# OPTIMIZATION OF AN IMPACT LIMITER FOR RADIOACTIVE WASTE PACKAGING

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## ABSTRACT

A certain class of packages for the transportation of radioactive wastes – Type B packages in the transport jargon – is supposed to resist to a series of postulated tests, the most severe for the majority of the packages being the 9 m height drop test. To improve the performance of the packages under this test, impact limiters are added to them, normally as a removable overpack, with the primary goal of reducing the deceleration loads transmitted to the packages and their contents. The first impact limiter concept, developed during the '70s, used a shell-type impact limiter attached to both ends of the package. Later on, wood was tested as impact limiter filling, which improved the package's mechanical performance, but not its thermal resistance. The popularization of the polymeric materials and their growing use in engineer applications have led to the use of these materials in impact limiters, with the extra advantage of the polymers good thermal properties. This paper proposes a methodology for the optimization of an impact limiter for a package for the conditioning of spent sealed sources. Two simplified methods for the design of impact limiters are presented. Finally, a brief discussion is presented on the methodology usually employed in the design of accident-resisting packages

**Key Words:** packaging design, computer codes, FE-Method, polymers.

## I. INTRODUCTION

The design of accident-resistant packages for radioactive materials is regulated by several national and international bodies. The most known transport standards are the ones of the International Atomic Energy Agency [1] — adopted in Brazil by the local nuclear authority [2] — and the American regulations, specified by the USNRC in the Title 10 of the Code of Federal Regulations, Part 71 (10 CFR 71) [3].

Both standards require that Type B packages - those designed to transport unlimited quantities of radioactive material - withstand a sequence of postulated accident conditions, which include a free drop onto a rigid target, a puncture caused by a protruding object, followed by immersion in deep water and a 30min. open fire.

The key to a successful test campaign is the resistance in good conditions to the first drop test, considered by experienced package designers the most severe solicitation. Impact limiters are often added to the package design to meet regulatory requirements.

The design of these limiters is getting growing attention, as observed in a recent draft report for discussion released by the American NRC[4]. Under the paragraph "Material Properties and Specifications", it is recommended that the designer should *"verify that the force-deformation properties for impact limiters are based on appropriate test conditions and temperature"*. Impact limiters are also considered in this report as a *typical area of review for package drawings*, specially with regard to *materials of construction and dimensions, foam or wood specifications, including density and the method of attachment.*

The primary goal in the design of an impact limiter is the reduction of the deceleration loads transmitted to the package during the impact duration (in the order of μs). In this sense, two of the most relevant properties of a limiter are its capacity for energy absorption, which being as large as possible leads to a minimization of volume and weight, and its relatively low peak crushing strength which prevents damage to the package and its contents. Another important property, though not as essential as the previously mentioned ones, is the limiter's resistance to thermal assault, owing to the fact that according to regulatory requirement these packages must withstand a fire test.

This paper proposes a methodology for the optimization of an impact limiter for a package designed to condition spent sealed sources. This methodology includes a characterization of the mechanical properties of cellular materials, the performance of drop tests and numerical simulation using a FE computer code. Two simplified methods for the design of impact limiters — the Janssen method and the approach using energy-absorption diagrams — are presented, along with an example of a package with impact limiters developed in the U.S. A brief discussion is presented about the methodology usually employed in the design of accident-resisting packages. Owing to the great complexity involved in this design, numerical simulation using computer codes and experimental analysis are carried out pari passu.

## II. MATERIAL AND CONFIGURATION SELECTION

Several materials and impact limiter configurations have been proposed by package designers.

One of the first and simplest concept was the shell-type impact limiter, consisting of a toroidal hollow metallic shell surrounding both ends of the package. In Japan, Sugita and Mochizuki [5] tested a configuration using Type 304 stainless. In Italy Aquaro and Forasassi [6] developed an impact limiter for a 64-ton LWR fuel cask. In Brazil, the Centro de Desenvolvimento da Tecnologia Nuclear successfully tested a shell-type impact limiter for a Type-A 200L drum-based package [7], as shown in Figure 1.

Figure 1(a) Type A package with shell type impact limiter tested at CDTN: before the drop test

Figure 1(b) After the test, the damaged impact limiter removed from the package


Figure 1(c) The package with some deformation at the lid

Later, the wood-filled impact limiter concept was introduced. Wood began to be used as impact limiter filling, due to its good energy absorption capacity and commercial availability. Cramer et al. [8] in the United States, Butler [9] in the United Kingdom and Diersch at al. [10] in Germany tested wooden filled impact limiters using respect. redwood, balsa and spruce.

In spite of the promising mechanical results obtained in the above investigations, wood proved to give a poor protection to the package in the event of a fire accident. Man-made cellular materials, specially aluminum honeycomb, aluminum foam and rigid polyurethane foam appeared then in the 80's as an alternative choice. In the United States, Duffey et al. [11] carried out an investigation that ranked these three materials, based on mechanical and thermal testing and evaluation procedures,. On a minimum volume basis and according to the thermal figure of merit, the rigid polyurethane foam was found to be the most favorable material.

An interesting example of package using impact limiters is the TRUPACT-II, shown in Figure 2 [12]. This is a cylindrical reusable metallic container with a flat bottom and a domed top with honeycomb and polyurethane foam sandwiched between its inner containment vessel and the external steel skin. Each TRUPACT-II can hold up to fourteen 55-gallon drums or two standard waste boxes. This package has been used to transport the national transuranic defense wastes to the Waste Isolation Pilot Plant, in New Mexico, USA.

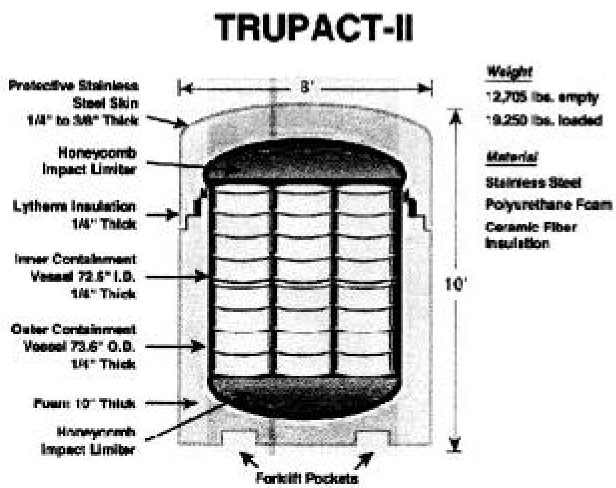


Figure 2. The TRUPACT-II, a package with impact limiter to transport transuranic wastes.

Based on the above investigations and results, the polyurethane foam was chosen as the filling material for the impact limiter to be developed by us in our research of optimization of an impact limiter for radioactive waste packaging.

## III SIMPLIFIED METHODS

As a first approach in the selection of foam density, several simplified methods can be used. Bearing in mind that in dynamic impact applications a balance has to be reached between the amount of absorbed kinetic energy (to be maximized) and the force transmitted to the packaged object (to be kept below the limit which can cause damage), there is always a best choice of foam density for a specific application.

One of these methods is based on the Janssen factor [13], $J$, which can be interpreted as a measure of the "efficiency" of the foam, or how close it comes to be the ideal foam.

This method uses the equations of conservation of energy and focuses on the peak acceleration (or deceleration) experienced by the falling object during the impact. Considering an object of mass $m$ protected by a layer of rigid foam of thickness $t$ striking a rigid surface with velocity $v$, the deceleration $a$ is given by Newton's law as

$$a = F/m, \qquad (1)$$

where the force $F$ is the product of the compressive stress in the foam times the foam area available for crushing.

Denoting the deceleration of an ideal foam as $a_i$, the conservation of energy during the impact can be expressed by

$$\frac{1}{2} m\, v^2 = m\, a_i\, t, \qquad (2)$$

where the left member is the kinetic energy and the right the work done by the constant force in the foam.

From this

$$a_i = \frac{v^2}{2t}. \qquad (3)$$

The value of $a_i$ can be easily calculated for a given test configuration, where the drop height and foam thickness are known parameters. On the other hand, the value of the peak deceleration for a real foam, $a_r$, can be measured through a Charpy impact test.

Defining the Janssen factor as the ratio

$$J = a_r/a_i, \qquad (4)$$

and $U$ as the strain energy density, that is, the energy absorbed per foam unit volume, a $J$-$U$ diagram can be built showing the dependency relation between these parameters. As shown in Figure 3, this curve has a minimum, when $J$ assumes its minimum value (by definition, $J$ is always greater than the unit). This is the point where the chosen foam provides its greatest energy absorbing "efficiency".

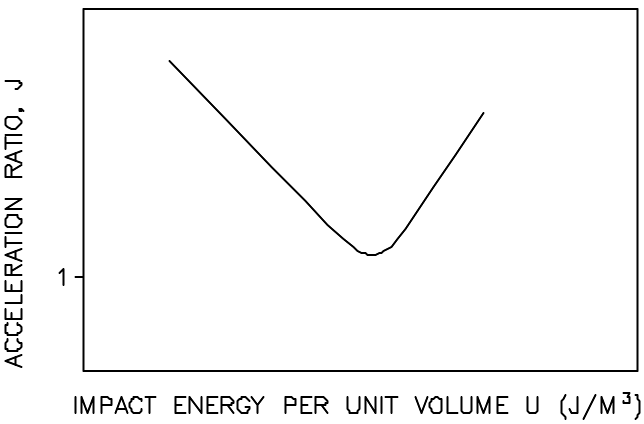


Figure 3. Diagram of the Janssen factor

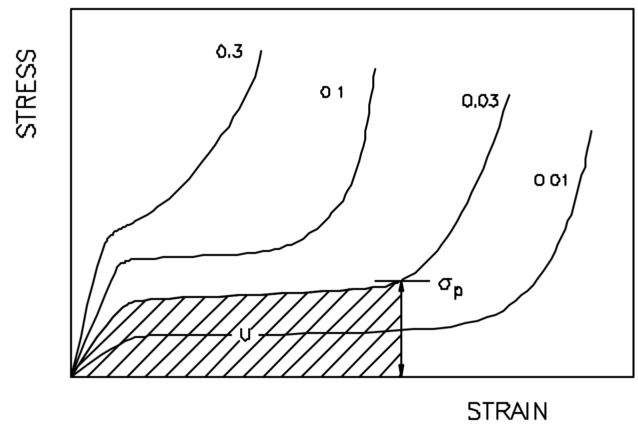


Figure 4(a). Stress-strain curves for various foam densities, measured at strain-rate $\varepsilon_1$. The area under each curve up to the stress $\sigma_p$ is the absorbed energy per unit volume.

Although relatively simple to use, this method lacks generality and a new diagram is needed for each foam density and impact energy level. Another disadvantage is that it does not provide quantitative information on the energy absorbed and on the crush stresses developed within the foam.

To overcome these limitations inherent to an empirical method, a different approach was proposed, combining empiricism and physical modelling [14]. In this method, energy-absorption diagrams are constructed from experimental stress-strain curves, according to the following steps. Initially foam samples with different densities are tested in compression at a fixed strain-rate $\dot{\varepsilon}_1$ and temperature $T_1$, yielding a family of stress-strain curves, as shown in Figure 4(a). The area below each curve up to the beginning of the *lock-up* (at stress $\sigma_p$) corresponds to the energy absorbed per unit volume, *U*. This value, normalized by the Young's modulus of the solid polyurethane (not the foam), $E_s$, to give generality to the method, is then plotted against the also normalized peak stress, $\sigma_p/E_s$, as depicted in Figure 4(b). It is clear from this graphic that the best foam option can be found along the line formed by the shoulders of the individual curves, where the most advantageous compromise between maximum allowed peak stress and maximum absorbed energy is reached. A curve envelope can now be drawn determining the best foam density for the desired *U* and $\sigma_p$, at the strain-rate $\dot{\varepsilon}_1$ and temperature $T_1$.

If the above sequence is now repeated for different strain-rates $\varepsilon_1,...,\varepsilon_n$, the corresponding envelopes can be plotted together, as shown in Figure 4(c). If we connect the points that represent the same density — the tangent points in (b) - by intersecting lines, we can straightforwardly find the best foam option for the desired or needed absorbed volume energy, peak stress and strain rate.

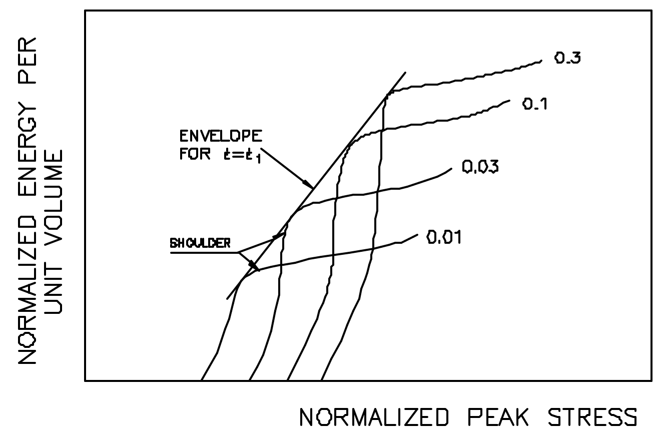


Figure 4(b) Specific absorbed energy plotted against stress $\sigma_p$, both parameters normalized by the solid polymer Young's modulus $E_s$.

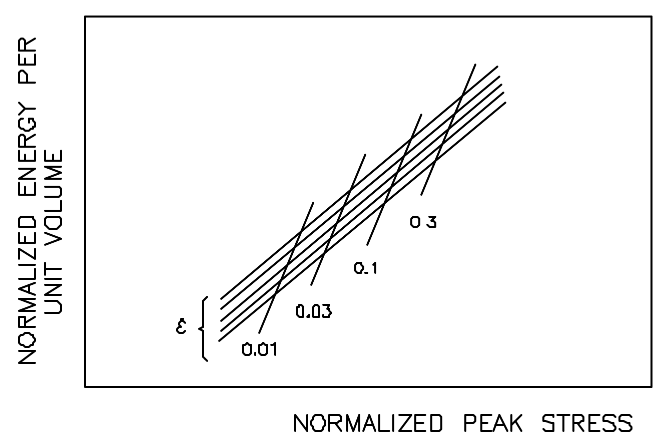


Figure 4(c) A family of envelope lines for different strain rates is plotted in the same axis as in (b), the points of same relative density (foam density/solid polymer density) connected by lines.

## IV. DESIGN VALIDATION – EXPERIMENTAL ANALYSIS AND NUMERICAL SIMULATION

The design of an impact limiter is a complex engineer problem. Several non-linearities involved in the impact scenario of the drop test – high strains and strain-rates, presence of non-linear materials, contact and sliding surfaces, transient loads and plasticity – allied to the inherent difficulties in the acquisition of the parameters of interest – accelerations, strains, impact duration – represent a real challenge even to the most experienced and skilled designers.

Owing to this complexity, it is a common practice in the design of accident-resistant packages to carry out together experimental analysis and numerical simulations, the acceptable agreement between calculation and experiment being the guarantee of a good design.

Several computer codes have been used to tackle this problem. In Japan, a simplified code, CRUSH, was developed to predict the accelerations of a cask body and the displacements of an impact limiter statistically.[15]. This code is suitable as a first approach to an impact limiter design by performing parametric studies. More complex codes have been extensively used, as DYNA3D, ABAQUS, ANSYS, HONDO and ADINA. A benchmark study of these codes was done by Ammerman.[16]

## REFERENCES


[1] INTERNATIONAL ATOMIC ENERGY AGENCY, **Regulations for the Safe Transport of Radioactive Materials (as Amended 1990)**, Safety Series 6,

[2] COMISSÃO NACIONAL DE ENERGIA NUCLEAR, **Transporte de Materiais Radioativos**, Norma CNEN-NE-5.01, 1988.

[3] U. S. NUCLEAR REGULATORY COMMISSION, Title 10, **Code of Federal Regulations**, Part 71, Washington, DC, USA, 1995.

[4] U. S. NUCLEAR REGULATORY COMMISSION, **Standard Review Plan for Transportation Packages for Radioactive Material**, NUREG-1609 (Draft Report for Comment), Washington, DC, USA, Nov. 1997.

[5] SUGITA, Y. and MOCHIZUKI, S., **The Development of a Toroidal Shell-type impact limiter for an irradiated fuel shipping cask, ,** International Symposium on Packaging and Transportation of Radioactive Materials, 7, USA, vol. 2, p. 1576-1583, 1983.

[6] AQUARO, D. and FORASASSI, G., **Analysis of the Behaviour under Impact Loads of a Shell-type Impact limiter for LWR Spent Fuel Transport Packaging,** International Symposium on Packaging and Transportation of Radioactive Materials, 7, USA, vol. 2, p. 1584-1590, 1983.

[7] MOURÃO, R. P. **Embalagem para Transporte e Armazenamento de Fontes Seladas Exauridas,** Centro de Desenvolvimento da Tecnologia Nuclear (Internal Report NI-CT3-001/96), Belo Horizonte, Brazil, 1996.

[8] CRAMER, S. M. et al., **Characterizing Large Strain Crush Response of Redwood**, Sandia Report SAND96-2966, Albuquerque, NM, USA, Dec. 1996.

[9] BUTLER, N., **Computer Modelling of Wood-Filled Impact Limiters**, Nuclear Engineering and Design, n. 150, p. 417-424, 1997.

[10] DIERSCH, R. at al., **Investigation of the Impact Behaviour of Wooden Impact Limiters**, , Nuclear Engineering and Design, n. 150, p. 341-348, 1997.

[11] DUFFEY, T. A. et al, **Characterization of Impact-Limiting Material**, Sandia Report SAND92-0773, Albuquerque, NM, USA, May 1992.

[12] **http://www.state.nv.us/nucwaste/yucca/wippfact.htm**

[13] WOOLAM, W. E., **A Study of the Dynamics of Low Energy Cushioning Materials Using Scale Models**, Journal of Cellular Plastics, p. 79-83, Feb. 1968

[14] GIBSON, L. G. and ASHBY, M. F., **Cellular Solids - Structure and Properties**. Pergamon Press, Oxford, 1988.

[15] IKUSHIMA, T. et al., **Simplified Computer Codes for Cask Impact Analysis**, International Symposium on Packaging and Transportation of Radioactive Materials, 7, Yokohama, Japan, vol. 3, p. 1419-1926, 1993.

[16] AMMERMAN, D. J., **Benchmarking of Finite Element Codes for Radioactive Material Transportation Packages**, Sandia Technical Report, s/d.