Test Machine for Measuring Heat Transfer

J. C. Roy and J. Fradin

ABSTRACT

Transport packages for radioactive materials generally consist of a body containing the radiation shielding, collision protection and tightness systems, and inner containers that vary according to the content of the package. Safe transport regulations of the International Atomic Energy Agency require proof that no damage can occur to the package under the effect of thermal power. This proof is easily furnished for the package body. For the inner containers, the calculations are often complex and their inaccuracy leads to drastic reductions in the allowable thermal power in the package, making tests essential. In most cases, however, although inner containers are readily available, the package body, having already been used, is contaminated with radioactive products. A machine is described that simulates a large number of package bodies. The inner containers are placed in the machine with heating resistors to simulate the thermal power of the contents, and the desired temperatures are measured.

The Regulation for the Safe Transport of Radioactive Materials published by the International Atomic Energy Agency (IAEA) requires proof that no change in a package or its contents can occur that jeopardizes the safety of the package under the effect of thermal power of the contents (IAEA Regulations, paragraph 230, 1973 revised edition, amended, and paragraph 543, 1985 edition). It should be noted that the IAEA Regulations serve as a basis for most national transport regulations.

The application of the IAEA Regulations requires justification that each of the materials of the package and of its contents remain at a temperature below its normal use limit in the conditions specified by the regulations and that no corrosion, expansion, or other detrimental process occur. It is therefore necessary to determine the temperatures reached at each point in the package and possibly to perform a number of measurements of these temperatures.

The performance of practical tests to confirm or clarify an approach by calculations is relatively easy and in any case classic for a prototype. In the most routine case, in which the behavior of new inner containers intended for use with package bodies already in service is to be investigated, the following problems arise:

1. Existing package bodies are not always available and in any case their immobilization is expensive;
2. The available package bodies are contaminated with radioactive products, their decontamination is expensive, and special precautions must nevertheless be observed, often making tests virtually infeasible; and
3. Justification by computation alone implies long, expensive calculations the results of which are not always easy to demonstrate or consideration of highly restrictive starting assumptions that heavily penalize the allowable thermal power in the package.

The solution to the problem is to have equipment capable of simulating the internal cavity of the largest possible number of package bodies so as to replace them in the tests that are performed with real inner containers or containers close to the real ones.

BRIEF PRESENTATION OF PACKAGES

General

Figures 1 and 2 are schematic diagrams of the Compagnie Générale des Matières Nucléaires (COGEMA) packages with horizontal and vertical axes. The package body contains shielding against (a) γ-radiation and (b) neutron radiation, (c) fire protection, (d) protective covers against impact, and (e) an inner cavity closed by (f) a lid that guarantees the containment of the contents. The inner container includes (g) a centering tool, (h) a canister containing (i) several boxes wedged by a material in the form of granules. A package body is frequently employed for specific tasks, for which inner containers are designed as required.

Determination of Temperature of Inner Cavity

During the fabrication of the prototype of a given package body model, tests are conducted to confirm

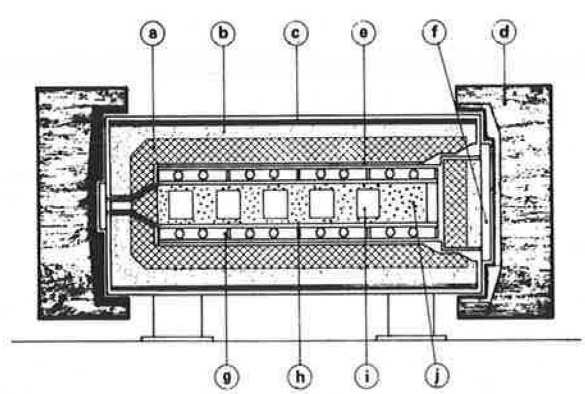

FIGURE 1 Horizontal package.

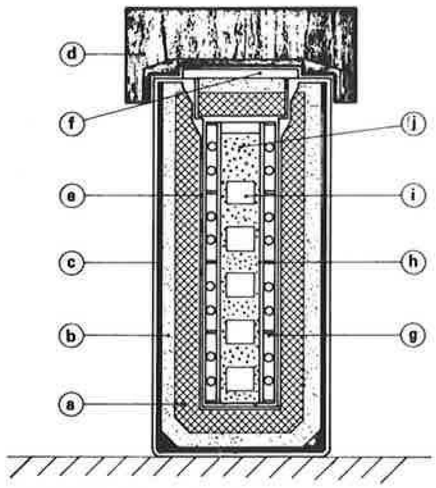

FIGURE 2 Vertical package.

the calculations of the heat removal capacity of the package body. This makes it possible to determine accurately the temperature reached by the inner cavity in accordance with the thermal power released by the contents (from zero power to the maximum service limit of the package), if required, by taking account of different distributions of the contents in the package.

Heat Removal Directions

The protective covers against impact consist of light insulating materials. During transport, the packages are carried on the beds of vehicles or wagons very often made of wood. This means that for both horizontal- and vertical-axis packages, heat removal occurs through the outer side wall of the package. This corresponds to a predominantly radial heat flux across the body of the package.

This assumption, which has been confirmed in actual conditions, has been adopted, and makes it possible to consider a single direction for the heat flux.

DESIGN SPECIFICATIONS OF THE EQUIPMENT

The internal cavity consists of a tube with a normally circular cross section, but possibly square or hexagonal. Its surface as well as the type of material employed (nearly always stainless steel) are variable. The machine must be able to accommodate cavity models of different cross sections without complicated manipulation. However, given the virtually radial direction of the heat flux, there is no need to represent the length of the cavities, and the definition of a representative minimum length is sufficient.

For a given thermal power, because of prior knowledge based on a package body prototype (discussed earlier), the temperature reached by the internal cavity is known. The machine must be able to obtain this temperature over a significant length of the simulated internal cavity with the inner containers and the material to be transported.

The maximum temperature is set at 200°C. The maximum temperature difference in the tests is set at 10°C in the horizontal position. This difference is sufficiently small to meet the accuracy required in the measurements, which is ±10°C. The minimum length of the test zone is about 1 m, to eliminate end effects.

The two ends of the simulated cavity are insulated in order to approach the radial flux hypothesis as closely as possible. To take account of the existence of horizontal- and vertical-axis packages, the machine is mounted on a frame to allow tilting.

To allow more thorough investigations, which require the separation of the different heat-transfer modes, the machine must be equipped with a system designed to create a vacuum in the internal cavity.

DESCRIPTION OF INSTALLATION

Basic Principle

The installation is designed for the simulation of the internal cavity of a package, represented by a tube with a given cross section and a length that is determined subsequently. The inner containers to be investigated, which contain a simulation of the radioactive content whose thermal power is represented by electric heating resistors, are placed inside this tube. At thermal equilibrium, the tube is at a temperature T_1. This value must then be changed to temperature T_2, the temperature of the real internal cavity of the package body investigated with similar inner containers and contents. Two alternatives are available:

1. Hot mockup: This technique consists of surrounding the tube with effective insulation that represents a thermal resistance greater than that of all known package bodies. The tube can be cooled or heated sufficiently to reach the desired temperature.
2. Cold mockup: In this case, the heat resistance between the tube and the surrounding air must always be less than that of all known package bodies. It suffices to heat the tube to the desired temperature.

The second alternative was adopted for simplified design considerations.

Heating of Simulated Cavity

Because the cavity must be capable of accommodating variable cross sections, it can only be heated by immersion in a fluid. Air is employed for that purpose in view of the required tube temperature (200°C) and for its ease of handling. Hence the simulated cavity is placed in an air duct the temperature of which is regulated in accordance with the temperature to be reached in the simulated cavity. Heat is supplied by a heating battery. Dampers for hot-air discharge and cold-air intake allow the passive form closed-loop circulation to rectilinear open-loop circulation as well as flow-rate adjustment between these two extremes. The axis of the simulated cavity is placed parallel to the direction of air flow.

Theoretical Curves

The simulated cavity is subjected to external forced convection in a lengthwise direction at a constant flow rate. Figure 3 gives the theoretical curves.

The equation applied is

$$d\phi = h\,(T_p - T_A)\,dS \qquad (1)$$

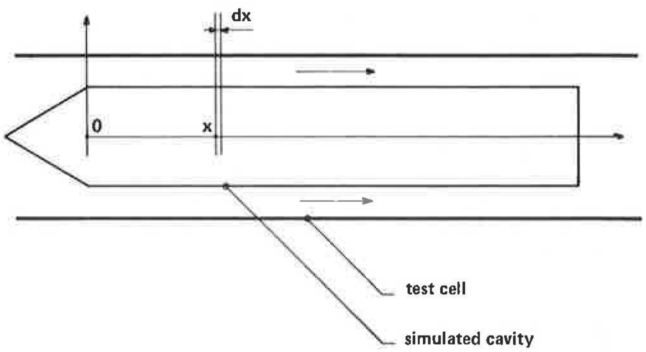

FIGURE 3 Theoretical diagram of simulated cavity.

where

- $d\phi$ = heat flux removed over an elementary length of the simulated cavity (dx),
- dS = surface area element corresponding to an elementary length of the simulated cavity (dx),
- h = heat transfer coefficient,
- T_p = wall temperature of the simulated cavity, and
- T_A = air temperature.

The surface area element dS depends only on the perimeter P of the cross section of the simulated cavity and on dx:

$$ds = Pdx \tag{2}$$

The heat transfer coefficient is expressed here by

$$h = [Nu(x) \times \lambda]/x \tag{3}$$

where Nu(x) is the Nusselt number on the abscissa x, identified along the axis of the simulated cavity, and λ is the thermal conductivity of air at temperature T_A.

The equation defining the system can thus be written as follows:

$$d\phi = \{[Nu(x) \times \lambda]/x\} \; (T_p - T_A) \; Pdx \tag{4}$$

which becomes

$$[Nu(x)/x] \; P\lambda \; (T_p - T_A) - (d\phi/dx) = 0 \tag{5}$$

The resolution of this equation helps to plot the theoretical curves shown in Figures 4 and 5, which show a slight variation in temperature after the abscissa x = 0.5 m. On the basis of these curves, the length of the simulated cavity was set at 1.5 m to employ a temperature range lying between the 0.5- and 1.5-m abscissas in performance of the tests.

Test Performance

General Description

Figure 6 gives an overall view of the test loop in which the following elements are shown: (a) fan, (b) heating battery, (c) test cell, (d) hot-air outlet damper, and (e) cold-air inlet damper.

Test Cell

Figure 7 is a diagram of the test cell. The principle adopted is the easy replacement of one simulated cavity by another. Hence the test cell is closed by (a) a lid placed on the top, to which (b) the simulated cavity is attached. The electric power supply cables for the heating resistors and the thermocouple wires pass through (c) the rear support.

The assembly consisting of the simulated cavity, its rear support, and (d) the junction box is

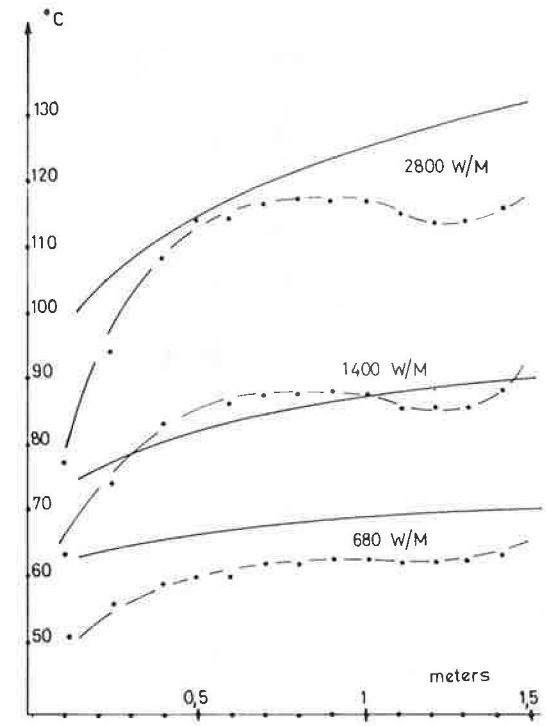

FIGURE 4 Temperatures on simulated cavity: horizontal position.

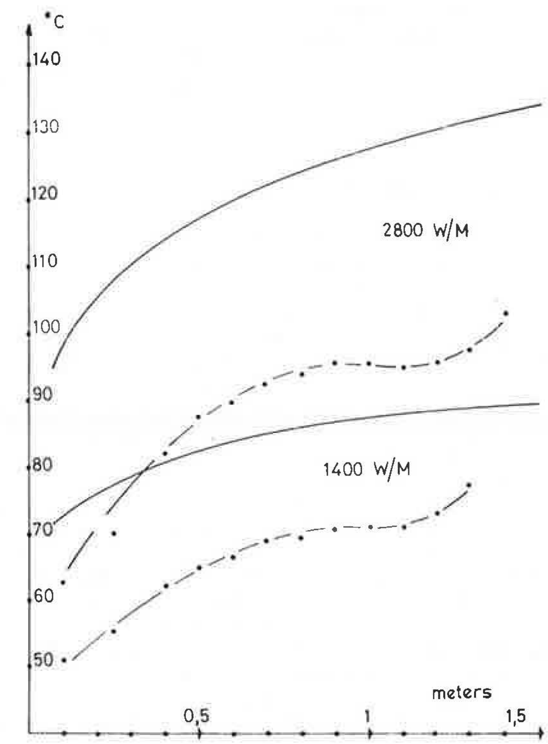

FIGURE 5 Temperatures on simulated cavity: vertical position.

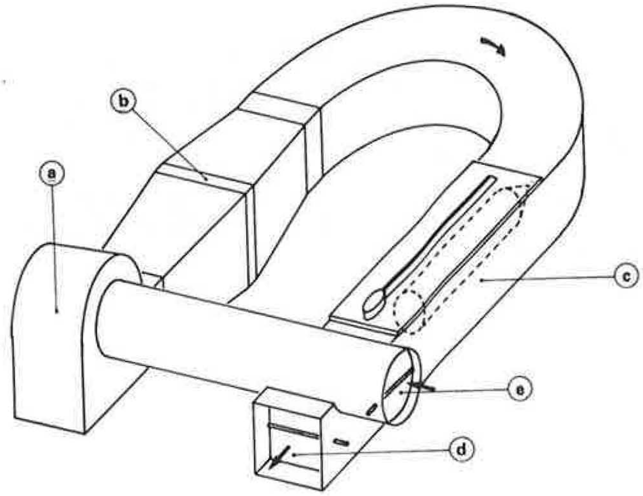

FIGURE 6 Test loop.

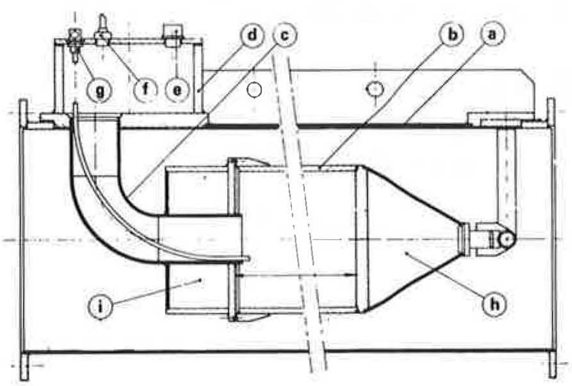

FIGURE 7 Test cell.

sealed. Thus the junction box contains (e and f) sealed passages for cables and wires and (g) a fitting to create a vacuum.

The front (in the direction of air flow) of (h) the simulated cavity is tapered. It is filled with an insulating material similar to that in (i) the rear part to approach the hypothesis of purely radial flux as closely as possible. During the tests, the support is also filled with insulating material.

Support Frame

Figure 8 gives the assembly diagrams of the test loop. The components of the test loop are mounted on (a) a frame tilting about (b) a pin fixed to (c) a support. The frame can be fixed in only two positions, horizontal and vertical.

Detailed Characteristics

Detailed characteristics of the test apparatus are as follows:

1. Heating battery, 6 kW;
2. Effective cross section of test cell, 0.33 x 0.33 m^2;
3. Air flow rate, 2 m^3/sec;
4. Insulation, 5-cm rock wool;

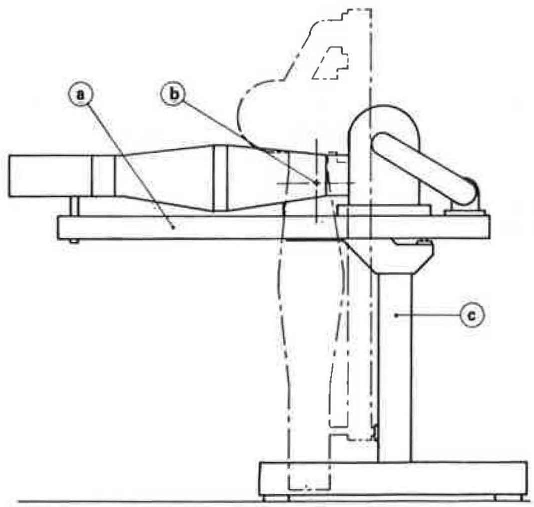

FIGURE 8 Test machine.

5. Total weight of assembly, 2500 kg; and
6. Overall dimensions: vertical position--height, 4.15 m; length, 2.5 m; width 2.4 m; horizontal position--height, 3.4 m; length, 4.4 m; width, 2.4 m.

QUALIFICATION TRIALS

Qualification trials have been performed so far with a simulated cavity that has an inside diameter of 202.7 mm. Figures 4 and 5 show the results obtained next to the theoretical curves.

The tapered form of the simulated cavity head creates disturbances in air flow between the wall of the test cell and the simulated cavity, favoring heat exchanges in the second half of the length of the simulated cavity and achieving an improvement in temperature uniformity and constancy. Thus in the horizontal position, the zone in which the temperature of the simulated cavity remains constant to within 10°C is more than 1 m long in all cases.

The zone is shorter in the vertical position. It should be noted that in this case, on real packages, the temperature of the internal cavity is not constant, but is higher at the top, reflecting what happens in the simulated cavity of the test machine. Similarly, in the horizontal position, the radial temperature distribution is not constant. The upper generating line is at a higher temperature, also reflecting the real temperature distribution.

CONCLUSIONS

The machine described here will initially serve to increase the allowable thermal power in a number of packages. To do this, it suffices to build models of the internal cavities of these packages, which must display a number of common characteristics:

- Fastening to a lid adaptable to the test cell,
- Ends of the same form as those of the simulated cavity described here, and
- Thermocouples positioned at 1.1 and 1.2 m from the tip of the simulated cavity, one to serve as a reference for temperature control and another for a measurement permanently recorded for monitoring.

Other uses are also possible:

• Comparative tests on a variety of inner containers designed to optimize heat exchanges and
• Qualification of computation codes.

Moreover, the machine itself is still in the developmental stage and is subject to further improvements.

ACKNOWLEDGMENTS

The authors wish to thank F. Hochner, F. Isidoro, A. Perrin, and P. Robin-Jouan, students at the Institut National des Sciences Appliquées (INSA) in Lyon, who participated in designing the test machine based on COGEMA specifications as part of their graduation thesis. They also wish to thank P. Haberschill, their professor, as well as the team of the INSA Energy and Automation Laboratory, where the work was carried out.

Stowing of Packages Containing Radioactive Materials on Conveyances

J. Draulans, G. Chevalier, P. Gilles, J. C. Jolys, I. Lafontaine, and M. Pouard

ABSTRACT

In a joint project funded by the Commission of the European Communities, the French Commissariat à l'Energie Atomique (CEA) and the Belgian company Transnubel have conducted research on the stowage of containers for radioactive materials on trucks. A search was made for data on normal and accidental transport conditions that resulted in the selection of 2 reference-type accidents: (a) a front-end collision with a rigid barrier at a speed of 50 km/hr, and (b) a side-on collision with an impacting vehicle at a speed of 25-35 km/hr against a truck loaded with a container. In addition, a mathematical model has been developed by means of the CEA Trico code to compute a frontal impact in which the 1.3-t container is stowed by means of 4 tie-down members, each for a nominal load of 2 t. The obtained results indicate that the stowage was insufficient and the attachment points too weak to hold the container on the platform. Real tests have been performed to verify these results and to look for a possible solution. Tie-down members and chocks have been defined on the basis of static and dynamic tests for use in 8 crash tests (5 front-end and 3 side-on). Different containers (low and high center of gravity) and different methods of stowage have been tried. On the basis of the obtained information, an attempt is made in this paper to prepare and propose a code of good practice for stowing packages on a truck platform by means of tie-down members and chocks.

Most of the available information on the transportation of packages that contain radioactive materials relates to the package itself. Some information can be found on the stowing of such packages, for example on trucks; however, only normal transportation conditions are considered. Almost no information was available on the stowing of such packages although accidental conditions are considered.

To obtain more data on the behavior of package tie-downs in normal and accidental conditions for the redaction of directives on the stowing of packages on ground transportation involves considerable study--and test tasks are financed by the Commission of the European Communities (CEC). This study was performed jointly by the Commissariat à l'Energie Atomique (CEA) in France and Transnubel in Belgium under contract to the CEC.

THE STUDY

During the first part of the study, standards and directives were collected in Belgium, France, the United Kingdom, Italy, the Netherlands, the Federal Republic of Germany, Sweden, and the United States. In addition, advisory prescriptions and information