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Global Security, Medical Isotopes, and Nuclear Science

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Global Security, Medical Isotopes, and Nuclear Science

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Abstract. Over the past century basic nuclear science research has led to the use of radioactive isotopes into a wide variety of applications that touch our lives everyday. Some are obvious, such as isotopes for medical diagnostics and treatment. Others are less so, such as National/Global security issues. And some we take for granted, like the small amount of 241Am that is in every smoke detector. At the beginning of this century, we are in a position where the prevalence and importance of some applications of nuclear science are pushing the basic nuclear science community for improved models and nuclear data. Yet, at the same time, the push by the basic nuclear science community to study nuclei that are farther and farther away from stability also offer new opportunities for many applications. This talk will look at several global security applications of nuclear science, summarizing current R&D and need for improved nuclear data It will also look at how applications of nuclear science, such as to medicine, will benefit from the push for more and more powerful radioactive ion beam facilities.

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INTRODUCTION

Basic nuclear science research has led to nuclear technology development that is used in a wide variety of applications such as medical diagnostics and smoke detectors. This connection between basic nuclear physics research, technology development, and applications is expected to continue as the nuclear physics community builds new accelerator facilities to explore isotopes very far from stability. The capability of these new accelerator facilities will enable nuclear data measurements important to many applications and enable new research using near stability isotopes because of unprecedented productions rates.

Thus, this paper will summarize a number of activities that illustrate this connection, showing current development for nuclear technology for applications and discussing current nuclear science research and the possible impact it could have on a number of applications. This paper will start by focusing on the global security issue of detecting fissile material in cargo containers, and then make the connection to the Surrogate Reaction technique and Stockpile Stewardship. How these activities relate to the push for building radioactive ion beam facilities will also be discussed. The paper will then end with a discussion on possible advancements in medical isotopes given the building of these new radioactive ion beam facilities.

DETECTING FISSILE MATERIAL IN CARGO CONTAINERS

The shipment of cargo containers through the world's seaport offers a tremendous opportunity of the illicit smuggling of material. If this material is fissile material, one successful attempt could lead to a catastrophic event for the destination country and the world. The problem of detecting fissile material in cargo containers is not only difficult because of the cost for one false negative, but the sheer volume is enormous. 90% of the world's trade moves through sea-going vessels. For the United States, six million containers enter annually, which averages to 8 containers per minute on a 24 hour, seven days a week basis. Thus, whatever system is developed must have very low false negative and false positive rates and take about 1 minute to make a determination. To try and address this threat scientists at Lawrence Livermore National Laboratory (LLNL) have been engaged in several technical approaches. I describe two of these below.

Neutron Interrogation

Fissile material has many unique properties, not the least of which is that the atoms have a significant probably of undergoing fission when exposed to neutrons. A fission event releases a significant amount of energy divided between the kinetic energy of the fission fragments, neutrons and gamma rays. This creates the possibility of an unique, detectable signature of fissile material. The Neutron Interrogation Team has focused on detecting high energy gammas from the beta decaying fission fragments. High energy gammas, between 3 and 4 MeV, were chosen because of the lack of natural background in this region and the ability to penetrate material. Gamma rays from the beta decaying of fission fragments were chosen the produce a significant signal after the neutron irradiation has stopped. An exploratory experiment at LBNL was done [1] which showed a significant signal exists when irradiating plutonium for 30 seconds and detecting gamma rays between 3 and 4 MeV for the 30 seconds following irradiation.

Based on this work, proof of concept work was performed at LLNL. Figure 1 shows the basic layout of the neutron interrogation setup. Plastic scintillator was used because of the relative expense and the ability to get large detectors. The relative poor energy resolution is not an issue because of the interest in looking at the sum of all gammas between 3 and 4 MeV. Also, a d-d neutron source was used, because of the need to stay below the threshold for the $^{16}N(n,p)^{16}O$ reaction, which produces 6 MeV gamma rays. A series of experiments have been completed have demonstrated of the viability of this technique under a variety of cargo geometries and materials to produce a signal at the 5 sigma level. Further tests are underway as well as planning for the next phase, a full technology demonstration of this technique.

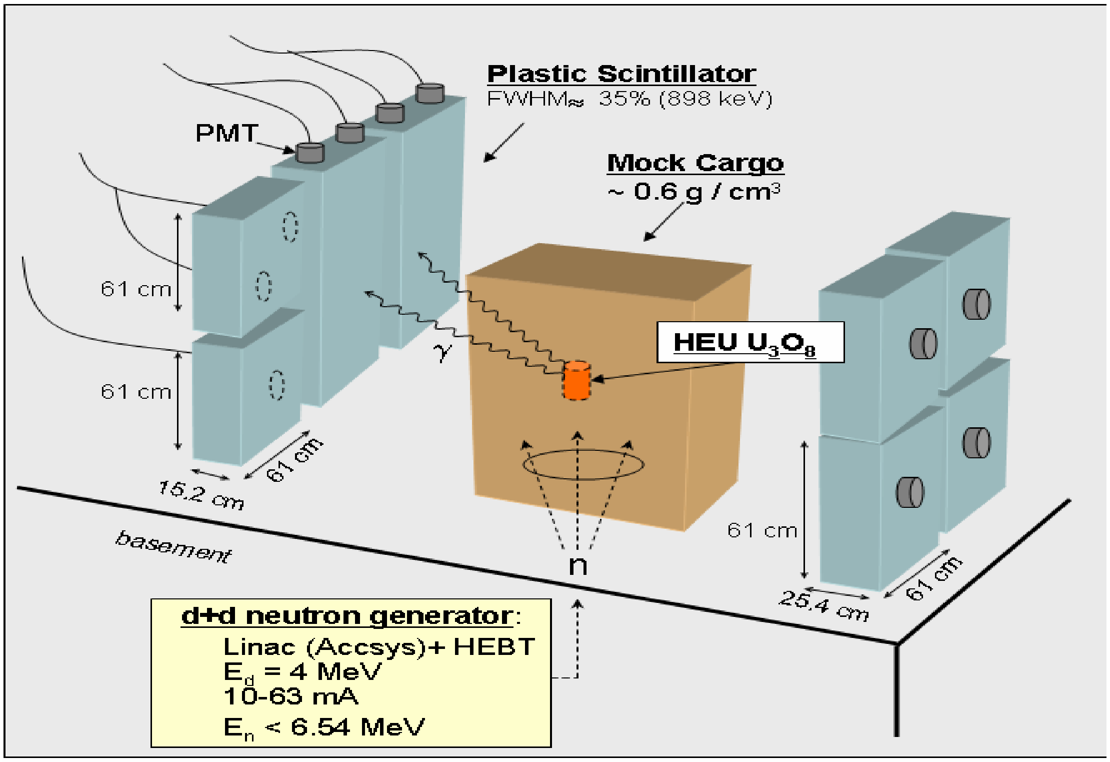

FIGURE 1. Layout of Neutron Interrogation setup at LLNL.

Nuclear Resonance Fluorescence

Another concept under development for detecting fissile material in cargo is to use nuclear resonance fluorescence. Figure 2 shows the basic concept for the detection technique. The main idea is to expose the material to a precisely tuned light source for specific and unique excited nuclear states of the fissile material. If that material is present in a cargo container, than the material will interact with the light and create a detectable signal. In order for this concept to work, a high resolution tunable light source in 0.5-2.5 MeV range is required. This light source is to be generated using Thomson scattering of laser light off an electron beam. Developing such a light source is also part of this project. Work is currently underway on developing the light source and the first proof of principle experiments are expected to be conducted in 2008.

ATTRIBUTION AND THE SURROGATE REACTION PROGRAM

Another program at LLNL currently underway relevant to global security is the Attribution Program. This program is geared around the problem of having of responding to nuclear event somewhere in the world. There would be many questions to be answered, including what was the yield of the device, what type of device was it, and what was the origin of the fuel. To answer these questions, radiochemical analysis of the debris will need to be conducted to look for quantities of specific radioisotopes. To further increase the reliability of the interpretation of the analysis, improved the nuclear data on many short-lived actinides are needed. Unfortunately, direct neutron cross sections measurements on these actinides are hard if not impossible because of the difficulty of making a target.

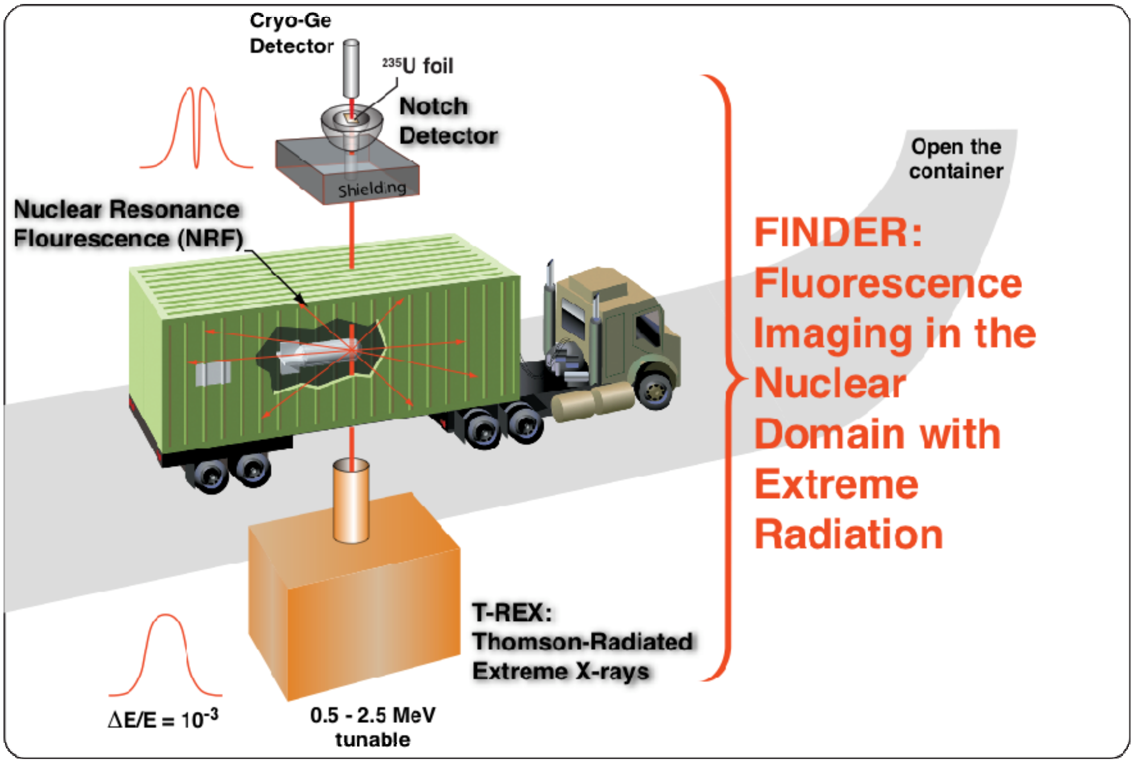

FIGURE 2. Schematic of the FINDER concept, to use nuclear resonance fluorescence to detect fissile material

To address this challenge, LLNL has been leading the effort to develop the surrogate reaction technique [2]. This technique relies on the fact that neutron cross section proceed in a two step process. First, the incoming neutron combines with the target nucleus to form an excited compound nuclear state. The probability for this formation is well predicted by optical model calculations. However, what is much more difficult to calculate is the probability for the compound nucleus to decay into the possible final states involving the emission of zero (neutron capture), one (neutron scattering), and two neutrons (n-2n reactions) emission. But if the compound nucleus if formed via a different reaction, specifically a reaction that emits a charged particle that can be detected, then it is possible to measure the probability for the compound nucleus to decay into decay into the possible exit channels. By combining this measurement with the optical model calculation, the neutron cross section can be determined. Figure 3 shows the idea behind the technique, graphically. The important assumption in this technique it that the compound nucleus equilibrates, thus it loses all information about how it was formed. Another important assumption is that difference in the spin distribution populated by the surrogate reactions is small as compared to direct neutron reaction. These assumption have been and continued to been check over different mass regions. To date, these assumptions have been shown to well justified, with the exception for neutron reactions below 1 MeV.

This technique has been applied in determining neutron cross section on ^{237}U, which has a 6.75 day half-life. A target of ^{237}U is impossible to make because it is impossible to make enough material and isotopically purify it to the quality needed for a cross section measurement. Since neutrons on ^{237}U would make a compound nucleus of ^{238}U then inelastic scattering on ^{238}U would make the same compound nucleus. This is exactly what was done to determine the fission cross section also shown in figure 3 [3]. Inelastic scattering of alpha particles on a ^{238}U target was used. This was the first every measurement of the fission cross section for ^{237}U

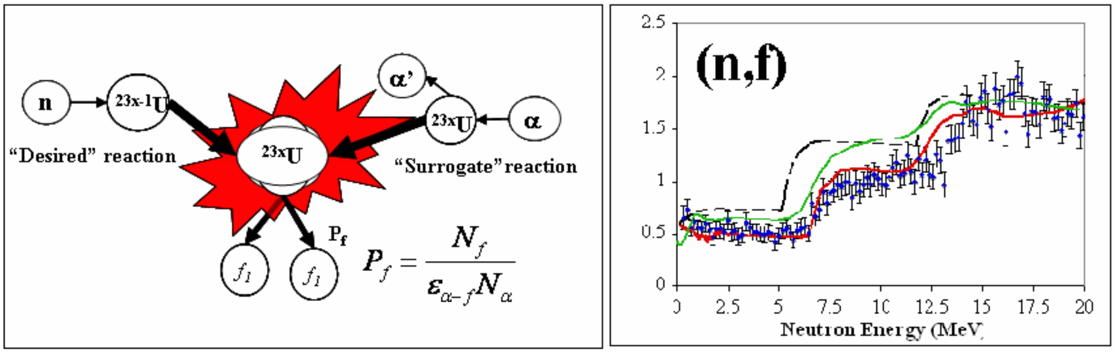

FIGURE 3. Diagram explaining the surrogate concept and experimental results for the ^{237}U(n,f) cross section as determined from inelastic alpha scattering on ^{238}U. The curves represent various database predictions for the cross section. The unit of the vertical axis is barns.

RADIOACTIVE ION BEAM FACILITIES

The surrogate reaction technique could also be very useful at planned next generation radioactive ion beam facilities. These planned radioactive beam facilities not only promise unprecedented productions rates for unstable nuclei, many of them also promise post acceleration for conducting nuclear structure experiments. This post acceleration is exactly what would be needed in order to conduct a surrogate measurement in inverse kinematics. There are several technical challenges that would need to be overcome in order to perform surrogate measurements at radioactive ion beam facilities, such as dealing with the increased energy loss in target and detecting the outgoing charged particle of the surrogate reaction. But if these issues are addressed then it would be possible to get information about neutron cross sections on very short lived nuclei like ^{95}Sr with a half life of 25.1 seconds.

In the US, there has been much effort in the low energy nuclear physics community to get approval to build a next generation radioactive ion beam facility. Figure 4 shows the current vision for such a facility from Michigan State University [4]. Argonne National Laboratory is other major competitor for the site of such a facility. Both design are based on a heavy ion linac capable of accelerating protons up to 500 MeV and Uranium atoms up to 200 MeV per nucleon. The total beam power from the linac will be 400 kW. The focus of the facility, at least from the beginning will be the fragmentation facility for generating isotopes. This involves directing the heavy ion beams on to a low Z target, such at lithium, beryllium, or carbon, and sending the produced fragment into a fragment separator. The separator will select the desired isotopes that will be sent to the in-flight experimental area or to a gas stopper. The in-flight experimental area is designed for the very short-lived species and will be most relevant for exploring isotopes relevant to the astrophysical r-process and near the drip lines. Isotopes directed to the gas stopper, will be slowed to 10's of keV and then either delivered to stopped beam experimental hall or to a charge breeder and reacceleration. The reacceleration is important for other astrophysics measurements and nuclear structure measurements.

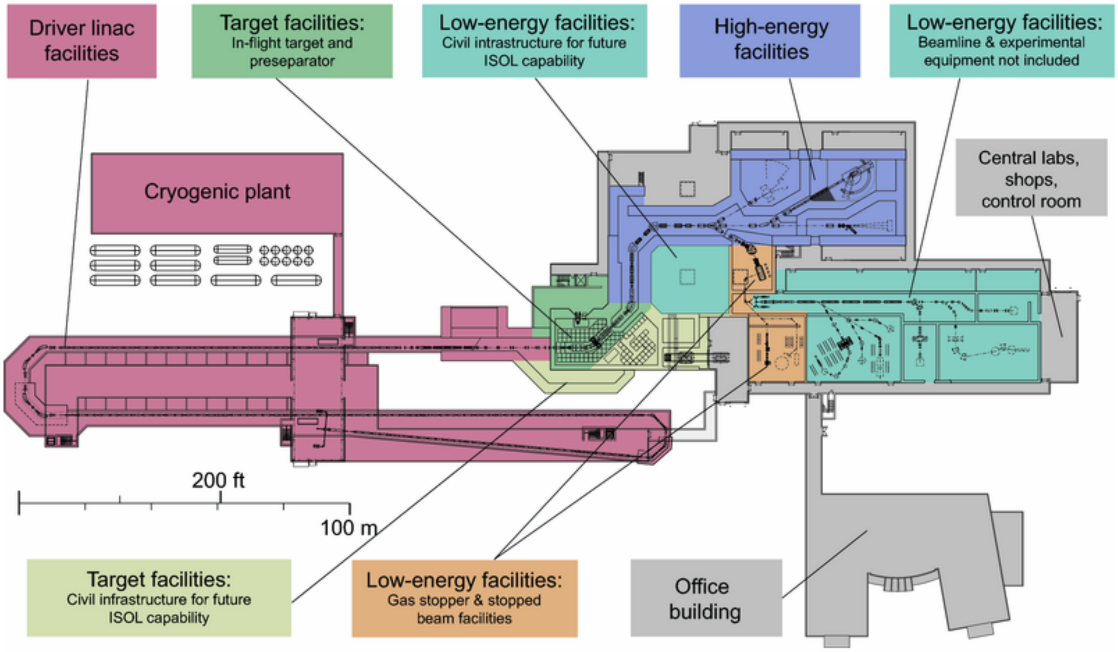

FIGURE 4. Layout of the the Isotope Science Facility, Michigan States proposed next generation radioactive ion beam facility.

It is predicted that such a facility will allow for the first time, any experimental measurements on many isotopes that are very far from stability. For the first time we will explore experimentally isotopes that are relevant to the r-process and explore near the neutron drip line for heavy mass systems. This facility will also provide much large production rates for isotopes near stability, which will enable many more types of experiments than were previously possible. Exploring in detail even near stability isotopes is important, because predictions for simple quantities such as mass vary widely once they get beyond know experimental data.

RADIOACTIVE ION BEAM FACILITIES AND MEDICAL ISOTOPES

Much of the basic science community is pushing for new more powerful next generation radioactive ion beam facilities because of the promise of exploring for the first time isotopes very far from stability. But there are many applications of radioactive isotopes that are not interested in exploring isotopes very far from stability because of the half-life would be too short for any practical use. But these applications would benefit from much higher production rates and a larger variety of available near stability isotopes. Most radioisotopes for applications today are made either in a nuclear reactor, which is limited to neutron rich nuclei, or in light ion accelerators. In both methods, there is no means to do mass separation which often limits the available purity of such isotopes. But radioactive ion beam facilities don't do offer mass separation and the ability to make both proton rich and neutron rich isotopes. This makes these facilities very attractive for exploring new isotopes for a variety of applications.

One such application is medical isotope. A prime example of how radioactive ion beam facilities could impact medical isotopes is given in reference [5]. G. Beyer et al., conducted an experiment using to study the effectiveness of using the alpha emitter ^{149}Tb in treating lymphoma in mice. ^{149}Tb has a 4.12 hour half-life and was made at the ISOLDE radioactive ion beam facility in CERN. The ^{149}Tb was attached to an antibody that is specific for the infected cells. Thus, the ^{149}Tb was delivered in close proximity to the infected cells, necessary for the alpha particle to affect those cells. The study divided the effect mice in the four groups. One received no treatment, the other two received just the antibodies, and the fourth received the antibody doped with ^{149}Tb. All the mice in the first three groups died. While, only 11% of the mice died in the group that received the ^{149}Tb. This was the first in vivo experiment to demonstrate the efficiency of alpha target therapy using ^{149}Tb. It is exactly this kind of research that would be greatly expanded when the next generation radioactive ion beam facilities come on line.

CONCLUSION

Basic low energy nuclear physics has led to the development of nuclear technology relevant to many important applications in today's world. Currently, there is much research going into to understand how our currently knowledge of nuclear physics can be used for a variety of global security issues. There is also interest in this area for improve nuclear data on short lived nuclei, which is also benefiting from improving our understanding of nuclear reactions. This relationship between basic nuclear physics and applications is expected to continue in the future with the push for the next generation radioactive ion beam facilities. These facilities will enable experiments on far from stability nuclei, which is of interest to the basic science community, but they also bring unprecedented production rates of near stability isotopes which will allow new possibilities for the application of radioisotopes to other challenges facing society.

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