SAFETY ISSUES IN ACCELERATOR OPERATION: GROUNDWATER CONTAMINATION

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Abstract
The Environment, Safety, Health, and Quality (ESHQ) is an integral part of how we do business at the Collider-Accelerator Department at the Brookhaven National Laboratory. Although the department has had a good track record with regard to safety, ground water contamination was observed in 1999 due to high intensity proton operations at the AGS. This paper will examine root causes and lessons learned from our experiences.

1. INTRODUCTION

Following the discovery, in 1997, of five Curies (Ci) of tritiated water contained in a plume emanating from the spent fuel rod storage pool at the High Flux Beam Reactor (HFBR), the Laboratory began an aggressive program to locate and characterise other sources of groundwater contamination. Four sources were found in the Collider Accelerator Complex. Three sources were associated with high intensity proton operation at the Alternating Gradient Synchrotron (AGS). One source was identified with the AGS internal beam dump known as the ‘E20 Catcher’. Another other source was identified with chronic beam losses on one of the final quadrupoles (VQ12) in the beam transport used to bring protons from the AGS to the production target for the muon g-2 experiment. A third source was associated with the beam dump in the decommissioned neutrino beam line and will not be discussed here. The highest concentrations of tritium (^{3}H) and Sodium 22 (^{22}Na) in the vicinity of the E20 catcher were found to be 2 times and 1.75 times the drinking water standard respectively. The highest concentrations of ^{3}H and ^{22}Na in the vicinity of VQ12 were found to be 90 times and 0.15 times the drinking water standard respectively. The drinking water standard is 20,000 pCi/L for tritium and 400 pCi/L for ^{22}Na. The drinking water standard limits the internal dose to 4 mRem for an individual who annually ingests water (200 gallons ~ 800 litres) contaminated at a concentration corresponding to the standard. With regard to the problems at the HFBR, it is interesting to note that self-illuminated EXIT signs that generate light by taking advantage of ^{3}H decay, contain approximately 20 Curies of the isotope. A Curie is a measure of the activity or concentration of a radionuclide. It is defined as 3.7×10^{10} disintegration per second.

2. MECHANISMS

Iron, concrete, and soil are the primary shielding materials for radiological protection. Most secondary particles created by the interaction of primary protons with accelerator components will be stopped in the shielding. When a high-energy secondary interacts, a variety of radioactive nuclei are produced. The mass numbers of the atoms produced range from the mass of the target-plus-one down to a mass number of three (^{3}H). Most of the nuclei produced are short lived. The two longest-lived isotopes produced are ^{3}H and ^{22}Na with half lives of 12.3 and 2.6 years respectively.

Radioactive nuclei created in concrete and iron are, in general, not dispersible. On the other hand, radioactive nuclei created in soil may be dispersed by water. Sodium and hydrogen tend to form water-soluble compounds that tend to be dispersed. Figure 1 shows a section of the AGS tunnel, which represents a typical shielding design. The bold inner rectangle depicts the concrete tunnel. The inner trapezoidal shape shows a ‘soil cement’ shield that was added in 1989 in preparation for the commissioning of the booster and higher intensity operation. The outer trapezoidal shape corresponds to the soil overburden. Rainwater seeping through the soil transports the radioactive materials in the soil downward to the water table. At the water table, the water flow again becomes horizontal, tending to transport the radionuclides in the direction of the laboratory boundary.

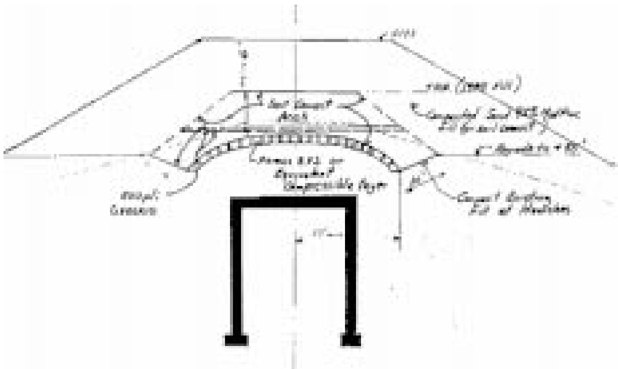

Fig. 1: AGS tunnel section view

The rate of migration of the nuclides is 0.75 feet per day. Given the migration rate, the location of the source two miles from the lab boundary, and the direction of groundwater flow, it would take in the order of two years for the radionuclides to reach the site boundary. Given the time scale, the concentration of radionuclides would be reduced when they reach the laboratory boundary owing to the radioactive decay of the nuclides and the continued influx of rainwater. Wells were drilled to map the extent of the contamination. The contamination was found to be confined to narrow plumes 20-30 feet across, approximately 40 feet underground, and in the case of the VQ12 plume, 250 to 300 feet long.

3. PAST OPERATIONS INVOLVING THE SOURCES OF CONTAMINATION

The catcher, at the E20 position in the AGS ring, was used as a beam dump from 1984 through 1999 when a new device was installed. E20 is a three-meter long block of tin-lead alloy (solder) with a beam tube at its centre. The device can be translated and skewed in the horizontal plane to minimise losses at injection. It was designed to accept any and all losses through the acceleration cycle including automatic or manual aborts of the circulating beam. It was not intended as, nor was it used as, a place to continuously dump particles. Operators were instructed to reduce the intensity of the circulating beam or to cease proton injection into the AGS rather than activate the catcher unnecessarily.

The quadrupole known as VQ12, part of the final focus for the muon g-2 experiment production target, was the source of the largest groundwater contamination problem that the Collider- Accelerator department has faced. The beamline optics were such that a beam position displacement at AGS extraction, was magnified by a factor of six at the downstream position of VQ12. The fact that ‘beam quality’ was only routinely monitored at the production target resulted in chronic beam loss at VQ12. One reason for the lack of beam quality monitoring was that new instrumentation was under development for RHIC and although intended for use during proton operation, its installation was delayed.

4. PRESENT OPERATIONS INVOLVING THE SOURCES OF CONTAMINATION

The E20 catcher has remained in the AGS ring. It has been positioned so that it intercepts none of the circulating beam. A new ‘beam scraper’ has been installed at the J10 position. An engineered solution has been employed to protect the groundwater. A gunite cap was placed over the soil at E20 and J10 to prevent rainwater from leaching ^{3}H and ^{22}Na out of the soil. During high intensity proton operations, operators review the loss pattern at E20 to verify that they are minimal. Operators prevent the deliberate dumping of more than three pulses of high intensity beam anywhere in the AGS.

VQ12 is still an integral part of the beam transport to the production target. The beam optics were re-worked in 1999 so that changes in beam position upstream do not cause losses downstream. New loss monitors were installed and four were placed in the vicinity of VQ12. Operators regularly monitor the losses in the beam transport. A gunite cap was placed over the soil around VQ12.

5. CONCLUSION - LESSONS LEARNED

Given that losses are unavoidable, and the fact that soil is routinely used for shielding, it is no surprise that the soil shield became activated. What was a surprise was the fact that the activation had spread. The root cause for the problem was inattention to detail throughout the organisation. The lack of attention to detail made the situation at E20 unavoidable in that activation was present but we were not expecting it to spread. The VQ12 situation, in my judgement, could have been averted but again the lack of attention to detail played a significant role. The initial optics in the beam transport were off the mark. The lack of working instrumentation was a mistake. The inability of the operators to identify the loss was a disappointment but not a surprise. Given the lack of instrumentation the discovery of the loss would have been difficult. Operations management was at fault too. The procedures provided for the operators had them focusing on processes rather than on positions along the beam path – hence their focus was diverted from the problem area.

A number of lessons were learned from our experiences and the lessons have had an impact on accelerator operations. Foremost in our education was the fact that operators must posess a greater awareness of the environmental impact of accelerator operation. Knowing that some beam losses are unavoidable, we learned to cover soil used as shielding wherever loses are expected in the chain of accelerators. We have learned to confirm assumptions made during the design phase regarding soil activation adjacent to new beam lines by conducting soil activation measurements.

Operators in the MCR have learned to do business differently. The Operators routine includes monitoring of beam losses at critical locations during high intensity proton operations. The routine monitoring is prescribed by formal procedures. We have learned not to rely on one instrument to determine beam quality; beam loses must be considered as part of the ‘quality equation’. ‘Watchdog’ software is used to generate alarms when high losses are experienced at critical locations, or during prescribed segments of the acceleration cycles in the Booster, the AGS, and the external beam transport. Critical to many of our lessons is the changed behaviour of the Operators. They have learned to react as required and to be proactive to prevent losses where possible.

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