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Flexible Neutron Shielding for a Glovebox Within the Idaho National Laboratory Radioisotope Power System Program

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FLEXIBLE NEUTRON SHIELDING FOR A GLOVEBOX WITHIN THE IDAHO NATIONAL LABORATORY RADIOISOTOPE POWER SYSTEM PROGRAM

Abstract: Neutron shielding was desired to reduce worker exposure during handling of plutonium-238 (Pu-238) in a glovebox at the Idaho National Laboratory. Due to the unusual shape of the glovebox, standard methods of neutron shielding were impractical and would have interfered with glovebox operations. A silicon-based, boron-impregnated material was chosen due to its flexibility. This paper discusses the material, the installation, and the results from neutron source testing.

INTRODUCTION

The Radioisotope Power System (RPS) Program at the Idaho National Laboratory (INL) uses a cylindrical-shaped glovebox for some of their operations involving Pu-238 sources. For protection of workers and to meet 10 CFR 835, Occupational Radiation Protections, Subpart K, for meeting As-Low-As-Reasonably-Achievable (ALARA) goals, shielding of this glovebox was requested. Although both neutron and gamma radiation are generated by the Pu-238 sources, the neutron emission rate is greater than that of the gamma radiation, and was of greater concern.

The inexpensive and common method of neutron shielding using rigid polyethylene materials was originally planned for the glovebox. However, the curved shape of the glovebox and the window locations made the use of polyethylene sheets impractical. Glovebox operations would have been too severely restricted, and, most likely would need to be removed for many operations. A practical solution was needed that would reduce exposure to the operator, but that would allow unhindered access for the glovebox operators.

FLEXIBLE NEUTRON SHIELDING MATERIAL

A flexible, silicon-based material with a high concentration of boron (25.3% by weight) was investigated to determine if it was a viable alternative to rigid polyethylene. Two suppliers of the material, Thermo Electron Corporation and Shieldwerx were contacted for information and to request 6” x 6” x 1/8” sample sheets of their materials for testing. Both samples were for the black, high-boron concentration, high-temperature rated (400°F without property degradation) material. The samples were requested for testing prior to the purchase and installation of shielding material on the INL glovebox.

Material Description

Both Thermo Electron and Shieldwerx’s materials were silicon elastomer-based material with 25.3 wt % boron. During testing of the materials at the INL, Thermo Electron discontinued their line of neutron shielding and removed technical data sheets from their website. However, Shieldwerx stated that their SWX-238 meets the same specifications as Thermo Electron’s material, including a thermal neutron attenuation factor of 259 for the 1/8" thick sheet. Material specifications from Shieldwerx for their SWX-238 Flexi-Boron are given in Table 1.

Composition Data	
Hydrogen atom density / cm3:	2.7×10^{22}
Natural isotope distribution:	99.98% ^{1}H
Boron atom density / cm3:	2.32×10^{22}
Natural isotope distribution:	19.6% ^{10}B and 80.4% ^{11}B
Weight percent of all isotopes of boron:	25.3%
Total Density:	1.64 g / cm^3
Radiation Properties	
Macroscopic thermal neutron cross section:	17.5 (cm^{-1})
Gamma resistance:	1×10^{10} rad
Neutron resistance:	5×10^{18} n/ cm^2
Physical Properties	
Recommended Temperature Limit:	400 °F (205 °C)
Percent Volatile by Volume:	0
Chemical Properties	
Trade Name & Synonyms:	SWX-238 Flexi-Boron
Chemical Family:	Boron Compound in silicon elastomer
Solubility in Water:	Negligible

Table 1. Shieldwerx Specifications for SWX-238 Flexi-Boron Shielding (Ref 2)

Sample Testing

The two 1/8" flexible neutron shielding samples and a 1" thick polyethylene block were tested with an Americium-Beryllium (Am-Be) 500 milli-Curie source and an E-600 ball and ion chamber detector. Readings were taken on contact and at one foot from the source. Source test results reported in this paper are also documented in Reference 3.

The results of this test showed similar neutron radiation levels with the two brands of flexible neutron shielding, but slightly higher readings when using the Shieldwerx sample. Because the Shieldwerx and Thermo Electron material results were not the same as had been expected, the tests were repeated with a similar source and an additional REM ball detector. Test configurations were slightly different between the two tests (different test locations, different technicians and different neutron sources), but the results were consistent. A summary of the second sample material test results is given in Table 2, and is taken from Reference 3.

	Neutron Readings (mRem/hr)		**Gamma Readings (mR/hr)**	
Shielding Type	**On Contact**	**@ 1-foot**	**On Contact**	**@ 1-foot**
Unshielded	70	12	80	3.7
1" Thick Poly	35	9	70	3
1/8" Thick Shieldwerx Flexi-Boron	60	10	80	3
1/8" Thick Thermo Electron Neutron Shielding	65	10	75	3

Table 2. Neutron Shield Testing using 500 mCi AmBe Source

Below is a summary of the sample material tests with the AmBe source:

- The 1" thick polyethylene piece reduced the neutron radiation by 50% on contact, and 25% at a distance of 1 foot.
- The 1/8" thick flexible neutron shielding reduced the neutron radiation by 7-14% on contact, and 17% at a distance of 1 foot.
- At a distance of 1 foot, the difference between the flexible shielding and the polyethylene in the tests became essentially negligible for these tests.
- Both the 1" thick polyethylene piece and the 1/8" thick flexible boron shielding reduced the gamma radiation readings by approximately 19%.
- The neutron radiation readings using the Shieldwerx shielding sample were slightly, but consistently, higher than those using the Thermo Electron shielding sample. Possible causes for the discrepancy include different sizes of materials (Shieldwerx sent a smaller piece of sample shielding than requested) and manufacturing differences (such as different boron concentrations or uneven distribution of boron in the silicon matrix). The differences were relatively minor, though, and since Thermo Electron had discontinued supplying flexible neutron shielding, the Shieldwerx material was ordered for installation on the INL glovebox.
- It was decided to install the Shieldwerx Flexi-Boron sheets to a 1/4" thickness in most areas, and a 3/8" thickness in the main operator area at the center of the glovebox.

INSTALLATION ON INL GLOVEBOX

The INL glovebox was manufactured from a 4-ft diameter, Schedule 80 pipe (verify) with dished ends. Installing shielding on this configuration was challenging. An overall thickness of 1/4" was desired for most locations, and 3/8" in the main operating area protecting the body of the operator between the gloves. 1/8", 1/4" and 3/8" thick sheets were ordered and manufactured by Solidwerx. Material thickness and size of sheets are limited by practical considerations such as manufacturability (curing of thick sheets) and ability to handle the material. The thicker sheets were beginning to show an increase in small holes from bubbles in the curing material. The sheets of material are considerably heavy (a large 2' x 3' x 1/4" thick sheet weighed nearly 13 lbs), and crack or tear relatively easily. The bend radius is published to be "as small as 1/4 inch", but at the INL, we found it to be quite susceptible to breaking if not handled carefully and the bend radii were kept as large as possible.

The 3/8" thick sheets were used in the main operating area, 1/4" thick sheets over large flat areas and over gloveport covers, and layers of 1/8" thick sheets were used on the dished ends and other difficult locations. The dished ends were covered by slicing the sheets and overlapping or removing additional materials. The second layer of 1/8" sheets was installed to cover the butt joints of the first layer and reduce neutron streaming. Paper templates were used to assist in cutting the materials around obstacles and to minimize the number of seams. The final appearance of the glovebox was highly dependent on the skill and patience of the technicians installing the material.

The base for the neutron shielding is silicon. As such, the shielding binds well to silicon caulking, such as RTV. The sheets of shielding were attached to the painted carbon steel glovebox and to each other with 100% silicon caulking using a caulking gun. Metal bands were installed around the glovebox for approximately one day while the silicon caulking cured.

Figure 1, below shows the glovebox with the shielding installation completed.

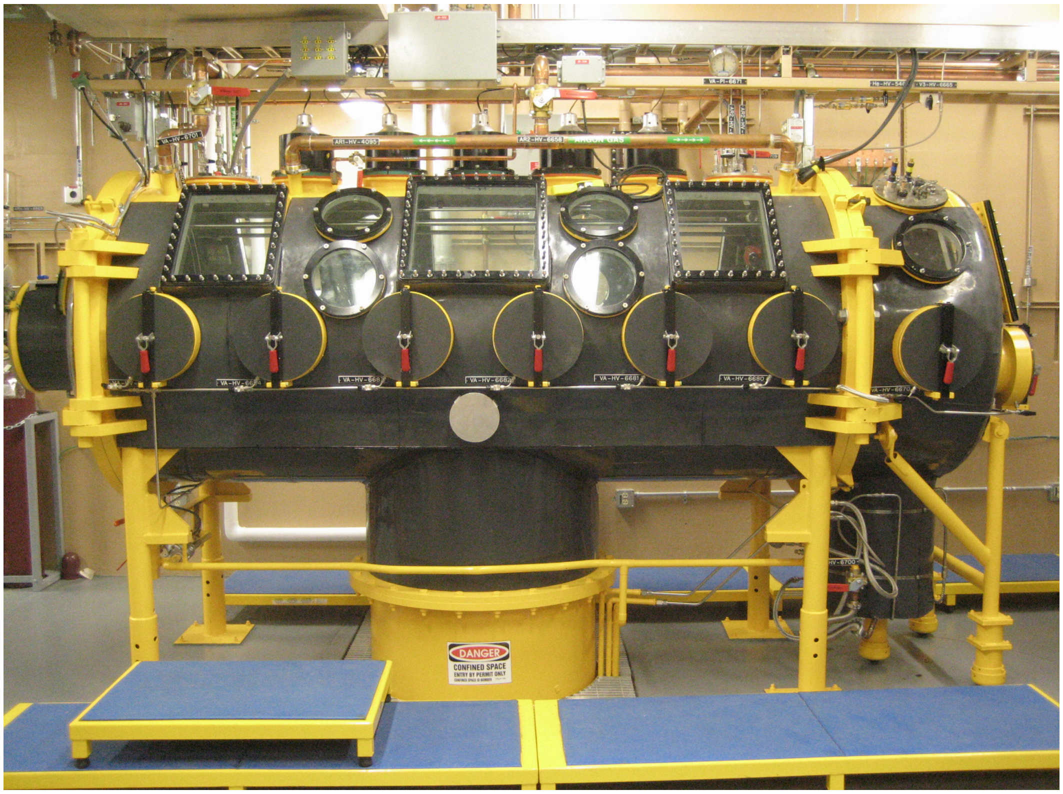

Figure 1. INL Glovebox with Flexible Neutron Shielding Installed

Pu-238 SOURCE TESTING IN THE GLOVEBOX

After installation of the shielding was completed, a Pu-238 source similar to those used in actual operations was placed in the glovebox for final neutron testing. Neutron radiation levels were measured in four locations, one shielded with flexible neutron shielding, one shielded by the thick polycarbonate window, and two unshielded. The locations were at different distances from the sources. After correcting for the distances ($I_1d_1^2 = I_2d_2^2$), the values corrected to 19" from the sources were:

1) 271 µrad – at an unshielded location on top of the glovebox
2) 130 µrad –on contact at the window (thick polycarbonate sheet)
3) 247 µrad –at an unshielded open gloveport
4) 121 µrad –at the shielded main operator station between the gloveports.

These results showed a 50% reduction in neutron radiation at the main operator station from the 3/8" thick shielding. The radiation level at the shielded operator station is also very close to the level at the thick polycarbonate window.

CONCLUSION

A flexible, silicon-based material impregnated with boron to 25.3% by weight was selected, tested and installed on the INL glovebox. The material was shown to be an effective neutron shield and is expected to significantly reduce neutron radiation exposure during operations involving Pu-238 in the INL glovebox. This material provided a practical solution to shielding an unusual shaped glovebox.

REFERENCES

1. 10 CFR 835, "Occupational Radiation Protection," Code of Federal Regulations, Office of the Federal Register, 1 January 1999.
2. Shieldwerx website: www.shieldwerx.com.
3. "Engineering Design File – Flexible Neutron Shielding Material Test and Evaluation", Aitken, Steve, Idaho National Laboratory (internal document), December 2006.

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