IPNDV Working Group 3: Technical Challenges and Solutions
Nuclear Material (6)—Technology Data Sheet

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Nuclear Material (NM) Technology Name: Active Neutron Interrogation

Physical Principle/Methodology of Technology:

Active Neutron Interrogation (ANI) is a broad category of measurement techniques that involve exposing an item of interest to a beam of neutrons, detecting the emitted neutrons or gamma-rays from the item, and using this information to assess the contents of the item of interest. Neutron interrogation can be used in various ways to support monitored dismantlement. This Technology Data Sheet discusses the techniques that use a constant neutron source to interrogate an item for verification of special nuclear material. Techniques that use a pulsed neutron source to confirm special nuclear material are discussed in Working Group 3 Nuclear Material 5 Technology Data Sheet. Techniques that use active neutron interrogation for the verification of high explosives are discussed in Working Group 3 High Explosives 2 Technology Data Sheet.

A range of particles are emitted from an item when bombarded by neutrons, depending on the type of material present. There are two neutron reactions of primary interest for disarmament applications. A neutron capture reaction results in the (nearly) instantaneous emission of a prompt gamma-ray, followed by the emission of beta particles and delayed gammas when the radioactive product nucleus decays. Fission results in the emission of prompt gammas and neutrons as well as the emission of delayed gammas and neutrons when the unstable fission product decay. Any of these emissions can be detected and analyzed to provide information about the item.

ANI can be used with gamma-ray detection and gamma spectroscopy to determine the energy of the gamma-rays and deduce the isotopes that are present in the item. This is possible because the gamma-ray energies are characteristic of the isotope that emits them. For example, ^{233}U) and ^{235}U can be identified from prompt gamma-rays and ^{238}U and ^{239}Pu can be identified from delayed gamma-rays. Other isotopes can be confirmed as long as a characteristic gamma-ray can be measured, which depends on concentration, neutron absorption cross-section, neutron flux, irradiation time, and measurement time. Notably, many Pu isotopes can be identified through passive gamma spectroscopy without the use of neutron activation. The measurement of prompt gamma-rays may be easier than the measurement of delayed gamma-rays in a disarmament scenario because higher neutron flux and longer measurement times may be necessary to obtain sufficient counts of delayed gamma-rays.

ANI can also be used with neutron detection and multiplicity counting or related analyses to confirm the absence or presence of neutron-multiplying materials including ^{233}U, ^{235}U, and ^{239}Pu, and to determine the mass of U or Pu. Whereas many Pu materials have a sufficient neutron flux to facilitate passive neutron measurements, adequate U measurements may require neutron bombardment from an external source to induce fissions. The ability to detect U is a major benefit of active neutron multiplicity counting over passive neutron multiplicity counting. The neutron emission information (timing or energy) does not directly indicate which isotope(s) is emitting neutrons. Conventionally neutron counting (passive or active) is often used with passive gamma spectroscopy to identify specific isotopes of U and/or Pu that are present in the item. It may be possible with sophisticated analyses such as characterization of the emission profile of the delayed neutrons to confirm that two or more isotopes are present.

A portable constant neutron source can be based on a radioactive isotope, such as ^{252}Cf, or on a portable neutron generator. In a typical neutron generator, deuterium (H-2) ions are bombarded against deuterium or tritium to produce neutrons. There are various considerations in the selection of a neutron source including neutron energy and facility preferences pertaining to safety and security.

Potential Monitoring Use Cases (pre-dismantlement, dismantlement, post-dismantlement, storage stage):

The primary applications currently envisioned are as follows. Additional use cases are possible.

ANI with neutron detection: Pre-dismantlement to confirm the presence or mass of fissile material (FM) to support warhead verification, post-dismantlement to confirm the presence or absence of FM to support dismantlement verification.

ANI with gamma detection: Pre-dismantlement to confirm the presence of Special Nuclear Material (SNM) to support warhead verification, post-dismantlement to confirm the presence or absence of SNM to support dismantlement verification.

Used to measure U, Pu, or U and Pu:

U, Pu, and U and Pu, depending type of detection and analysis used

For detection technologies, what does the method determine/measure (e.g., presence of nuclear material, isotopics, mass, etc.)?

ANI with neutron detection: Presence and mass of fissile material

ANI with gamma detection: Presence of specific isotopes of interest

Physical Description of Technology (e.g., approximate size, weight):

The equipment setup would include a portable neutron source and a detector. Gamma detectors are usually small (approximately the size of a shoebox). Neutron detectors are usually larger, and may involve a well-type cavity or one or more detector panels that are placed next to the item of interest. Shielding may or may not be needed to reduce personnel exposure or to optimize the radiation received by the detector. Instrumentation is needed to receive and process information from the detector and a computer is needed to perform the analysis. The instrumentation and computer equipment may be commercial or optimized (e.g., simplified) for a disarmament scenario. All necessary equipment would likely fit on one or two wheeled trolleys.

Time Constraints (e.g., measurement times including distance from object, time to install the equipment):

Setup and measurement times depend on the type of detection and analysis performed and may be 30 minutes to 1 hour for set up and 10 minutes to 1 hour for the measurement. Factors that increase the time required include:

- HPGe gamma detectors need to be cooled and this may require up to 6 hours.
- Movement of radioactive neutron sources and permission to turn on a neutron generator may entail safety and security checks that may take a few minutes up to an hour.
- The sensitivity of absence measurements is directly related to the measurement time.

Measurement time to measure 500 g of Pu (0.1 ^{239}Pu/^{240}Pu) or 500 g of ^{235}U at 1 m from the surface of the container (order of magnitude: seconds, minutes, hours, days):

Several minutes to 1 or 2 hours, depending on number/size of detectors used and the accuracy/precision desired

Will this method work in the presence of shielding? If so, what is the maximum amount of shielding that will still allow the method to work?

Gamma emission and detection may be hampered by materials surrounding the item that are dense or have a high atomic number, such as steel or lead. Measurements may be possible with up to (approximately) 0.5" of lead, but this value is sensitively dependent on the energy of the desired gamma-ray.

A primary advantage of neutron detection is that neutrons are only slightly attenuated by steel and other materials often found in nuclear material containers. However, certain isotopes absorb neutrons and act as a neutron shield. For example, some nuclear containers use borated polyethylene to reduce the neutron dose to personnel handling the container. Several inches of borated polyethylene would likely be needed to impact the neutron measurement.

Technology Complexity (e.g., hardware, software, and ease of use by personnel):

The neutron source, whether a radioactive material or a generator, requires operation by skilled or trained personnel. Gamma spectroscopy can be automated so that a technical person is not needed to interpret the results. Neutron counting and neutron multiplicity can also be automated. In some cases, review of the results by a technically skilled person can improve confidence that the measurement and analysis worked correctly. Many detector systems require a technically skilled person for setup and assembly, but it would be possible to design a system specifically for use by minimally trained personnel.

Infrastructure Requirements (e.g., electrical, liquid nitrogen, etc.):

Infrastructure requirements depend on the type of detection system used. Considerations include:

- HPGe detectors require cooling either with liquid nitrogen or a cryogenic cooler.
- Radioactive neutron sources will likely require facility assistance for retrieval and transport.
- The detectors (potentially including He-3 neutron detectors or high-resolution gamma detectors) will likely require wall power.

Technology Limitations/Variations (e.g., detection limits for nuclear material, operational temperature range, differences in technology detector materials):

Boron straws and other He-3 alternatives for neutron detection have recently become comparable to traditional He-3 detectors in terms of cost and detection capability. Important considerations in the selection of an optimal neutron detector include size (bigger detectors allow faster/more accurate measurements but can be harder to deploy) and ability to understand the degree of coupling (well counters allow reproducible measurement of the neutron interactions between the item and the detector, but can be bulkier and harder to deploy).

The primary considerations for gamma detectors are resolution (higher resolution offers better discrimination between gamma-rays), the potential need for cooling, calibration stability, and the detection efficiency at the gamma-ray energy of interest.

Information Collected by the Technology (used to help determine if an information barrier is required for use):

ANI with gamma detection: This approach often involves collection of a gamma spectrum which may be classified.

ANI with neutron detection: This approach often involves collection of neutron timing and correlation information, such as the rate at which pairs of neutrons are detected. This information can be used to estimate item parameters such as mass, and therefore may be classified.

Safety, Security, Deployment Concerns:

Any use of a neutron source can introduce safety concerns.

Well-type neutron counters may be large and bulky to transport.

Technology Development Stage (Technology Readiness Level, TRL):

The techniques discussed in this Technology Data Sheet are well-developed and in most cases commercially available. For the purpose of dismantlement verification, it may be necessary to optimize the equipment to improve portability, the ability of either treaty partner to verify and trust the equipment, and/or to include an information barrier.

Cost Estimate:

The high-cost items are the neutron source and the detection equipment. Neutron generators may cost in the range of €200,000, depending on quality. High resolution gamma detectors may cost in the range of €50,000, and neutron detectors may cost in the range of €50,000–€200,000 depending on size.

Additional System Functionality (e.g., outside the monitoring use case):

The ability to create a gamma spectrum is potentially classified and only a small part of that information may be used for the analysis.

Where/How the Technology Is Currently Used (e.g., international safeguards, border protection):

Nuclear waste characterization, international safeguards, domestic safeguards, fundamental research on materials such as environmental samples

Examples of Equipment:

Active Well Coincidence Counter (AWCC) based on neutron interrogation and neutron multiplicity counting: http://www.canberra.com/products/waste_safeguard_systems/pdf/JCC-51-SS-C36907.pdf.

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