DPA is not representative of the initially created lattice defects but a measure of the number of atoms permanently displaced to a stable interstitial positions. Its magnitude is used to correlate damage on materials irradiated under different radiation environments. In a typical power reactor core of the order of 10^{-6} DPA/s are generated.

Relatively little data exist for samples in fast neutron spectra, and almost none at high temperatures. In general, the core materials in Generation IV reactors are expected to experience temperatures 500^{o}C-1000^{o}C and DPA in the range 30-100. Some aspects of the behavior of such reactor cores can be simulated by neutron bombardment of representative samples. The fast neutron fluxes available from the proposed source along with the convenience of use will make possible such studies and be a potential useful first step toward a larger such facility that could meet the national need for a fast neutron irradiation facility.

The only accelerator-driven sources that produce evaporation, unmoderated, fission-like spectrum neutrons are those provided by GeV proton or deuteron beams or electron beams in the 10's MeV range. In both cases high Z targets with adequate thermal cooling are used as converters. Electron driven sources have a clear advantage in facility cost for fluxes up to $\sim 10^{15}$ n/s*cm^2[26]. Figure 2 shows a comparison of electron-driven sources (photofission) and proton-driven-sources (spallation) where one can see significantly higher investment costs for spallation sources.

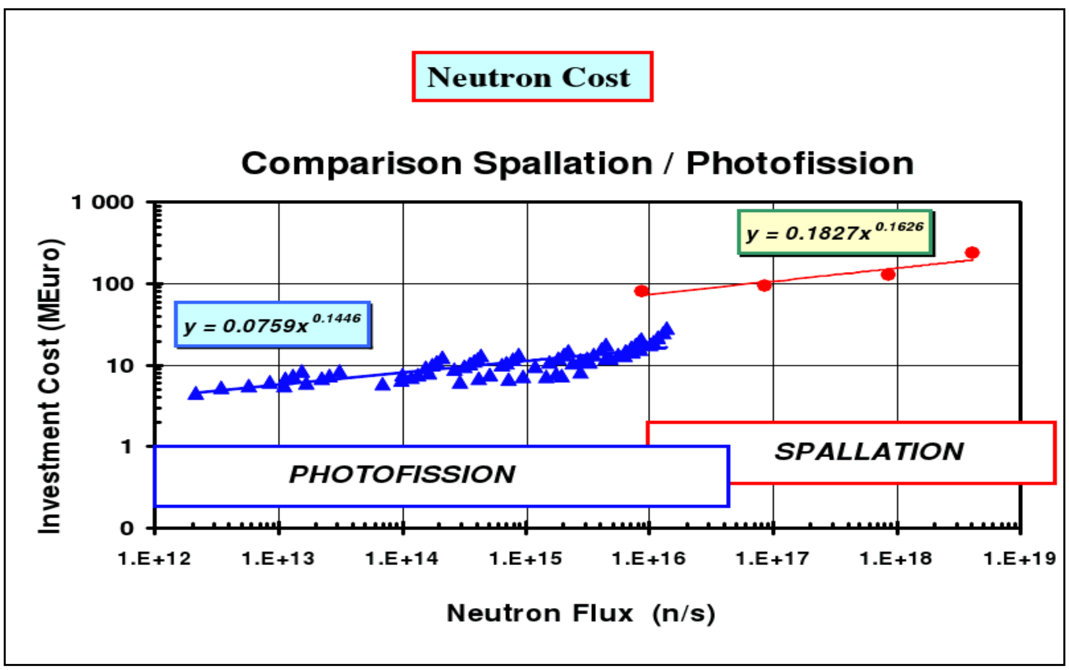

Figure 2. Comparison of the investment costs for electron-(photofission) and proton-(spallation) driven sources. Adopted from Henri Safa's talk at the Henri Safa, EURISOL Target Working Group Meeting, Saclay, May 21, 2001.

	Fast Neutron Source	Thermal Neutron Source	Gamma Source
Environmental samples analysis		✔	✔
Analysis of astromaterials		✔	✔
Archaeological samples analysis		✔	✔
Antiquities authentication		✔	✔
Radiobiology	✔	✔	✔
Electronics sensitivity to radiation	✔	✔	
Photonuclear isotope production			✔
Radiation-induced damage to materials	✔		

Table 1. Summary of end station usage for different applications.

The photo-produced neutron yield depends on the target material. For electron energies above ~15 MeV, high Z materials have the greatest yield per incident electron. Yield is directly proportional to beam current and it increases with energy. If the target material is fissionable, yields are ~2x higher due to the contribution of photofission neutrons. It is possible to take advantage of neutron multiplication if a fissile material assembly is present around the target structure. Such multipliers have exhibited neutron yield gains of more than 10. However, fissionable target materials and fissile material multiplying configurations carry the burden of higher levels of regulation and residual activity than those posed by non-fissionable converter materials. Above ~30 MeV the energy dependence of the yield begins to flatten out and one needs to consider the relative cost of a higher energy accelerator versus increasing the beam current to achieve a given neutron output. At electron energies above ~ 40 MeV the cost effectiveness of neutron production changes little.

c. ***Description of the Research Instrumentation and Needs***

Setup overview: linear electron accelerator, shielding and ventilation system:

The proposed multipurpose testbed would consist of three interchangeable end-stations to be placed in front of the linear electron accelerator. The fast neutron source variant will be a high Z material cylindrical target. An electron beam will produce bremsstrahlung photons which knock out neutrons from the target. MCNPX simulations show that the surfaces of constant neutron flux are ellipsoids of rotation about the cylinder axis so that sample cavities should be arranged around and parallel to the axis, as in a revolver pistol. The thermal neutron source end-station will be very similar to the fast neutron source; however, neutrons will be moderated by water. The bremsstrahlung gamma variant will consist of a thick high Z radiator, which will produce bremsstrahlung photons. The electrons will be stopped by a thick low Z electron filter. MCNPX simulations and preliminary experiments were done to estimate neutron and photon flux as well as energy deposition and sample heating. Standard target cooling schemes will be incorporated into these end-stations. Below is a summary of the important characteristics of the proposed irradiation testbed:

- Irradiation parameters (neutron, gammas, mixed) and energy spectra would depend on the modification:
  - Fast neutron source would have an evaporation energy spectrum very similar to a fission spectrum, with the capability to fully or partially moderate this spectrum
  - Slow neutron source would use slow, moderated neutrons
  - Photon source would use bremsstrahlung photons
- The accelerator technology is simple, reliable, and inexpensive to build and operate as compared to fast reactors, accelerator spallation sources, or cyclotrons.
- The neutron and photon producing target technology has been proven by a number of groups including previous experiments at the IAC.
- Ready access to the facility for other universities and national labs researchers.

The interchangeable end stations will be placed in front of the linear electron accelerator (LINAC). The LINAC is composed of two 2856 MHz sections, the first section is a standard standing wave, side coupled cavity, buncher/pre-accelerator injecting a 27 MeV beam (unloaded) into the second section which is a standard SLAC type traveling wave accelerator. Each section is provided with microwave power from its own 5 MW peak output klystron. The total unloaded output energy is expected to be ~ 50 MeV. The system's klystron modulator, which drives both klystrons, is capable of supporting .35% duty factor microwave power from the klystrons, but the klystrons have a maximum duty of .7%, so considerable accelerator output power upgrading is possible. Assuming the maximum duty of .30% for the electron beam and a peak beam current of 100mA (which is about maximum for the first section) the average output beam power is ~12 kW. From the load line below right, the energy at this beam current is 40MeV.

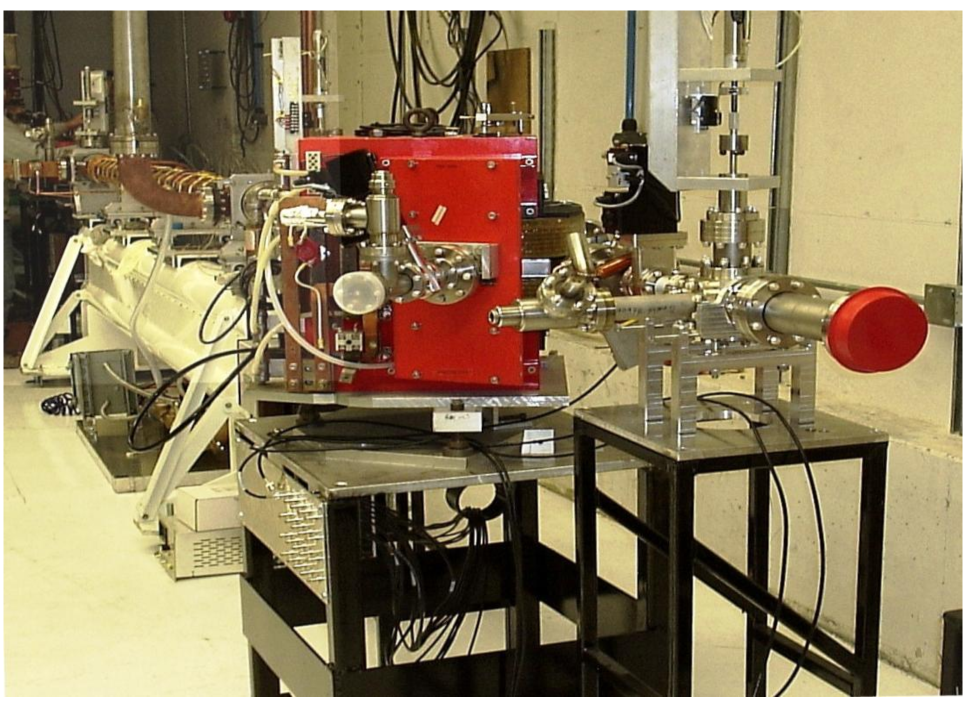

Figure 3. 10 kW 40 MeV LINAC. The proposed testbed will be placed right at the end of the beamline, surrounded by a thick concrete shielding wall.

The accelerator is located in a well shielded hall with standard interlocks, warning lights and radiation area monitors. The high photon and neutron fluxes associated with this device will require additional shielding above and beyond the standard concrete-shielded accelerator halls that we currently employ. To address this we will construct a ~ 2000 kg removable concrete shielding with HEPA ventilation system around the bremsstrahlung target and sample holder that will simultaneously strongly attenuate gamma dose beyond the sample irradiation region while producing much less neutrons than, for example, a comparable shield made of lead.

Post-irradiated samples will be pneumatically translated to a low-radiation environment and/or shielded location, depending upon their activity, where they can be subsequently analyzed by HPGe detectors. The above design and construction modifications are well within the experience and capabilities of IAC staff engineers and scientists. A schematic layout of the existing accelerator is shown in Figure 3.

Fast neutron source end station:

Neutrons from accelerator sources are commonly generated by nuclear reactions such as (γ, n), (d, n) and (d, t). Among the above three methods, photo-nuclear production has the highest neutron yield per incident beam-power. Also, its neutron energy spectrum is principally a nuclear evaporation spectra, as found in unmoderated fission. Another possible method of neutron production is a spallation source with even higher neutron yield and also an evaporation spectrum. However, in this case very high energy and very expensive beams are necessary. Thus, the (γ,n) reaction is the most attractive for small-scale, inexpensive neutron production from accelerator sources.

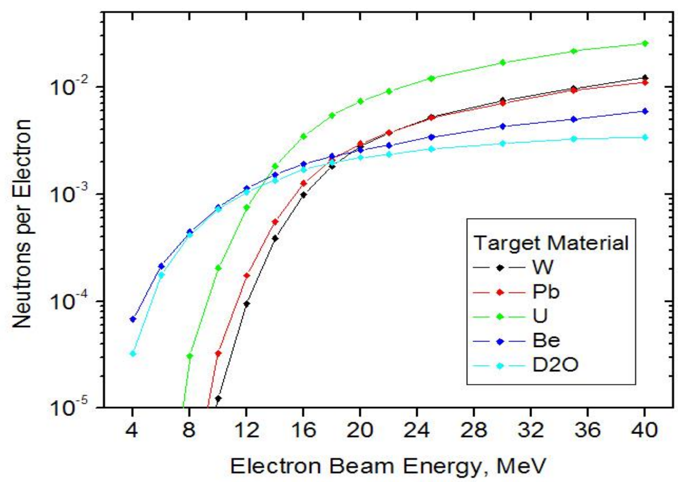

Figure 4. Average neutron flux through a target as a function of the electron beam energy for different target materials.

As shown in Figure 5, the photo-produced neutron yield depends on the target material. A cylindrical geometry is suggested by the cylindrical beam symmetry. We have completed MCNPX simulations that predict that, for electrons in the energy range of 40-50 MeV, the cylindrical target should have minimum dimensions of radius ~3cm and length~ 5cm. The surfaces of constant neutron flux are ellipsoids of rotation about the cylinder axis so that narrow sample cavities (tubes) should be arranged around and parallel to the axis, as in a revolver pistol. The MCNPX calculation was used to investigate the effects of bombarding a tungsten cylinder with 40 MeV electrons moving perpendicularly into the center of one of the circular ends of the cylinder. With a 40 MeV electron beam at 0.25 mA average current and with the choice of irradiation volumes of ~ $0.5cm^3$ one can achieve a number of irradiation regions where the flux is near $10^{13}n/cm^2*s$ over the volume (Figure 6).

Numerous lower flux positions can also be provided. The limit on the number of irradiation volumes is the effect the target void spaces will have on production. More detailed simulations, including thermal behavior, electron and photon flux, are required to design the final form of the converter target.

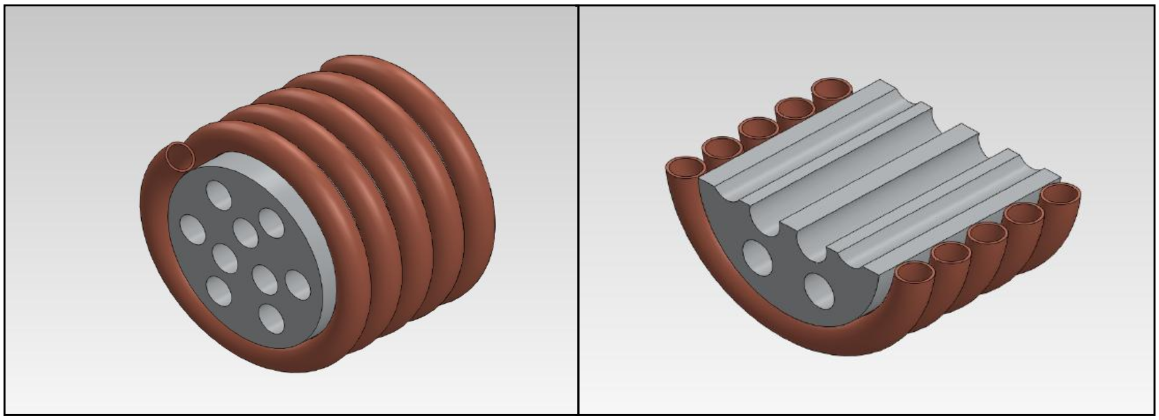

Figure 5. A schematic drawing of the fast neutron source. A high Z material cylinder will have cavities for sample. Water cooling will be enough for 10 kW, for higher powers other cooling schemes need to be designed.

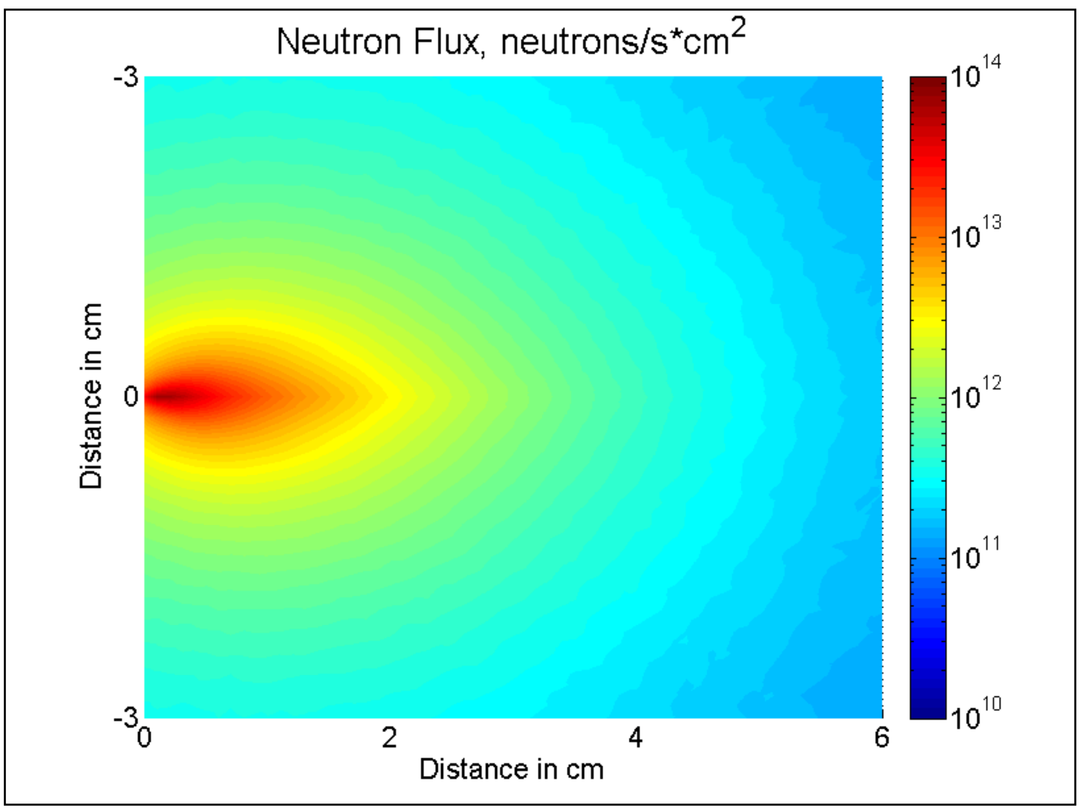

Figure 6. MCNPX simulations results for neutron flux through the tungsten cylinder 6 cm long and 3 cm in radius(shown as black contour line). The 40 MeV electrons are incident from the left.10 kW beam is assumed for the simulations.

Thermal neutron source:

Surrounding the high Z cylinder by neutron moderating material, such as D_2O or graphite, we can create relatively high and uniform thermal neutron flux regions. They can be used for NAA, radiobiology and electronics sensitivity to radiation studies. Schematic setup is shown on Figure 7. Neutron and photon flux was simulated for D_2O as a moderator (Figure 8). Energy distribution through the tungsten cylinder and the moderator were simulated using MCNPX software (Figure 9). The neutron fluxes enabled by this device are high enough to support synchronous PAA/NAA research. These fluxes, in conjunction with the gamma flux, will also support research in nuclear waste burnup (especially ^{99}Tc and ^{129}I, which are the principle components of long-term dose of spent fuel), as well support radiobiology, thermal neutron damage to electronics, and isotope production research.

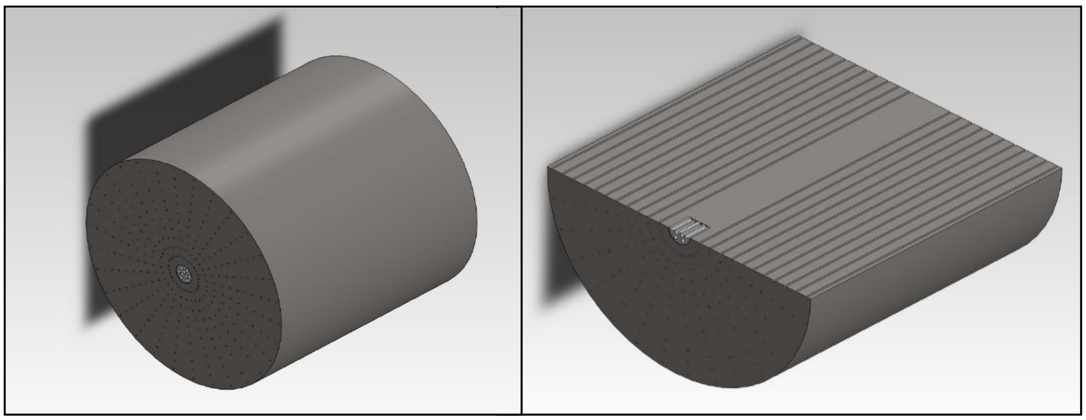

Figure 7. A schematic drawing of the thermal neutron source. A high Z material cylinder will be surrounded by a thick layer of moderating material (for example D_2O), which will have cavities for samples.

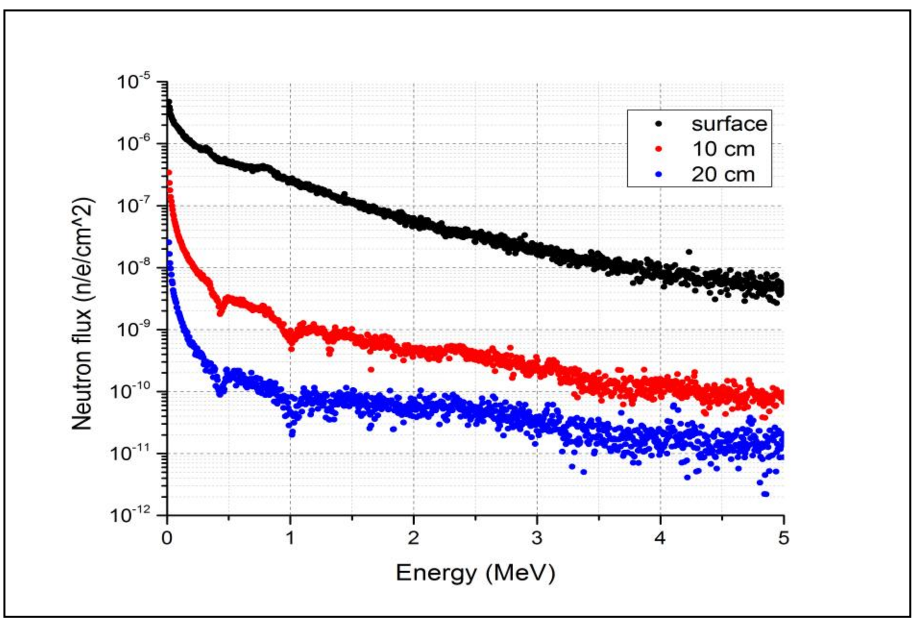

Figure 8. MCNPX simulations results for neutron energy distribution through the tungsten target and D_2O moderator. Neutron flux is calculated per incident electron!

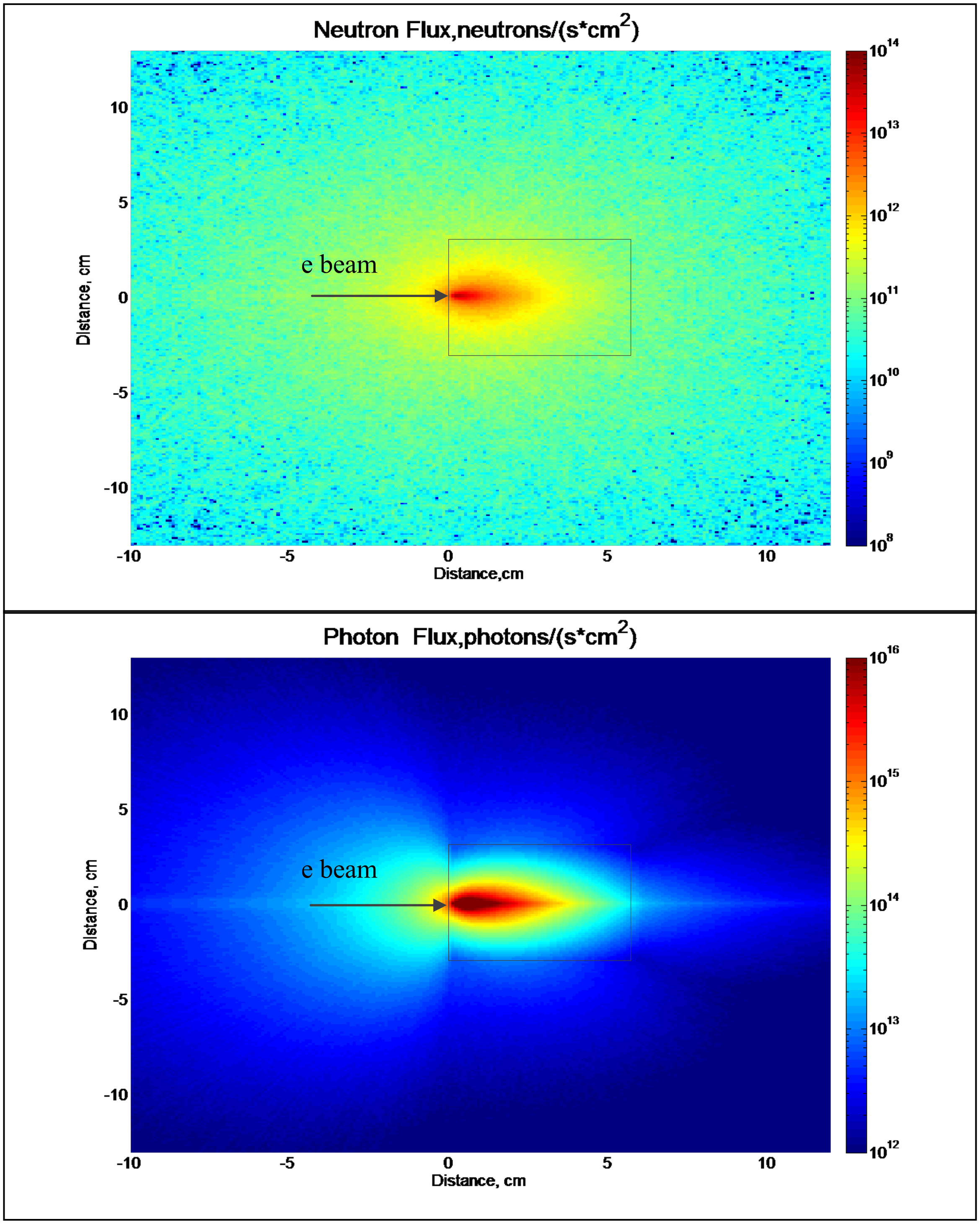

Figure 9. MCNPX simulations results for neutron flux(top) and photon flux (bottom) through the tungsten cylinder surrounded by a thick layer of D_2O. The 40 MeV electrons are incident from the left.10 kW beam is assumed for the simulations.

Gamma source:

Bremsstrahlung gamma source will mostly be used for the photon activation analysis (PAA), which is based on photonuclear reactions. This is best achievable with a linear accelerator that accelerates electrons to above 20 MeV. The electrons then hit a converter, which is a metal foil that converts the electron's energy into high-energy bremsstrahlung photons. The photons continue onward and are absorbed by the nuclei of a sample, which causes the nuclei to be in an excited state. These excited nuclei, in turn, decay by emitting nucleons (neutrons or protons) leaving a radioactive daughter nuclei which emit delayed radiation. The radioactive yield ***A*** of the sample depends on a number of parameters, such as the number of target nuclides that are irradiated ***N***, the threshold energy of the nuclear reaction $\boldsymbol{E_{threshold}}$, the maximum energy of photons $\boldsymbol{E_{max}}$, the photon flux density ***φ(E)***, the photonuclear reaction cross-section ***σ(E)***, decay constant of the daughter nuclide ***λ*** and irradiation time $\boldsymbol{t_i}$ (Eq. 1):

$$A(t_i) = N \cdot \int_{E_{th}}^{E_{\max}} \varphi(E) \cdot \sigma(E)\, dE \cdot (1 - e^{-\lambda \cdot t_i}) \qquad (1)$$

Typically, PAA accuracy is ensured by activating a calibration material with known concentrations of elements in addition to the sample of interest. By comparison of the yields of particular daughter nuclides in the calibration material, the concentration of parent nuclides in the sample can be determined. Induced yields will be measured using high resolution HPGe gamma ray detectors and associated electronics, data acquisition and custom analysis software. A typical spectrum is shown in Figure 10.

The Idaho Accelerator Center (IAC) has all the necessary equipment for the PAA technique, from high power linear electron accelerator to high purity germanium (HPGe) detector and data acquisition system. Several samples, including metal foils, ceramic pellets and dust filters were already irradiated and their gamma activity was measured. These preliminary experiments revealed trace elements and impurities at the ppm to ppb level [2]. The detection level can be significantly improved by optimizing the electron beam energy and power as well as the time of the irradiation. Preliminary gamma source end station design and simulated photon flux is shown on Figure 11 and Figure 12.

Dealing with a high power electron beam (10-30 kW) requires special attention to a number of issues which are usually not a significant problem at lower power. One of them is cooling. Tens of kilowatts of power will be delivered into centimeters of target material.

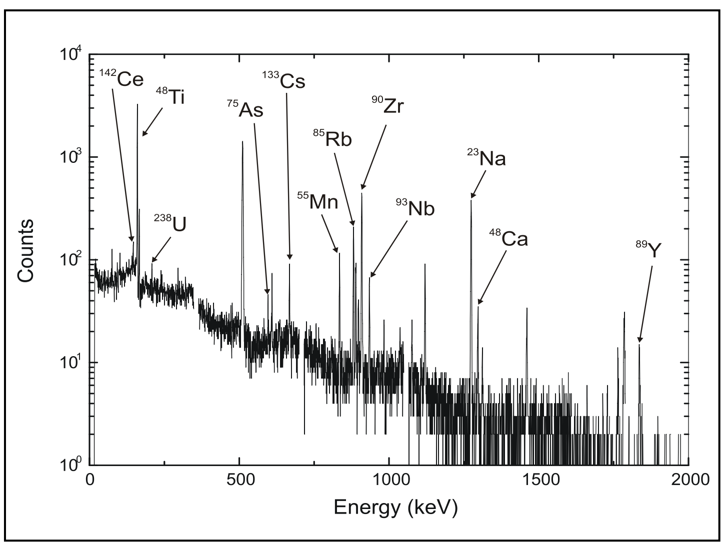

Figure 10. A typical spectrum obtained at the Idaho Accelerator Center by placing an irradiated sample in the high-purity germanium detector. The parent nuclides are labeled with each peak.

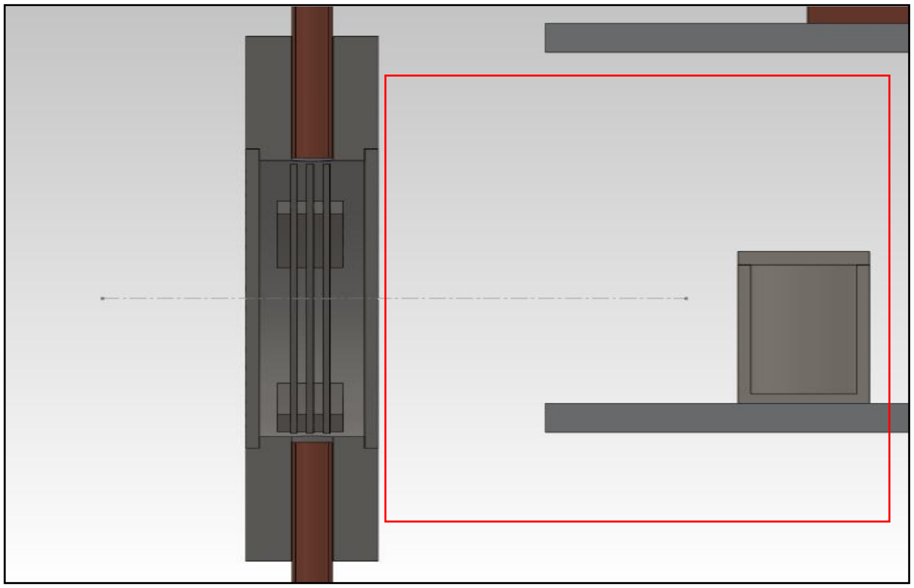

Figure 11. A schematic drawing of the photon source. Water-cooled tungsten converter plates will generate bremsstrahlung photons which will activate sample material. A conveyer belt system will be used for quick multiple sample activation. A right cylinder region (10 cm x 10 cm) shown in red was used for photon flux simulations below (Figure 12).

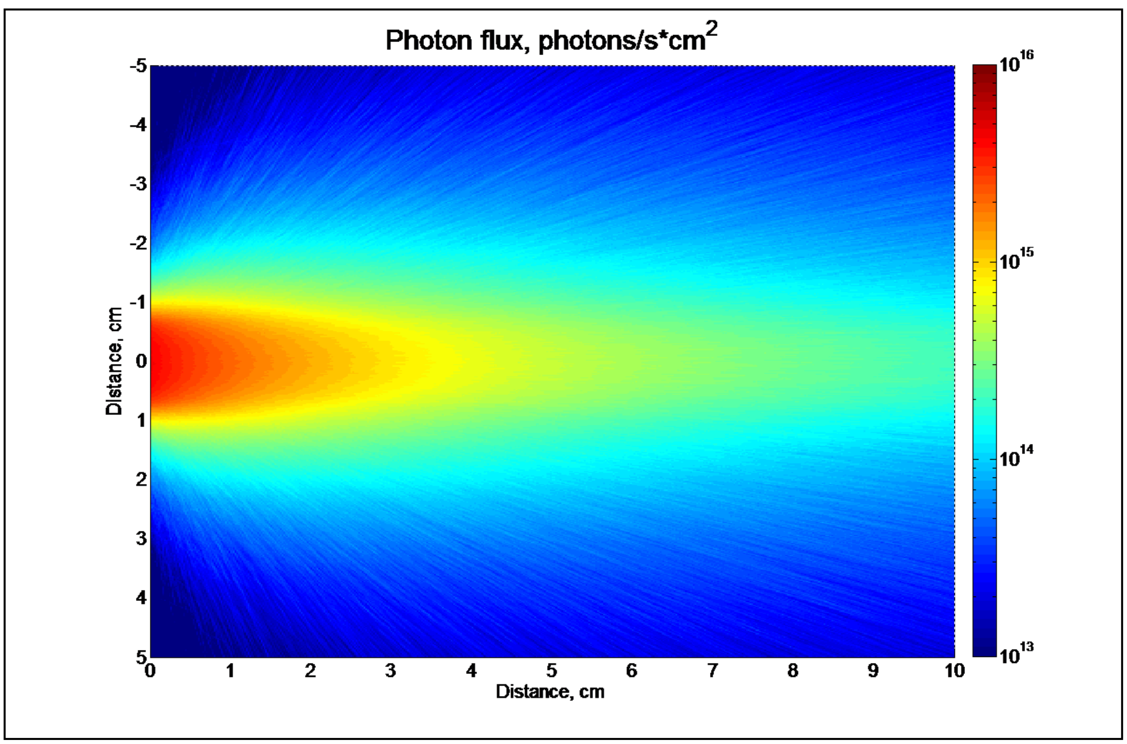

Figure 12. MCNPX simulations results for photon flux generated by a tungsten converter. The 40 MeV electrons are incident from the left .A 10 kW beam is assumed for the simulations.

Of course, such a huge amount of localized heat will cause a tremendous temperature increase, and possible melting of the target and the samples unless the target is properly cooled. To avoid this, a cooling system needs to be designed and tested. For 10 kWatts a relatively simple water cooling system might be enough. In to water flow around the cylinder, it might be necessary to use some of the cavities for water circulation as well. More calculations will be done to estimate heat transfer and temperatures through the cylinder for different cooling systems to choose the optimum one. Experiments will be performed to confirm the simulations, first at low power, then at high power.

Another important issue in high radiation fields is radiolytic reactions, especially if water is present. It is well known that the irradiation of water ionizes it, and releases free radicals. These free radicals interact with other water molecules and cause them to form hydrogen and hydroxide ions. The two hydroxide ions then proceed to chemically combine to produce hydrogen peroxide. The life-time of many of those radiolysis products is short, on the order of milliseconds or less, except O_2 and H_2O_2. The corrosion due to short lived species is of primary concern only when they are produced close to the materials that are exposed directly to the radiation. Their effect is negligible if produced at some distance away from the material because of their short lifetimes. The long lived chemical species however can contribute substantially to the corrosion process. We will follow the high-power target scheme described by Capiello [25] and James [26]. Great resistance to radiolytic degradation was shown in their reports by using tantalum-clad tungsten.

d. Impact on Research and Training Infrastructure

The science mission, which is quite broad, will enable research that U.S. researchers currently have great difficulty pursuing because of the dearth of such facilities. The addition of this unique high-power, multi-radiation test-bed will enable renaissance of radiation applications.

Areas like PAA, which has been successfully used at the IAC for several years, can take its place as a powerful, nondestructive and penetrating characterization tool. Similarly, high-flux, fast neutron irradiation capabilities will enable advances in nuclear materials. Developing the test-bed will improve our center's capabilities to conduct world-quality elemental analysis. Adding an intense fission-spectrum and/or thermal spectrum neutron source would allow us to extend our capabilities even further and would attract investigators from different areas of physics, engineering, astronomy, and humanities.

This testbed will also be an instruction tool for Idaho State University physics and nuclear engineering students, both during construction and afterward, when it becomes a research tool. Once complete, students from many disciplines, including astrobiology and other microbial disciplines, students from nuclear engineering, electrical engineering, environmental sciences, archaeometry, radiochemistry and physics will all be served by this device. This device will also serve undergrads at ISU and nationally though the ISU NSF-REU program.

e. Management Plan

The proposed irradiation test-bed facility will be placed at the Idaho Accelerator Center, which has ten operating accelerators in five research facilities with over 40,000 sq. ft. of laboratory space. The operational and user personnel at these facilities consist of twenty scientists, eight engineers, and three administrative assistants. Personnel at the Idaho Accelerator Center have extensive experience designing and commissioning accelerators.

The proposed work scope will be accomplished within the planned 2-years of performance taking advantage of the project team experience in relevant nuclear R&D. The Idaho Accelerator Center team will complete the optimization and construction of targetry for the test-bed irradiation facility for gamma, fast neutron and slow neutron irradiation experiments.

Year 1: Monte-Carlo simulations for optimum converter material and geometry, mapping of neutron and photon flux through the converter. Experiments will be done to confirm the simulations. We will resolve the heating issues, corrosion issues and temperature control issue and conduct experiments for both bremsstrahlung target and sample irradiation positions. We will acquire hardware and materials for three target end-stations, and begin of construction and testing of all three. Design of radiation shielding and HEPA ventilation systems will also be complete. Dr. Starovoitova will lead the effort on simulations and measurements. Dr. Harmon will lead design and optimization efforts, while Dr. Wells will assume overall responsibility of keeping the project on-track and on-schedule.

Year 2: Completion of all three targets. Completion and final benchmarking of performance of target, inclusion radiation fluxes, temperature control, corrosion control, etc. Final experiments will fully demonstrate performance of targets will be completed. Possible converter modifications will be done for in-situ sensor observations.

<u>Deliverables and outcomes:</u>

1. An intense fast fission-spectrum neutron irradiation facility will be developed.

2. The nuclear physics and engineering aspects will be analyzed, explored for potential efficiency maximization approaches and documented. The potential to scale the facility up will be assessed and a report on the facility optimization will be delivered.

3. Cost/benefit analysis will be performed using neutron flux, temperature and dosimetry data.

4. One graduate student and two undergrads will complete their degrees.

5. Target capabilities for the neutron and photon fluxes, doses and sample temperatures will be quantified. Project results will be documented in methodology specifications, reports, and journal articles. The R&D progress will be via technical reports.

6. The radiation testbed will be operated by the IAC scientists and engineers. The letter of support from the IAC director is attached.

7. The anticipated cost of using the testbed will be included in the costs for the IAC high-power accelerator. That machine will cost $500/hour. Expertise to maintain and operate this testbed resides with the IAC engineers and scientists.

8. Allocation of beam-time for use of the testbed falls under the duties of the IAC scheduling committee. The irradiation testbed instrument will, like all end-stations at the IAC, have a lead scientist (PI Wells) assigned to oversee and attract users. The PI in turn will work with all other IAC PIs to further grow the customer base. We anticipate heavy usage of this robust instrument.