A METHOD OF ASSESSMENT OF DOSE RESULTING FROM AN ACCIDENT INVOLVING A MULTIPLE-PACKAGE SHIPMENT

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ABSTRACT

Methods are available for the assessment of radiation dose resulting from an accident involving a shipment of radioactive material. This paper considers a shipment of Type A packages transported in a van from the supplier of radioisotopes to users. If the vehicle transporting many such packages encounters an accident, the radiological consequence would depend upon the severity of the accident, the number of packages damaged, the package failure fraction, the nature and quantity of the radioactive contents, the weather conditions and the nature of occupancy around. The impact of the accident would be distributed among the packages resulting in different failure fractions. An attempt is made to develop a method to predict the dose resulting from such an accident and identify the data required for making such an assessment.

MULTIPLE PACKAGE SHIPMENT

Methods are available for the assessment of radiation dose resulting from an accident involving a shipment of radioactive material [(1)]. They assume that all the packages being transported in a vehicle suffer the same impact. PSA techniques are used for such dose assessment [(2)]. This paper considers shipments consisting of a number of packages containing radioactive material, otherwise known as multiple package shipment. If such a shipment meets with an accident, the resulting dose to the public can be assessed using the conventional methods, calculating the total dose due to the failure of all the damaged package, assuming that the packages failed to the same extent. In reality the impact of an accident, be it mechanical or thermal, would be distributed among all the packages being transported in a vehicle. In a real accident, it would be possible to actually inspect each package and determine the loss of shielding and / or of containment suffered by each package. However, in order to predict the extent of hazard associated with such an accident, a theoretical method of assessment needs to be established.

FACTORS DETERMINING DOSE DUE TO A TRANSPORT ACCIDENT

The dose resulting from an accident that leads to package failure and release of activity can be calculated using the expression,

$$E = q \; D \; \Sigma \; l(i) \; [\Sigma \; p(i, j) \; f(j)] \qquad Sv \qquad \text{Eq. (1)}$$

Where,

D = dose resulting from unit release of activity of the specific radionuclide, $SvBq^{-1}$
q = activity of the radionuclide released from the package
p (i, j) = probability of occurrence of accident of severity, j, in populationn zone, i, km^{-1}
f(j) = failure fraction of the package for the accident of severity category, j
l(i) = total distance traversed by the shipment through zone, i km

For a given accident severity, the package failure fraction can be characterised on the basis of the design features of the package.

ACCIDENT SEVERITY AND PACKAGE RESPONSE

For evaluating the response of a package to accidents it would be necessary to subject the package to all the accident conditions of transport. If an index can be assigned to the severity of accidents, it can take a continuous range of values which can be described as slight, minor, major, severe, etc. For the purpose of evaluating the dose using Probability Safety Assessment (PSA) methods, studies have been made to group transport accidents into several categories (1). It is not possible to evaluate the response of a package to all possible severity categories. In an earlier study, accidents were categorised in accordance with their comparability with the regulatory tests (3). The advantage with such categorisation, given in Table 1, is that the response of a package to an accident of a given severity category can be predicted on the basis of the assessed response of the package to the corresponding regulatory test.

The failure fraction, f(j), of a package is an assessed design characteristic of the package which is the probability of failure of a package, in an accident, j. Given the particulars about the radioactive contents, one can calculate the released activity and the resulting dose using eq. (1).

FAILURE FRACTION OF INDIVIDUAL PACKAGES

Delivery vans are common examples of vehicles that carry multiple-packages. Such vans, in general, carry standard shipments. The shipments are made generally in the urban environment. Given that the shipment encounters an accident of severity, j, all packages may not be affected to the same extent. The damage suffered by the packages may vary and be represented by a failure fraction that ranges from 0 to 1 (where 1 denotes complete loss of containment). It may be assumed that

(i) the total impact energy was equally divided among all packages or

(ii) the impact energy was divided among the packages according to a certain distribution.

The first approach is artificial though it may simplify dose calculations. The second is more realistic but calls for an experimental or a theoretical basis.

DISCRETE DISTRIBUTION OF IMPACT

Considering an impact on one side of the vehicle, the package placed nearest to that side will suffer the maximum damage because the packages under consideration are not generally anchored to the body of the vehicle. The impact distribution may be such that the impact suffered by the nth package is related that suffered by the (n - 1)th package.

Package failure fractions can be determined in terms of the regulatory tests. Accidents can be categorised in relation to the regulatory tests. The impact simulated by the tests are not continuous. That is, accident severity categories are characterised by a discrete distribution. Hence in the evaluation of package failure, the impact suffered by the packages could be described by a discrete distribution. The failure fraction of a package to an impact of severity lying between category j and j+1 may be conservatively assigned the value that corresponds to the severity j+1.

In an accident involving any multiple-package shipment -

- the number of packages damaged increases with the severity of the accident and
- packages are damaged to different extents.

It is suggested that the distribution of the affected number of packages, after an impact to the vehicle, may be taken as

$$n(i, j) = n(i) * a(j) * \exp[-b(j)] \qquad \text{Eq. 2}$$

where, n(i) is the total number of packages of identity, i, in the delivery van;

n(i,j) is the number of packages, i, which suffered an impact that correspond to an accident of severity j and j+1; and

a and b are constants characteristic of the accident severity.

Where all packages are of identical design , n(i) = N and n(i,j) can be written as n(j), given by

$$n(j) = N * a(j) * \exp[-b(j)] \qquad \text{Eq. 3}$$

The activity released following an accident of severity, j , can be computed from

$$A(j) = p(j) * f(j) * n(j) * q \qquad \text{Eq. 4}$$

where p (j) is the probability of accident, of severity, j, q is the activity of radionuclide contained in the package and n(j) is the number of packages containing the radionuclide which suffered an impact that corresponds to an accident of severity in the range j and j+1. The resulting dose can be computed by the currently used methods based on PSA techniques.

EXAMPLE

Conventional method – Uniform package failure:

The collective dose due to an accident in an urban environment involving a vehicle carrying 50 packages containing radiopharmaceuticals, which are commonly transported within a city from the supplier to the user, was calculated using INTERTRAN2 which is a computer code developed by the International Atomic Energy Agency based on the code, RADTRAN 4 [2] and the earlier version of INTERTRAN[5] . The shipment particulars and the calculated dose values are given in Table 2. In these calculations, the total activity released is evaluated thus:

$$Q \quad = \quad n\, q\, \Sigma\, p(j)\, f(j) \qquad \text{Eq. 5}$$

where n is the total number of packages and q is the activity in each package

q is the activity content in a package

p(j) is the probability of accident severity j and

f (j) the corresponding failure fraction of the package

The resulting dose is given by

$$D = K\, Q \qquad \text{Eq. (6)}$$

where, K is the dose conversion factor.

This method overestimates the accident dose by taking f(i) the same for all the n packages.

Suggested method – Graded discrete package failure:

All the packages considered in our example are Type A. The failure fraction of any of these packages would be zero in the first and the second of the 12 severity categories of accidents, i.e., $f(j) = 0$, for $j = 1$ and 2. In the case of severity category 5 and f(j) was assessed to be less than 0.5. In all other cases f(j) may be conservatively assumed to be 1.

If the accident is of severity category j, the summation of package failure in the entire shipment would be

$$FF(j) = [\, f(j)\, n(j) + f(j-1)\, n(j-1) + f(j-2)\, n(j-2) + ...+ f(1)\, n(1)\,]$$

The quantities f(j) take the values 0, 0.5 and 1 as noted above. Given that an accident of severity j occurs, the number of packages which suffer primary, secondary and tertiary impacts, viz., n(j), n(j-1) , n(j-2), etc have to be determined. The accident dose using PSA technique with this modification would calculate the total dose as,

$$D = K \, \Sigma \, A(j) \, FF(j)$$

$$= K \, \Sigma \, [\, p(j) * \Sigma \, f(j) * \Sigma \, n(j,r) * q(r) \,] \, [f(j) \, n(j) + f(j-1) \, n(j-1) + ... + f(1) \, n(1)] \quad \text{Eq.(9)}$$

This method of dose estimation clearly is not unduly pessimistic and is more realistic than the currently adopted method.

Arbitrarily assuming $a(j) = b(j) = N / j$, varying j from 1 to 12, rounding off decimal fractions to integer values and ensuring that $\Sigma \, n(j) = 1$, we can calculate n(j) and A (j) using Eq. (3) and Eq. (4) respectively. Using the values of p(j), the dose, D, was calculated only for inhalation dose. The inhalation dose was determined by calculating the inhaled activity from the released activity using the values given in literature (1) . The results are given in Table 2 under the column, present method. In the case of ^{99}Mo, if the cloudshine dose which is about two orders of magnitude higher than inhalation dose for this radionuclide, also had been calculated using this method, the difference in the total dose would be significant. In the present calculation the inhalation dose coefficient values given in IAEA BSS (4) have been used. The maximum values correspond to the dose to children of age < 1 year and the maximum to that to adults of age>17 years.

DISCUSSION

The method suggested in the above example above needs to be verified and modified as necessary. The most important components of the above example which needs to be examined are a(j) and b(j) which have been assigned arbitrary values. Such examination has to be based on experimental and theoretical studies.

TABLE 1

ACCIDENT SEVERITY CATEGORY

SEVERITY CATEGORY	MECHANICAL IMPACT	THERMAL IMPACT FIRE DURATION (MINUTES)
I	NEGLIGIBLE	NEGLIGIBLE
II	≤ TYPE A TEST	NEGLIGIBLE
III	NEGLIGIBLE	≤ 30
IV	≤ TYPE A TEST	≤ 30
V	> TYPE A TEST ≤ MECHANICAL TEST	NEGLIGIBLE
VI	NEGLIGIBLE	> 30
VII	≤ TYPE A TEST	> 30
VIII	> TYPE A TEST ≤ MECHANICAL TEST	≤ 30
IX	> MECHANICAL TEST	NEGLIGIBLE
X	>MECHANICAL TEST	≤ 30
XI	> TYPE A TEST ≤ MECHANICAL TEST	> 30
XII	> MECHANICAL TEST	> 30

TABLE - 2
SHIPMENT PARAMETERS
MODE: ROAD (WITHIN BOMBAY CITY ONLY)

SOURCES IN THE CONSIGNMENT	ACTIVITY PER PACKAGE (GBq)	# OF PKGS	INHALATION DOSE Sv	
			CONVENTIONAL METHOD	SUGGESTED METHOD
I131	7.4	50	6.8E-07	8.1E-14 3.6E-12
MO99	7.4	50	3.1E-08	1.6E-14 2.4E-13
I131	9.25	50	8.5E-07	1.0E-13 4.5E-12
I131 & MO99	7.4 each	25 each	3.5E-07	4.9E-14 1.9E-12

Shipment Distance = 25 km in all cases

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