Production of Radioxenon for Nuclear Explosion Monitoring

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INTRODUCTION

There exists a global and national need for nuclear explosion monitoring for treaty verification and forensics. Recent geo-political issues reinforce this need. One key component of current monitoring efforts is the detection of radioactive xenon in the atmosphere. Radioactive xenon is a relatively intense product of fission. Because it is a noble gas it is difficult to contain, so a radioxenon signature eventually betrays any covert nuclear weapons detonation. Nuclear power plants and medical isotope production also release measurable amounts of radioactive xenon into the atmosphere necessitating more sophisticated monitors that can distinguish the source of radioxenon.

RADIOXENON DETECTION

Measuring relative radioxenon activity ratios from a combination of four xenon isotopes and isomers can distinguish between production sources. These isomers and isotopes are listed in Table 1 along with their half-lives and ^{235}U fission yields. Due to the required sensitivity for measuring minute quantities of radioactive gasses in the air, β-γ coincidence detectors are used [1]. Dual-detectors of this type are triggered from coincident charged particle and gamma-ray signals. The beta-particle detection material is only sensitive on the inside surface of a volume, thereby greatly reducing other environmental background. The basic design is usually a plastic scintillator material coupled to a high-efficient gamma-ray detector.

One drawback of current β-γ coincidence detectors is that xenon can diffuse into the plastic scintillator material and some of the radioxenon nuclei have half-lives of several days. Therefore, a spike in the radioxenon concentration can lead to elevated background signals lingering for many days that are indistinguishable from β-γ coincidence events from the air sample being monitored. This is called a "memory effect" and can be mitigated by evacuating the detection volume and waiting a few half-lives for the radioxenon to decay away, or by coating the surface of the plastic scintillator with something to prevent xenon diffusion. This coating also reduces the energy resolution of the plastic scintillator leading to less accurate monitoring results. However, a process to supply samples of specified radioxenon activity ratios would support future development and characterization of new radioxenon detectors.

CONTROLLED RADIOXENON PRODUCTION

Producing radioxenon in a controlled manner could facilitate development of new radioxenon detectors. Niowave is uniquely capable of developing a radioxenon production process by leveraging equipment and expertise that overlap existing Niowave projects. Niowave has a subcritical Uranium Target Assembly (UTA) along with the accelerators and licenses to induce fission and extract radioisotopes. We also have the radiochemistry and radiation safety expertise to extract radioisotopes from solid or powdered uranium fuel rods.

Fig. 1. Picture of prototype Gas Extraction Module (GEM) attached to UTA, comprised of an extraction line, series of valves and gauges, and a cryogenic collection cup (inside the lead castle).

UTA is a pool-type subcritical assembly designed and built at Niowave. UTA is driven by an external neutron source, for example a ^{252}Cf source, DD neutron generator, or superconducting electron linac equipped with a photoneutron converter. Low-enriched uranium and natural uranium pellets are cladded in aluminum rods, which are loaded into a stainless-steel tank filled with light water, which serves as a coolant, moderator, reflector, and shielding. UTA has the versatility to vary the core configuration and moderating materials to operate as a thermal or fast core and consists of

35 LEU fuel rods in the inner core and 23 NU fuel rods in the outer ring loaded in pin pitch of 1 inch. The calculated effective multiplication factor of k_{eff} is 0.43. The total fuel loading in UTA is 1.6 and 4.6 kgU of LEU and NU, respectively.

By converting the uranium fuel to a powdered form, we can extract volatile gases from UTA. The prototype gas extraction module (GEM) uses a cryogenically-cooled trap to "pump" the radioactive gases into a small vessel for monitoring with a high purity germanium HPGe detector. Fig. 1 is a picture of UTA with the prototype GEM.

Table 1. Radioxenon cumulative and independent yields [2].

Nucleus	Half-life (days)	Cumul. Yield	Indep. Yield
^{131m}Xe	11.9	3.1E-4	3.6E-9
^{133m}Xe	2.2	1.9E-3	1.1E-5
^{133}Xe	5.3	6.59E-2	4.4E-6
^{135}Xe	0.38	6.61E-2	6.9E-9

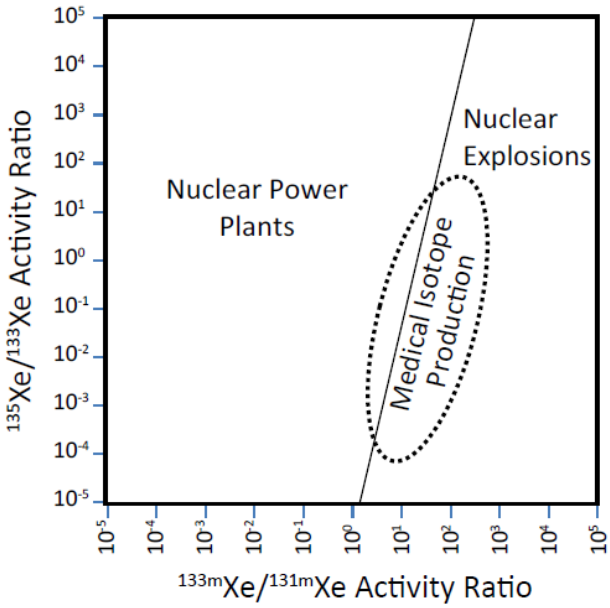

Fig. 2. Radioactivity ratios chart for determining source of radioxenon (from Ref. [3]).

PRELIMINARY RESULTS

By taking advantage of the drastic differences between the cumulative and independent fission yields (see Table 1) of the four radioxenon nuclei, the source of any detected radioxenon can be determined. Fig. 2 is a plot of the activity ratios chart used to determine the source of any measured radioxenon. Longer irradiation time, leading to cumulative fission yields from thermal-neutron fission of ^{235}U, will result in activity ratios on the left side of the chart. Faster reaction times, like explosions, will result in activity ratios on the right side of the chart. Some medical-isotope production facilities may emit radioxenon activity ratios in between those two extremes. The line that separates power plants from explosions follows the changes to the relative ratios as the radioxenon sample decays. Successive measurements of a sealed sample of radioxenon, measured at different times, will be parallel to this delimitation line.

By adjusting the extraction method for GEM, we expect to produce radioxenon activity ratios in a range between the two extremes; allowing use to tune radioxenon samples to mimic all production sources. The irradiation time of the UTA can be run for days before extraction, thereby allowing many of the radioxenon precursors to increase the total xenon yield, or extraction could be done continuously during short irradiation times to get activity ratios closer to the independent fission yield of the xenon nuclei. The former extraction method yields radioxenon ratios consistent with power plants while the latter is consistent with nuclear explosions.

Preliminary results of a with GEM and UTA demonstrate extraction of a pure sample of short-lived noble-gas fission products. The neutron irradiation was from 5 MeV electrons impinging a photoneutron convertor target for about 2 hours from a Niowave superconducting electron linear accelerator. The identified nuclides included ^{87}Kr, ^{88}Kr, ^{135m}Xe, ^{137}Xe, and ^{138}Xe. We also saw some longer-lived ^{135}Xe.

The capability to produce an accurately tuned sample of radioxenon will greatly enhance future efforts to develop improved radioxenon β-γ coincidence detectors thereby improving nuclear explosion monitoring.

NOMENCLATURE

GEM = Gas Extraction Module
HPGe = High-Purity Germanium
UTA = Uranium Target Assembly
NU = Natural Uranium
LEU = Low ^{235}U-Enriched Uranium

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