IPNDV Working Group 3: Technical Challenges and Solutions
High Explosives (3)—Technology Data Sheet

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High Explosives (HE) Technology Name: Nuclear Quadrupole Resonance (NQR) Explosive Identification System

Physical Principle/Methodology of Technology:

Nuclear quadrupole resonance (NQR) uses the quadrupole moment of the nucleus for an identification of the type of explosives present.

NQR spectroscopy is an analysis technique related to nuclear magnetic resonance (NMR). Unlike NMR, NQR transitions of nuclei can be detected in the absence of a magnetic field. The NQR resonance is mediated by the interaction of the electric field gradient (EFG) with the quadrupole moment of the nuclear charge distribution. Because the EFG at the location of a nucleus in a given substance is determined primarily by the valence electrons involved in the particular bond with other nearby nuclei, the NQR frequency at which transitions occur is unique for a given substance. A particular NQR frequency in a compound or crystal is proportional to the product of the nuclear quadrupole moment, a property of the nucleus, and the EFG in the neighborhood of the nucleus. It is this product that is termed the nuclear quadrupole coupling constant for a given isotope in a material and can be found in tables of known NQR transitions.

Any nucleus with more than one unpaired nucleon will have a charge distribution that results in an electric quadrupole moment. Allowed nuclear energy levels are shifted unequally due to the interaction of the nuclear charge with an electric field gradient supplied by the non-uniform distribution electron density (e.g., from bonding electrons) and/or surrounding ions. As in the case of NMR, irradiation of the nucleus with a burst of Radiofrequency electromagnetic radiation, if of a particular frequency, results in absorption of some energy by the nucleus, which can be viewed as a perturbation of the quadrupole energy level. Unlike the NMR case, NQR absorption takes place in the absence of an external magnetic field. The re-emitted radiation is then detected. Application of an external static field to a quadrupolar nucleus splits the quadrupole levels by the energy predicted from the Zeeman interaction. The technique is very sensitive to the nature and symmetry of the bonding around the nucleus. It can characterize phase transitions in solids when performed at varying temperature. Due to symmetry, the shifts become averaged to zero in the liquid phase, and thus NQR spectra can only be measured for solids.

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

Verification of explosives present/absent. Works best for bulk detection, 100 g or more. Shielding of RF signals is a potential limitation.

Pre-dismantlement: Unlikely, due to shielding of RF radiation between HE and detection apparatus.

Dismantlement: Possible, depending on the use of pinhole(s) for insertion of the NQR probe that needs close proximity (less than approx. 1 m).

Post-dismantlement: In insensitive form, yes. In sensitive form, depending on the use of pinhole(s) as above.

Storage stage: Yes, if not heavily shielded.

For detection technologies, what does the method determine/measure?

Presence/absence of HE.

Identification of the type of explosives present. The NQR spectrum of an explosive substance (e.g., TATB, HMX, RDX) is unique and easily identified.

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

A detection system consists of a radio frequency (RF) power source, a coil to produce the magnetic excitation field and a detector circuit that monitors for a RF NQR response coming from the explosive component of the object.

A few modules in a 19” rack + probe.

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

Set-up and calibrate equipment 1 hour (finished system). Measurement time, from a few minutes up to 1 hour. Absent detection takes longer time. Only short distance measurements (less than 1 m).

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?

Cannot measure through metals, but do not need optical access to the sample; pinhole is sufficient.

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

A finished system should be easy to set up and operate.

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

Electrical power.

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

Sensitive to temperature variation and absence detection takes longer time. In both cases this is due to a fairly low signal-to-noise-ratio.

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

Presence/absence. Identification of the explosives.

Safety, Security, Deployment Concerns:

None, except usual ones when working with HE.

Technology Development Stage (Technology Readiness Level, TRL):

Commercial NQR system exists but must be adopted and tested for this special case. New probes need to be developed. For nuclear weapon purposes, including dismantlement verification, the technology is at TRL 3.

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

Does not use ionizing radiation. Does not require imaging analysis.

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

The technology has, for example, been tested for landmine detection and explosives concealed in luggage.