Annual Report

ADVANCED NEUTRON GENERATOR FOR SNM IMAGING (IMAGING NEUTRON GENERATOR)

SL11-ImgNeutGen-PD2JD, OR11-NeutGenSupp-PD2JD

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1. INTRODUCTION

Associated particle imaging (API) is a neutron interrogation technique for detecting concealed or heavily shielded objects such as special nuclear material (SNM), explosives, and other contraband. In API, 14 MeV neutrons are formed in the deuterium–tritium fusion reaction along with an associated 3.5 MeV alpha particle that travels in the opposite direction of the neutron as a result of conservation of linear momentum. Characteristic signatures (gamma rays, fission neutrons, etc.) produced from neutron-target reactions in the interrogated object provide information on the target material. In contrast to traditional neutron interrogation techniques, API is a "self-collimating" method in which the alpha particles are used to determine the position and direction of the emitted neutrons, thereby significantly reducing the background noise by only selecting events caused by neutrons emitted in the direction of the interrogated object.

This project designs, fabricates, assembles, tests, and demonstrates an advanced API-type neutron generator with an integrated position-sensitive alpha detector based on a *negative ion source.* Advantages of this type of ion source are that it provides deuterium and/or tritium ion beams of 100% atomic fraction (increases neutron output with lower power requirement), inherently suppresses secondary electron emission at the target (increases operational lifetime and eliminates alpha detector damage), and negligibly degrades the beam spot size over time (improves the spatial resolution for imaging). The performance goals for the imaging neutron generator are to produce 10^6 D-D n/s (10^8 D-T n/s) from a 1-mm-diameter beam spot when operating at a few hundred watts of power and to reliably operate over a >1000 hour lifetime. The increased output and emitted neutron directional resolution improve the capability to assess actual or potential nuclear threats. For example, the signal-to-noise can be increased a factor of 25 over present fast-neutron transmission imaging of thick objects, and the ability to determine the enrichment of shielded highly enriched uranium is significantly enhanced for treaty verification, nuclear safeguards, nuclear material control and accountability, nuclear forensics, and national security

2. RESULTS, DISCUSSION AND CONCLUSIONS

The goal of this project is to develop a reliable API-type neutron generator that has higher neutron output, longer lifetime, and higher spatial fidelity than existing technology. The first-generation neutron generator utilizes the $D(d,n)^3He$ fusion reaction to produce 2.5 MeV neutrons for operational performance testing and, in turn, provide design guidance for developing the D-T API neutron generator. Work at SNL focused on designing, fabricating, and assembling the RF-driven plasma ion source, extraction system, and electron filter; the high voltage neutron production target; and the main vacuum chamber with diagnostics (Figures 1 and 2). After system assembly was complete, the negative ion source was tested for extracting negative D^- ions with high current. The electron filter was tested with argon gas, as negative argon ions are intrinsically unstable so only electrons manifest. No current was measured at the target, which indicated that the electron filter was operating as designed. The negative ion source was tested with both alumina and Pyrex ionization chambers (cups). Alumina has very good dielectric properties and is also an excellent tritium barrier material. A Pyrex cup was also tested because of its off-the-shelf commercial availability and low cost, but quartz would be more optimal for this application because of its more robust material properties. With the Pyrex cup, 80 μA of total negative current (electrons + ions) were measured at the target. An infrared camera was used to thermally image the Pyrex cup-to-metal interface, and the results showed that external air cooling was adequate to keep temperatures at acceptable levels, at least for short times. The ion source was also tested with the alumina cup, which unfortunately cracked after less than an hour of operation, presumably due to thermal shock from the plasma start-up and shutdown. In this regard, operating with tritium in an ion source having an external RF antenna would require a robust cup-to-metal braze joint for vacuum sealing. The problem is that the cup-to-metal seal can be subjected to very high temperature gradients from the plasma that can lead to thermally induced stress in the cup and/or joint and cause damage such as cracking. Because of these issues, a negative ion source based on an *internal* RF antenna configuration has been designed so that the braze joint is further away from the plasma in the ion source. In addition, the entire plasma chamber can be made from low carbon stainless steel or aluminum with water cooling channels to cool the source, thereby reducing outgassing and sputtering during plasma operation.

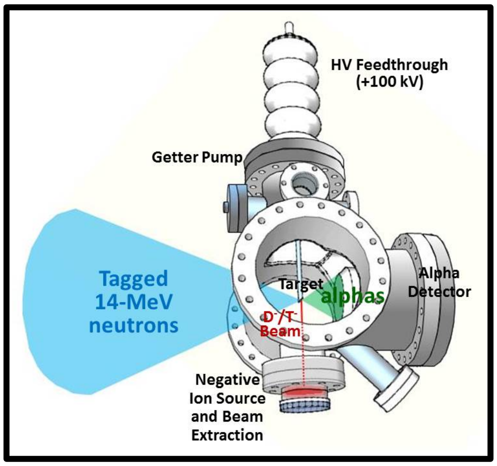

Figure 1. Schematic of the Imaging Neutron Generator based on a negative ion source.

Recently, SNL achieved three major project milestones, namely 1) demonstration of neutron production of ~10^5 D-D n/s using a negative ion beam, 2) verification of a 1.0–1.5 mm beam spot on target via a high resolution infrared camera, and 3) stable operation of the neutron generator at +100 kV for D-D neutron production for over 60 minutes. Experiments were successful in operating the negative ion source with hydrogen or deuterium at high power (>1 kW) for an extended period. The bright red color of the RF plasma indicated that predominantly atomic species are produced (Figure 3). A stainless steel mesh was incorporated inside the ion source to separate the RF plasma from the extraction region. This provided better filtering of the RF field inside the extraction region, improving the survivability of negative ions and increasing negative ion production. The neutron output was simultaneously measured

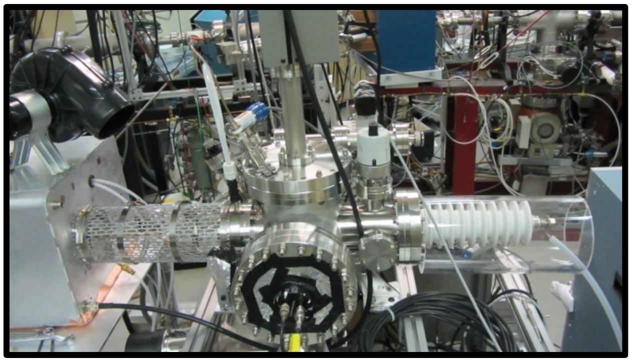

Figure 2. Photograph the Imaging Neutron Generator based on a negative ion RF-driven plasma.

with a ^{3}He neutron detector module available at SNL and, more quantitatively, with a silicon surface barrier detector mounted inside the vacuum chamber to measure proton reaction particles.

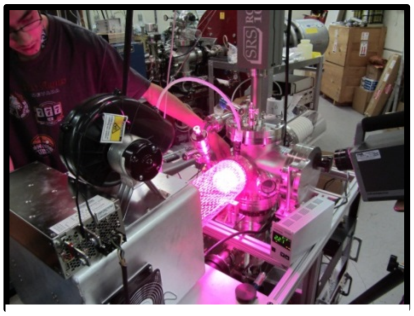

Figure 3. Photograph of the deuterium plasma in the ion source.

ORNL is developing the position-sensitive alpha detector for the imaging neutron generator. The work scope was divided into building a low-risk near copy of the unit that ORNL presently uses on Thermo-Fisher API120 D-T generators, and building a higher-risk detector with a wider field of view to enable faster measurement times of inspected objects. The construction and off-line testing of the low-risk alpha-particle detector component was successful, and it will soon be tested on the unsealed neutron generator. Photographs of the low-risk alpha-particle detector are shown in Figure 4. Unfortunately, the vendor will no longer frit the fiber-optic window to the frit flange, so this detector is now one of a kind. The larger field-of-view detector was designed and components were fabricated. The plan for this detector was to use a large fiber-optic faceplate sealed with an aluminum wire seal. The seal was successfully tested up to 180°C with a stainless steel blank substituting for the window. Unfortunately, after four attempted fusions by the vendor, the larger size fiber-optic window could not be successfully fused by use of the material with the required optical properties (Schott 75C). As a result, the construction of the wider field-of-view detector was unsuccessful.

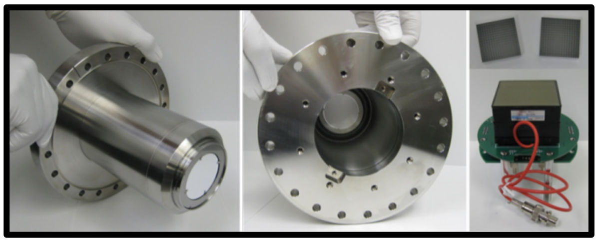

Figure 4. Photographs of the low-risk alpha-particle detector and corresponding readout with a Hamamatsu H9500 256-anode photomultiplier tube.

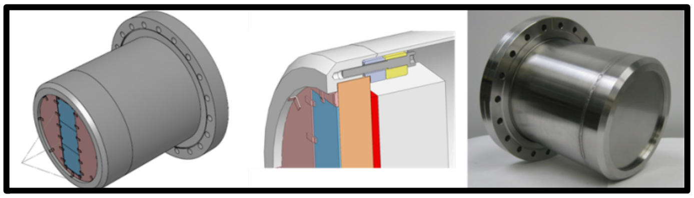

Figure 5. Design of the large field-of-view detector and photograph of the prototype detector with a stainless steel blank substituted for the fiber-optic window.

3. PATH FORWARD

SNL will build, assemble, and test the tritium-compatible negative ion source with *internal* RF antenna. A new magnet configuration in the extraction region will be tested; the configuration allows the magnets to be removed without breaking vacuum during bakeout for tritium operation. It also allows the use of stronger, more robust, neodymium magnets and makes it possible to easily adjust and optimize the magnet field to increase the negative ion current.

ORNL will test the existing alpha detector in the SNL D-D generator, and likely use the balance of project effort to build a detector based on a commercially available quartz or sapphire viewport.