Packagings for Severe Accident Protection*

A.R. York II, M.A. Kincy, J.M. Freedman, D.L. Humphreys

Advanced Systems Department, Sandia National Laboratories, Albuquerque New Mexico, USA

Introduction

Sandia National Laboratories is developing packagings for the safe air transport of radioactive material (RAM). Air transport packagings must contain the RAM payload during high speed impacts and subsequent fires. The packagings considered have capabilities beyond those of a Type B packaging. Recent development activities have focused on developing packagings for impact protection of 30 m/s (100 ft/s) and 60 minute fires. For multiple shipments, this protection level may be near optimal when the potential for RAM release is considered. However, in anticipation of changes in regulations, the goal is to develop packagings for impact protection up to 85 m/s (280 ft/s). The risk of RAM release is related to packaging performance and design approaches and testing on several packagings are described.

Assessment of RAM Release Potential

The relationship between packaging performance and protection against radioactive material release was determined by McClure (1989) (Figure 1). Packaging performance is based on the capability to withstand impact onto an unyielding target followed by exposure to an all-engulfing fire. Protection level is defined as the percentage of accidents that will not result in a RAM release.

The studies by McClure suggest that increased impact protection beyond 80 m/s (262 ft/s) provides little additional protection, but increased fire protection up to 120 minutes can yield significant added protection. The following example illustrates a trend in packaging performance and protection level that shows increased packaging protection beyond a certain level does not effectively reduce the risk of a RAM release.

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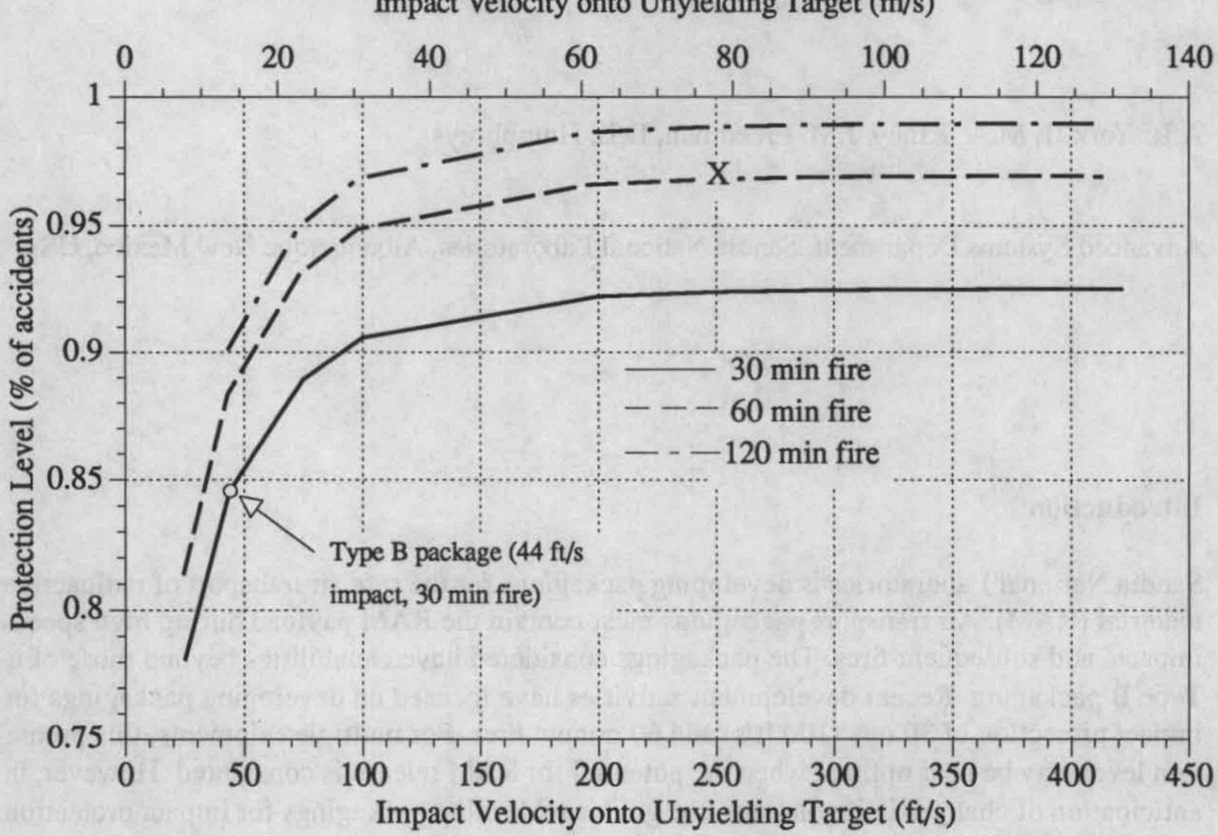

Figure 1. Packaging Protection Levels for Aircraft Accidents

Consider a Type B packaging that can survive a 13 m/s (44 ft/s) impact onto an unyielding surface and a 30 minute fire compared with a robust packaging that can survive a 76 m/s (250 ft/s) impact onto the same surface and a 60 minute fire, denoted by "X" in Figure 1. The Type B packaging will have a release in about 15% of the air transport accidents (85% protection level) while the robust packaging will only have a release in about 3% of the accidents (97% protection level).

Release likelihood (RL) is defined as the ratio of the percentage of accidents resulting in a release relative to the Type B packaging. Thus the more robust packaging has a RL=3/15=1/5, or a release will occur in one-fifth as many accidents as the Type B packaging.

Air shipments may be weight-limited so that the same plane could require 4 shipments using a robust design for every shipment with the Type B packaging. A robust design is packaging 3 in Table 1 with the packaging concept shown in Figure 2. Define NS as the ratio of the number of shipments required relative to the Type B packaging. If NS were based on volume, this ratio would be larger than four.

When these results are combined, the RL is substantially lower for the more robust design, whereas, the number of shipments in which an accident might occur is significantly greater.

Hence the shipment adjusted relative release likelihood ratio (RL*NS) is 1/5*4 = 0.80. The ratio quantifies the relative release of RAM, with a lower number indicating lower release potential. Thus the robust packaging has a slightly lower risk (0.8) of RAM release than the Type B package (1.0).

Table 1 lists similar data relative for four packagings of different protection levels. The packaging with the lowest RL*NS ratio is packaging 2, which will protect against impacts of 100 ft/s and fires of 60 minute duration. A potentially lower risk is associated with a moderate level of packaging performance instead of the highest protection level, which may appear contrary to the intuitive assumption that more packaging protection directly equates to a lower potential for RAM release. The trend shown in Table 1 indicates that optimal configurations are near the protection level afforded by packaging 2.

Table 1. Packagings and Protection Levels

Packaging	Impact Protection (m/s)/(ft/s)	Fire Protection (min)	Protection Level (%)	Weight (kg)/(lb)	RL	NS	Ratio (RL*NS)[a]
1-Type B	13/44	30	85	295/650	1	1	1.00
2	**30/100**	**60**	**95**	**436/960**	**1/3**	**1.5**	**0.50**
3	76/250	60	97	1136/2500	1/5	3.8	0.77
4	129/422	120	99	3636/8000	1/15	12.3	0.82

a. The relative release likelihood ratio is a comparison to a Type B packaging.

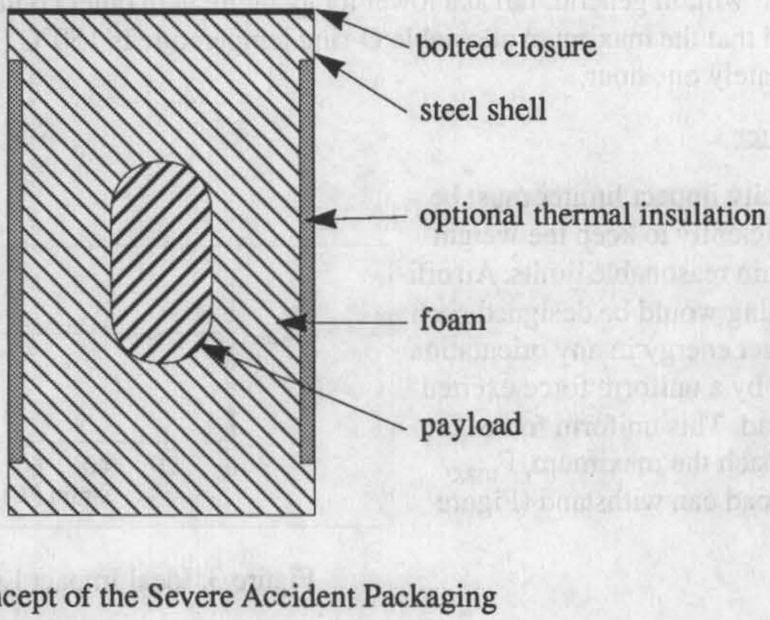

Figure 2. Basic Concept of the Severe Accident Packaging

Packagings that offer a higher protection level will cost more than the Type B packaging. Packagings two and three are estimated to cost more than the Type B packaging by about a factor of 1.6 and 10, respectively. Therefore, trade-offs can be made between protection level, cost of the packaging, and cost of transportation when selecting a particular packaging.

Severe Accident Container Design Approach

For severe accidents increasing the impact performance to 30 m/s (100 ft/s) and the thermal performance to a 60 minute fire significantly increases the protection level above the level provided by a Type B package and reduces the risk of RAM release. Sandia is considering a range of packaging performance levels and configurations to arrive at optimal configurations. The basic configuration is illustrated in Figure 2.

Steel Shell

The steel shell confines the thermal insulation and impact limiting materials in a configuration that allows both materials to perform as intended. The steel shell must endure high strain and high strain rates without rupturing during the impact onto an unyielding surface. Rupture may cause displacement of the impact limiting material resulting in excessive payload stresses. Rupture also leads to decreased thermal performance as the thermal path resistance to the payload is decreased.

Thermal Insulation

The generic packaging configurations with impact performance ≥ 100 ft/s can readily meet thermal requirements. The large amount of impact limiting foam that surrounds the payload also provides adequate insulation. For packagings of lower impact performance, thermal insulation as shown in Figure 2 may be required.

It is assumed that an elastomeric O-ring configuration will be used to seal the RAM containment vessel (payload). The O-ring is the governing factor in the thermal design of this packaging because it will, in general, fail at a lower temperature than other containment components. It is assumed that the maximum allowable O-ring temperature is 150°C (300°F) for a duration of approximately one hour.

Impact Limiter

A high-velocity impact limiter must be designed efficiently to keep the weight and size within reasonable limits. An efficient packaging would be designed such that the impact energy in any orientation is dissipated by a uniform force exerted on the payload. This uniform force should approach the maximum, F_{max}, that the payload can withstand (Figure 3).

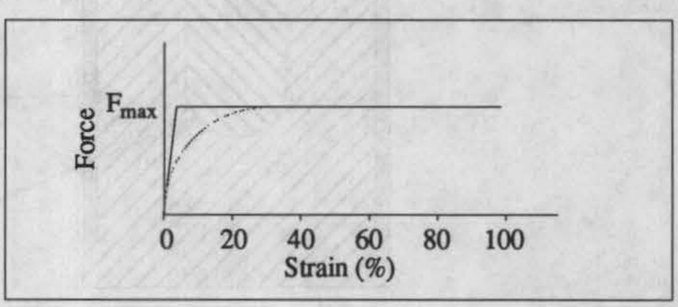

Figure 3. Ideal Impact Limiter Characteristics

Rigid closed cell polyurethane foam is used as the impact limiting material in the packagings configured as shown in Figure 2. Foam has nearly isotropic material properties and is relatively easy to incorporate into complex geometry. These characteristics are quite advantageous when compared to wood or honeycomb, both of which have directional dependent material properties and can be difficult or expensive to incorporate into a packaging design.

An example of foam, redwood, and honeycomb strength characteristics is illustrated in Figure 4. Only one strength is shown for honeycomb because it has very little strength transverse to the longitudinal axis of the honeycomb cells. Note that for each of these materials the strength in the plateau region is relatively constant over a large strain region, which is a desirable characteristic. The inset of Figure 4 illustrates the dramatic increase in foam strength that is typical of impact-limiting materials at extremely high strains.

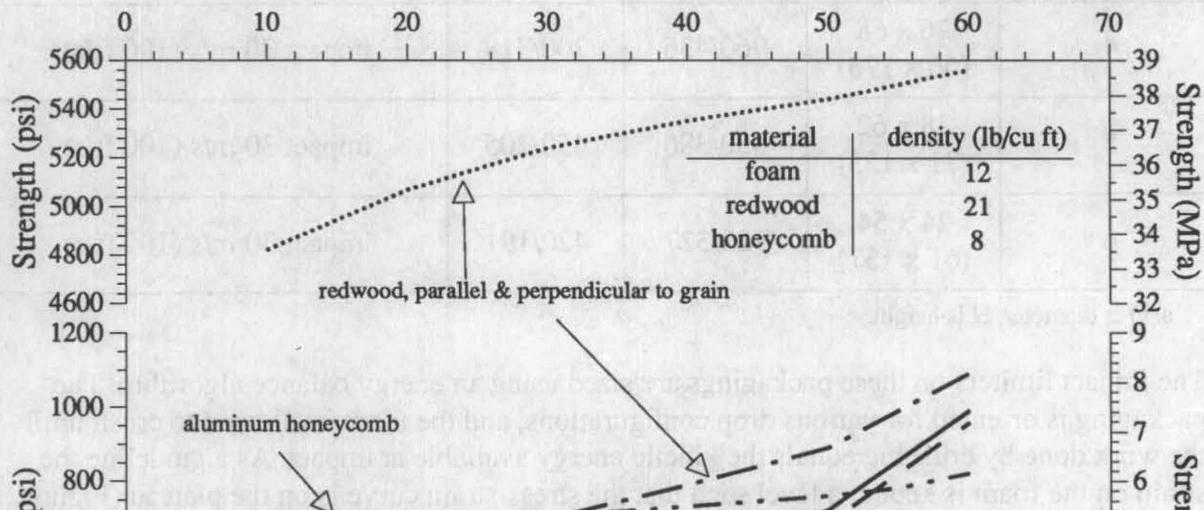

Figure 4. Typical Strength Properties of Foam, Redwood, and Honeycomb

Packaging Design and Testing

Seven different packagings having the generic configuration shown in Figure 2 have been tested as listed in Table 2. The goal of these tests is to develop packaging designs with an impact capability of 30 m/s (100 ft/s) and establish a basis for the development of a packaging with an impact capability of 85 m/s (280 ft/s).

Table 2. Packaging and Test Configurations

Packaging Designation	Dimensions Ø x H (in.)[a] (cm)	Total Weight (lb)/(kg)	Payload Weight (lb)/(kg)	Test Configuration
1	16 x 21 (41 x 53)	133/60	80/36	impact 26 m/s (85 ft/s) burn 830°C (1525°F), 30 min.
2	16 x 42 (41 x 107)	341/155	251/114	no impact burn 1010°C (1850°F), 70 min.
3	20 x 48 (51 x 122)	460/209	251/114	impact 30 m/s (100 ft/s)
4	26 x 68 (66 x 173)	960/436	700/318	impact 30 m/s (100 ft/s)
5	28 x 62 (71 x 155)	850/386	450/205	impact 30 m/s (100 ft/s)
6	24 x 54 (61 x 137)	720/327	420/191	impact 30 m/s (100 ft/s)

a. Ø is diameter, H is height.

The impact limiters on these packagings are sized using an energy balance algorithm. The packaging is oriented for various drop configurations, and the foam is allowed to crush until the work done by crushing equals the kinetic energy available at impact. As a guideline the strain on the foam is kept at a level such that the stress-strain curve is on the plateau (Figure 4). At very high strain levels (>70%) the forces required to do work are very high, and thus the containment vessel must be extremely robust to withstand these higher forces. The design approach is to first size the packaging estimating the payload weight and iterate to determine the final packaging design and payload weight. An evaluation of the payload is required to satisfy criticality and shielding requirements.

It was established by testing packaging 2 (Table 2) that a packaging designed for high speed impacts (>30 m/s (100 ft/s)) can withstand the thermal test requirement (800°C (1475°F)) for 30 minutes without additional thermal insulation as shown in Figure 2. The amount of impact limiting foam that surrounds the payload provides sufficient insulation to keep temperatures at the payload relatively low (<150°C (300°F)), thus ensuring that the O-ring seals will not be adversely affected.

Packaging 1 was fully tested in accordance with 10 CFR 71 (York 1992). As can be seen in the table, its impact performance was verified up to 26 m/s (85 ft/s). Packaging 1, however, uses additional thermal insulation in the form of an alumina-silica blanket that lines the interior of the steel shell. Figure 5 shows the relative sizes of packagings 1, 3, and 5.

Packagings 3-6 were successfully tested at impact velocities of 30 m/s (100 ft/s). Various orientations were tested. Figure 6 and Figure 7 illustrate packagings 3 and 5 after cg over corner and side drops, respectively. Drop tests on packagings listed in Table 2 indicate that the foam crushed as expected.

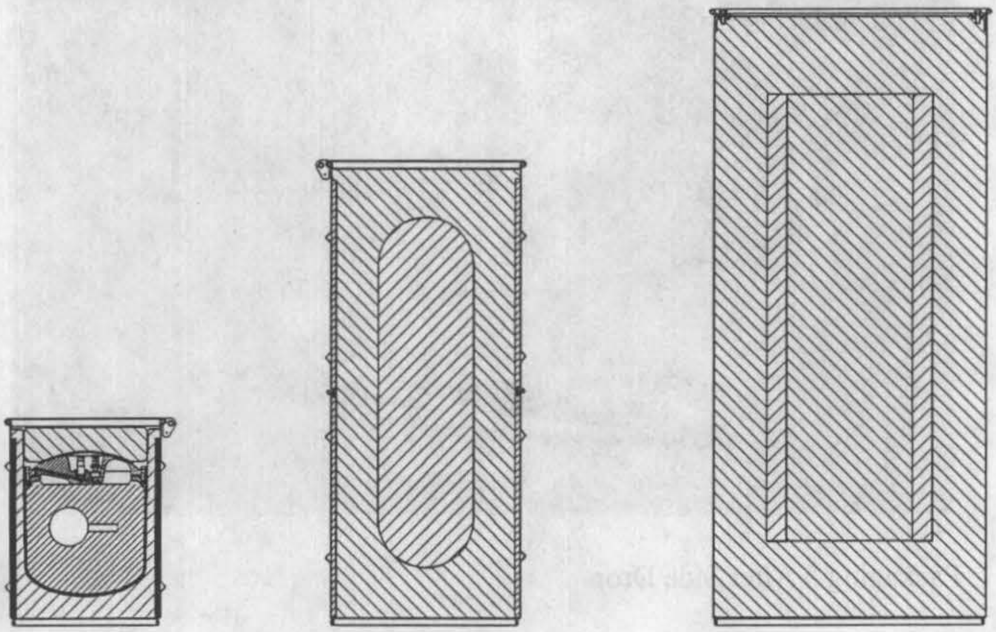

Figure 5. Relative Sizes of the Packagings 1, 3, and 5

Figure 6. Packaging 3 After CG Over Corner Drop

Figure 7. Packaging 5 After Side Drop

Conclusions

The packaging that offers the lowest potential for RAM release is not necessarily the packaging that provides the highest level of impact or fire protection. Development activities have established the feasibility of the packagings listed in Table 2, which provide impact protection of 30 m/s (100 ft/s) and fire protection for 60 minutes. These packagings will increase the protection level and reduce the potential for RAM release in comparison to a Type B packaging. These packagings can be produced with a modest increase in both cost and weight compared with a Type B packaging.

References

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