Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Disclaimer:

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U. S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

1) warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
2) representation that such use or results of such use would not infringe privately owned rights; or
3) endorsement or recommendation of any specifically identified commercial product, process, or service.

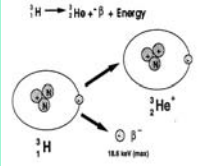
Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

Twenty Years of Tritium Exposure to Polymers at SRS

Elise B. Fox and Mark Kranjc

Properties of Tritium

- Beta Particle (b)
  - Max travel of tritium b particle in air is 7 millimeters in air.
  - Max travel in tissue (water) = 6 microns
  - Plastic can be used as shielding
- Tritium is still an internal radiation hazard
  - Reaction of T_2 with water and oxygen can form tritiated water (HTO)
  - Tritiated water is easily absorbed in the body
  - Tritiated water is 10,000 times more hazardous to the human body than elemental tritium

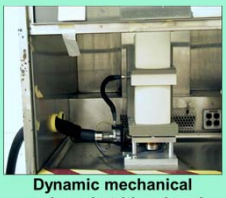


Tritium Permeates Polymers

- Polymers shield beta radiation at the surface, however, tritium is able to permeate into the bulk polymer over time and drastically increase the rate of product degradation
- Product use life is significantly reduced from the manufacturers estimates.
- Metal is the primary containment material due to lower degradation rates including more malleable metals used as seals.
- Polymer use in tritium is restricted to applications where the unique properties of flexibility and elasticity are required (ex. rubber containment gloves, valve seals, gaskets, etc)

Polymer Research at SRNL

- Began in earnest over 20 years ago over concerns of a formulation change by the manufacturer of Buna-N (nitrile rubber) o-rings
- Found that synthetic rubber experiences negligible radiation damage up to an absorbed dose of 10^5 Gy, begins to exhibit some damage up to 10^6 Gy, and exhibits very severe damage at higher does
- Determined need for facilities to characterize the effects of tritium in polymers
- Currently available characterization techniques include:
  - Dynamic Mechanical Analysis (DMA)
  - Time-Domain Nuclear Magnetic Resonance (TD-NMR)
  - Fourier-Transform Infrared Spectroscopy (FT-IR)
  - Bend test
  - X-ray Diffraction (XRD)
  - Auger



Dynamic mechanical analyzer in tritium hood

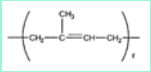
Polymers Used in Tritium

- Polytetrafluoroethylene (PTFE-Teflon™)

  - Uses: valve seats, non-stick surfaces
  - Properties: low coefficient of friction, non-stick, high strength, tough, chemical resistant, thermal resistance
  - Drawbacks: subject to creep, becomes brittle in tritium environments, generates HF within containment, use is restricted
- Polyethylene- High Density and Ultra High Molecular Weight (HDPE and UHMPE)
  - Uses: valve seats, gloveport plugs
  - Properties: HDPE MW = 200,000 to 3,000,000, UHMWPE > 3,000,000 g/mol, high strength to weight ratio, tough, low coefficient of friction, resistance to abrasion
  - Drawbacks: becomes brittle in tritium environments

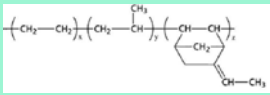
- Polyisobutylene Elastomer (Butyl Rubbber)
  - Uses: containment gloves
  - Properties: low permeability elastomer
  - Drawbacks: still allows some permeation of water, oxygen, and tritium; becomes brittle in tritium environments

isobutylene (app. 96 mole%)



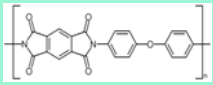
isoprene (app. 4 mole%)

- Ethylene Propylene Diene Monomer (EPDM) Elastomer
  - Uses: o-rings
  - Properties: creep resistant
  - Drawbacks: becomes brittle in tritium environments

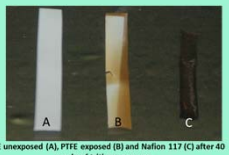


ethylene propylene ethylidene norbornene

- Polyimide (Vespel™)



  - Uses: valve seats
  - Properties: one of the most radiation resistant polymers, heat resistant, chemical resistant, creep resistant, does not produce significant off-gassing,
  - Drawbacks: high coefficient of friction when unfilled, difficulty in processing, cost, has a tendency to absorb a small amount of water



PTFE unexposed (A), PTFE exposed (B) and Nafion 117 (C) after 40 weeks of tritium exposure.

Current and Previous Work

- Validation testing of materials used in Tritium service
  - Teflon
  - UHMW-PE
  - EPDM
  - PBT
  - Nylon-6
- Nafion characterization for PEME in isotope separation
  - Nafion®
- Normatex pump replacement
  - GraFOIL®
  - PEEK
  - Vespel® (polyimide)
- Next generation polymer development
  - Nanotube and graphene filled EPDM
- Polymer sensor materials
  - PANi
  - PEDOT-PSS

Needs

- Increased polymer resistance to embrittlement in a tritium environment while maintaining elasticity, compressibility, and permeation resistance
- A more puncture resistant containment glove that does not restrict dexterity
  - Hexarmour overglove restricts dexterity. Made from a thick woven fabic glove that has hard plastic hexagonal sections adhered to the surface
- More durable rubber o-rings
- Seals and gaskets for vacuum pumps