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Application of Polyurethane Foam for Impact Absorption and Thermal Insulation for General Purpose Radioactive Materials Packagings.

A. C. Smith
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 2943,
allen.smith@snl.doe.gov

P. S. Blanton
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 3738,
paul.blanton@srnl.doe.gov

G. A. Abramczyk
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 2996,
glenn.abramczyk@srnl.doe.gov

W. L. Daugherty
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 2849,
william.daugherty@srnl.doe.gov

J. S. Bellamy
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 1083,
steve.bellamy@srnl.doe.gov

S. L. Williamson
General Plastics Manufacturing Co.
Tacoma, WA 98409
(253) 473-5000,
Sharon_williamson@generalplastics.com

Abstract
Polyurethane foam has been employed in impact limiters for large radioactive materials packagings since the early 1980's. Its consistent crush response, controllable structural properties and excellent thermal insulating characteristics have made it attractive as replacement for the widely used cane fiberboard for smaller, drum size packagings. Accordingly, polyurethane foam was chosen for the overpack material for the 9977 and 9978 packagings. The study reported here was undertaken to provide data to support the analyses performed as part of the development of the 9977 and 9978, and compared property values reported in the literature with published property values and test results for foam specimens taken from a prototype 9977 packaging. The study confirmed that, polyurethane foam behaves in a predictable and consistent manner and fully satisfies the functional requirements for impact absorption and thermal insulation.

Introduction
Polyurethane foam has been used as the overpack impact absorbing and thermal insulating material since the early 1980's (References 1 – 9). The polyurethane is typically foamed in place. That is, it is injected as a two-component liquid and reacts, rising and hardening to form a rigid foam structure. Alternatively, foam components can be produced separately and assembled into the package overpack. Applications have included both Type A and Type B packages of all sizes. Polyurethane foam was selected

as the overpack material for the 9977 and 9978 to provide the impact and thermal protection required and to enable the packages to withstand the Regulatory crush test.

In the course of development of these packagings, structural and thermal analyses were performed to demonstrate their ability to withstand the Hypothetical Accident Conditions sequential tests. The analyses employed the foam manufacturer's published data and results of testing performed to support the development program. Data published in the open literature was also reviewed. The crush stress and thermal conductivity are the principal properties of importance for radioactive materials packaging overpack performance.

Crush Strength

In order to evaluate the consistency of urethane foam properties from batch to batch, the published values from the various references were compared with the properties tabulated by General Plastics for the various densities of Last-A-Foam FR-3700. Where possible, values for the density of foam employed in the 9977 were considered. However, the degree of consistency between the General Plastics data and that from other sources is indicative of the ability to obtain consistent, predictable properties, even though it is for other densities.

When foam materials are crushed, the initial response is elastic, with crushing beginning typically at about 5 to 10% strain, and the stress remaining nearly constant up to over 50%, Figure 1 (Reference 10and 11). Above 50% to 60% strain, the slope of the stress-strain curve increases rapidly. For purposes of comparison of the information from the various sources, the stress for 10% and 20% strain is tabulated below.

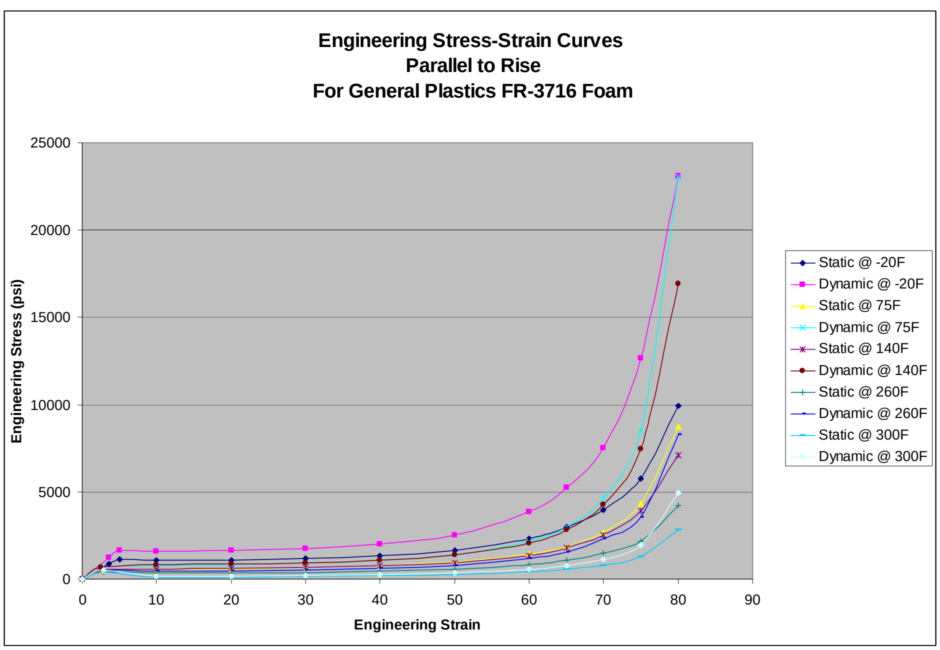

Figure 1. Typical Stress Strain Results for Polyurethane Foam.

Table 1 shows that, for given density, crush properties are highly consistent for materials from a wide range of sources and are generally consistent with current published information.

For the 9977 General Purpose Fissile Package development, General Plastics prepared specimens from material taken from the drum sidewall and from the bottom of a prototype package, Figures 2 and 3. The structural specimens were nominally 2 in. square and 1 in. thick and enabled testing for both parallel-to-rise and perpendicular-to-rise orientations. Tests were performed in accordance with ASTM D1621-94.

Table 1. Comparison of Published Data with Last-A-Foam Reference Data

		10% Strain,		20% Strain	
Application	Density lbm/ft3	Package Foam Crush Stress, psi	General Plastics Last –A- Foam Stress, psi	Package Foam Crush Stress, psi	General Plastics Last –A- Foam Stress, psi
9977	16		776 (766 perp)		802
Sandia CRETE	16.23	767	776	767	802
Sandia CRETE	29	2320	2249		
Seo, et al	29	2030	2249	2300	2469
TRUPACT-II	8.25	235	228 (for 8 lbm/ft3)	235	221
Sandia BUSS	18	1000	958	1250	1002
AT-400	30	2500	2390		
RH-TRU 72-B	11.5	376	430	376	430
MH-1A ('87 last-a-foam data)	4	88	96		
MH-1A ('87 data)	15	700	691	750	710
HIFR ('87)	17	960	865	1000 -	900

Table 2. Summary and Comparison of Crush Test Results for SN-6

Specimen Sample Location	Test orientation relative to foam rise	In-situ sample			Batch Sample "free rise"		
		Density	Stress at 10% strain,	Nominal stress at 10% strain*	Density	Stress at 10% strain	Nominal stress at 10% strain**
		(lbm/ft^3)	(psi)	(psi)	(lbm/ft^3)	(psi)	(psi)
Sidewall	Parallel	16.73	726.4	841	15.46	651.3	730
Sidewall	Perpendicular	17.83	816.8	952	16.29	692.5	795
Bottom	Parallel	16.8	732.8	847	16.27	706.8	800

* Nominal stress corresponds to interpolated data from GP handbook at measured density of SN-6 sample.

** Nominal stress corresponds to interpolated data from GP handbook at measured density of batch sample.

Figure 2. A 9977 package was sectioned to obtain in-situ specimens for material property tests.

Figure 3. Thermal conductivity specimens were taken from the section of the side wall shown in Figure 2.

Thermal Conductivity

Polyurethane foam is an excellent thermal insulator. This characteristic is beneficial for minimizing the thermal challenge for containment systems under fire conditions. For packages whose contents generate significant heat, the package must permit dissipation of the internal heat generated to the environment. A higher thermal conductivity is important for this purpose. The foam specified must have a high enough thermal conductivity to maintain acceptable interior temperatures, but still provide adequate thermal protection during a fire.

The General Plastics data shows a linear relationship between density and thermal conductivity. This dependence on density is supported by the data from other sources. Thermal conductivity values reported in several sources were compared with the published GP Last-A-Foam property data.

Table 3. Comparison of Published Thermal Conductivity Data with Last-A-Foam Reference Data

Application	Density lbm/ft3	k, Btu/hr ft F, @ ca. 75F	k, General Plastics Last–A-Foam (2007)
TRUPACT II (1989)	8.25	0.0193	0.0217
72-B (2001)	11.5	0.0188	0.025
MH-1A ('87)	15	0.0194	0.0273
Piping Tech. & Prods data	16	0.022	0.0281
9977*	18.48	0.02844	0.0283

*Side wall perpendicular to rise.

The table shows that there is variation in the reported values of thermal conductivity from source to source and batch to batch. For example, the material employed in the TRUPACT-II is General Plastics Last-A-Foam, but the reported value of thermal conductivity differs from the General Plastics published data by 11%. Variations in material composition among manufacturers will result in differences in thermal conductivity for material from the different sources. The changes associated with elimination of Freon as the blowing agent (i.e., the bubble producing agent) may account for some of the difference between older applications and present data. As the data in Table 2 shows, the installed density is typically greater than the free-rise density, for a given installation. Since thermal conductivity is directly related to density, the thermal conductivity of the foam installed in the package will be greater that that of the free-rise sample by a corresponding amount.

It is recognized that the thermal conductivities for polyurethane foam of the densities considered here are quite low, so that all are very good thermal insulators. Studies of the effects of thermal properties on thermal response of packages have shown that differences in thermal conductivity on the order of those shown here have little effect on the performance of the package in a fire event (References 12 and 13). Accordingly, the thermal response of the packages will not be greatly affected by the variations from batch to batch or for differences in parallel-to-rise or perpendicular-to-rise values.

Application of Data

As noted above, the data set developed in this study was employed in the analyses performed for the 9977 and 9978 packagings. The structural analysis was performed using ABAQUS and employed the crushable foam option for the overpack material. The thermal analysis was performed using MSC.Patran Thermal. The results were compared with corresponding experimental results from the package certification testing (References 14 – 18).

The structural analysis predicted impact decelerations of 216 g for the bottom down drop and 184 g for the horizontal drop. These compare with decelerations of 200 to 236 g for the bottom down case and 168 for the horizontal case. In both cases the values agree within about 10 %.

The thermal conductivity determined by analysis of the experimental results for the Normal Conditions of Transport case were found to closely agree with the manufacturer's data for the polyurethane foam.

In the course of a Fire event, polyurethane foam decomposes in a very complex process. For this reason, the ability of the packages to withstand the HAC Fire event was demonstrated by test. A thermal analysis was performed for the preconditioning phase, in which the test article was heated to simulate the interior temperatures which would be present for a package with heat generating contents. A Cooldown analysis was performed for the post fire cooling period. For this case, the thermal conductivity of the decomposition product region was assumed to comparable to air. The manufacturer's data for thermal conductivity was employed for these analyses.

Conclusions

Polyurethane foams can be produced in a wide range of densities. The properties of the foam are largely dependent on the density, so that control of the density permits control of structural and thermal properties.

For structural properties, the material is well characterized, with consistent and predictable properties. As a result, for a given density, the properties from differing lots are closely comparable. For the structural properties, this is observed over a range of materials from various sources.

For thermal conductivity, material behaves consistently, with thermal conductivity varying with density. However, samples from different sources exhibit much greater variability than for the structural properties. Accordingly, thermal conductivity measurements for the "as installed" material are recommended for new package designs.

Disclaimer

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