TRTR/IGOR 2005 Annual Meeting

Poster Session

Ten Year Review of Tritium Build-up in Heavy Water Coolant/Moderator for 20 MW Test Reactor and Resulting Radiological Consequences

David R. Brown, CHP
National Institute of Standards and Technology
Safety, Health and Environment Division
Reactor Health Physics Group

Abstract:

At the heart of the NIST Center for Neutron Research (NCNR) is a twenty-megawatt, heavy water cooled and moderated, test reactor (aka…NBSR). Neutron moderation by heavy water presents many features that are attractive in the design of a research reactor facility. Specifically, its lower neutron absorption cross-section and better scattering characteristics allow for improved core optimization for neutron research purposes. The down side of using heavy water is the production of tritium from the neutron activation of deuterium. If the reactor systems were hermetically sealed from the outside world this concern would be more manageable and not as much of a problem, however, they are not and we must manage the buildup of tritium carefully.

There are many aspects of the facility that must be closely monitored to maintain a guiding principle of ALARA (As Low As Reasonably Achievable) with respect to this tritium build-up for radiation protection purposes. First and foremost is tritium uptake and internal exposure to personnel. The potential for significant exposure must be considered when performing maintenance on reactor and experimental components that allow direct access to heavy water systems. Direct contact with the water can result in significant uptake as well as elevated airborne concentrations of tritium resulting in substantial personnel exposures. Also of concern are; tritium contamination of materials and components for disposal as radioactive waste, ambient (…or background) concentrations of airborne tritium within the reactor building and experimental areas, liquid and gaseous effluents to the sewer and environment, as well as cross contamination of other reactor and experimental systems. This presentation will review and summarize a compilation of data collected over a ten year life span of a typical heavy water inventory in the NBSR.

Reactor and System Parameters:

Licensed Power – 20 Megawatts (thermal)
Peak Thermal Neutron Flux – 5E14 $_0n^1/cm^2/sec$*
Primary Cooling System D_2O Volume – 40,000 liters (10,500 gal)*
Primary Cooling Flow Rate at Full Power – 34,000 liters/min (9000 gpm)*
Reactor Vessel D_2O Volume at full power – 9,300 liters (2460 gal)*
Reactor Secondary Volume – 475,000 liters (125,000 gal)*

* - nominal values

Methods Used for Detection and Measurement of Tritium

1. Airborne Tritium:
    a. Sample collection using passive or active "Cold Trap", to freeze out airborne water vapor. Collected sample is then counted by liquid scintillation counting (LSC). Corrections are made for air temperature and relative humidity. The resulting calculations are very reliable and reproducible.
    b. Tritium "Bubbler" sampler system; A measured volume of sampled air is pumped through a series of vials containing ethylene glycol, then passed thru a catalytic converter to combine free tritium to oxygen atoms to form water vapor. Recombined tritium is then pumped thru another series of vials containing ethylene glycol. It is assumed that all airborne tritium is collected in this process. All vials are then sampled and counted by LSC. Total collected activity is calculated and airborne concentration is determined.
    c. Ionization Chamber; The air volume is sample via "grab" sample mode or continuous monitoring, the air is collected or passes thru a fixed volume ionization chamber, ionization current collected in the chamber is precisely measured. Airborne concentration is then determined by applying calibration factors for tritium in air for the specific counting system.. This method assumes only tritium in the air is causing the ionization. In the presence of other airborne radioactivity, appropriate corrections must be made to the data.
    d. Gas flow proportional counting; A measured flow of sampled air is mixed with a known volume of quenching gas that is then pumped through a fixed volume detector chamber. While similar to the method described previously, the characteristics of gas flow proportional counting allow for a better distinction between the signal produced from low energy beta particles like that from Tritium, from higher energy events. One method of accomplishing this is called rise time discrimination, where the rate of rise of the signal is proportional to the energy of the event.

2. Surface Tritium Contamination:
    a. Smear or swipe counting; The surface to be checked is sampled by standard swipe methods. The swipe is then counted by LSC or with a "windowless", gas-flow proportional counter. Measurement by LSC has the benefit of providing a qualitative nuclide identification of Tritium by analysis of the beta spectrum.

3. Tritium Bioassay
    a. Uptake of Tritium by personnel is measured by LSC of urine samples. Tritiated water intake will reach equilibrium with the water in the body within a few hours of intake. Uptake can be determined easily by LSC of collected urine samples. Using published data, the resulting committed effective dose equivalent (CEDE) from the Tritium uptake can be easily determined. In some cases a follow-up of multiple samples can be done to

better estimate the CEDE. The most determinate factor being the actual biological half-life if the tritiated water for the exposed individual. The published and accepted value is about 10 days. It is know from experience that actual values can easily range from 2-15 days, this would have a significant impact on the calculated CEDE for that person.

^3H	Nuclide Safety Data Sheet Hydrogen-3 [Tritium]	^3H

I. PHYSICAL DATA

Radiation:	Beta (100% abundance)	
Energy:	Max.: 18.6 keV; Average: 5.7 keV	
Half-Life [$T_{½}$] :	Physical $T_{½}$:	12.3 years [link to web decay calculator][1]
	Biological $T_{½}$:	10 - 12 days
	Effective $T_{½}$:	10 - 12 days*

* Large liquid intake (3-4 liters/day) reduces effective $T_{½}$ by a factor of 2+; ^3H is easily flushed from the body

Specific Activity:	9650 Ci/g [357 TBq/g] max.	
Beta Range:	Air:	6 mm [0.6 cm; 0.25 inches]
	Water:	0.006 mm [0.0006 cm; 3/10,000 inches]
	Solids/Tissue:	insignificant [No ^3H betas pass through the dead layer of skin]

II. RADIOLOGICAL DATA

Radiotoxicity[2]:	Least radiotoxic of all nuclides; CEDE, ingestion or inhalation:
	Tritiated water: 1.73E-11 Sv/Bq (0.064 mrem/uCi) of ^3H intake
	Organic Compounds: 4.2E-11 Sv/Bq (0.16 mrem/uCi) of ^3H intake
Critical Organ:	Body water or tissue
Exposure Routes:	ingestion, inhalation, puncture, wound, skin contamination absorption
Radiological Hazard:	External Exposure - None from weak ^3H beta
	Internal Exposure & Contamination - Primary concern

III. SHIELDING

None required - not an external radiation hazard

IV. DOSIMETRY MONITORING

Urine bioassay is the only readily available method to assess intake [for tritium, no intake = no dose]
Be sure to provide a urine sample to Radiation Safety whenever your monthly ^3H use exceeds 10 mCi, or after any accident/incident in which an intake is suspected

V. DETECTION & MEASUREMENT

Liquid Scintillation Counting is the only readily available method for detecting ^3H
NOTE: PORTABLE SURVEY METERS WILL NOT DETECT LABORATORY QUANTITIES OF ^3H

VI. SPECIAL PRECAUTIONS

- Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake]
- Many tritium compounds readily penetrate gloves and skin; handle such compounds remotely and wear double gloves, changing the outer pair at least every 20 minutes.
- While tritiated DNA precursors are considered more toxic that ^3H_2O, they are generally less volatile and hence do not normally present a greater hazard
- The inability of direct-reading instruments to detect tritium and the slight permeability of most material to [tritiated] water & hydrogen [tritium] facilitates undetected spread of contamination. Use extreme care in handling and storage [e.g. sealed double or multiple containment] to avoid contamination, especially with high specific activity compounds.

---

[1] URL for web-based decay calculator: http://phantom.ehs.uiuc.edu/~rad/ram/raddecay.html

[2] Federal Guidance Report No. 11 [Oak Ridge, TN; Oak Ridge National Laboratory, 1988], p. 122, 156; Radionuclide and Radiation Protection Data Handbook [Delacroix, et al; Radiation Protection Dosimetry. Kent, England: Nuclear Technology Publishing 1998], p. 19.