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CONTAINMENT ANALYSIS OF TRUPACT-I*

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Abstract

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TRUPACT-I is a packaging which will be used to transport contact-handled transuranic (CH-TRU) wastes generated by defense programmes in the United States of America. The paper presents a general approach to the containment analysis for TRUPACT-I. The maximum activity per TRUPACT-I packaging is determined for a stated seal leak rate and filter penetration efficiency in order to comply with regulatory release limits for normal and hypothetical accident conditions.

1. INTRODUCTION

1.1 Containment System of TRUPACT-I

The inner door, inner frame, fasteners, filtered vent, inner door seal and containment liner constitute the containment system of TRUPACT-I. The containment system is continuously vented through four filters in the filtered vent mounted in the inner door frame. This vent prevents the formation of an unacceptable pressure differential (over 34.4 kPa [5 psig]) between the cavity and the package exterior which could develop under operating extremes of altitude variation, environmental temperature range and heat or gas generation from the contents. Gas venting from the containment cavity will pass through the filter elements, thereby trapping airborne activity which would be present in the form of fine particulates. No gaseous radionuclides will be shipped in TRUPACT-I.

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1.2 Waste Contents

TRUPACT-I has been developed for the transport of contact-handled transuranic (CH-TRU) wastes among generating, storage, or repository sites. The CH-TRU wastes addressed contain plutonium isotopes and daughter products and will be packaged in Type A drums or boxes. A_2's for the mixtures of isotopes considered range from 0.003 Ci (0.11 GBq) for heat-source plutonium to 0.010 Ci (0.37 GBq) for weapons-grade plutonium. The waste forms and their packaging significantly limit the dispersibility of the particles attached to or mixed with the wastes.

The allowable activity in a TRUPACT-I shipment is determined by a number of factors, including isotopic mixture, dose rate, criticality safety, heat generation and potential release of activity from containment. For normal transport, TRUPACT-I must not release any of its radioactive contents, as demonstrated to a sensitivity of 10^{-6} A_2 per hour. For hypothetical accident conditions, TRUPACT-I must not release more than an A_2 quantity in one week [1].

2. SOURCE TERM FOR RELEASE OF ACTIVITY

Aerosolized particles containing radioactive material are assumed to be released from one of the 36 Type A containers in the shipment into the interior of TRUPACT-I during normal transport and from all of the containers during a hypothetical accident. This assumption is conservative because Type A containers should not fail under normal conditions of transport. The aerosol may potentially be released from TRUPACT-I to the environment through the filtered vent or hypothetical leak holes.

The source term is determined by the assumed fraction of activity present in the Type A containers that escapes into the TRUPACT-I cavity and is available for release, the maximum activity in a TRUPACT-I shipment discussed above and the particle size distribution.

2.1 Activity Release Fractions

The total fraction of activity that is available for release from TRUPACT-I, RF, is the product of three terms:

$$RF = (WCF)\ (LC)\ (AC).$$

Assumed values used for each term are summarized in Table I.

TABLE I

Values of Release Fractions Used in the Containment Analysis

	Normal Conditions	Hypothetical Accident Conditions
Fraction of waste containers that fail (WCF)	0.03	1.0
Fraction of contents within the failed container that leak to the TRUPACT-I cavity (LC)	0.0001	0.10
Fraction of leaked contents that are aerosolized and available for release (AC)	0.01	0.01

2.2 Particle Size Distribution

A conservative particle size distribution for airborne wastes [2] is used as the basis for the release source term. This distribution contains a large activity fraction (70 percent) of particles of diameter 0.1-0.3 μm or smaller. During normal handling of the drums before shipment, small particles will have agglomerated to larger particles on the order of 0.1 μm in diameter.

3. MODEL FOR RELEASE OF ACTIVITY FROM TRUPACT-I

The door seals and the filters are the only potential paths for release of activity because the remaining components of the containment system will be verified to be leaktight and are not susceptible to mechanical or thermal damage during normal transport or the hypothetical accident. The driving mechanism for the release is a pressure differential between the interior and exterior of the package. While the filtered vent will prevent a significant pressure differential from occurring, this model conservatively assumes a maximum pressure differential of 30.3 kPa (4.4 psig). This pressure differential could result if TRUPACT-I could experience an elevation change of 2900 m (9,500 feet) in one hour, starting from sea level, which is very unlikely to occur.

The pressure differential will cause gases present inside TRUPACT-I to flow through the filtered vent or through leak holes in the seal from the TRUPACT-I cavity to the exterior of the package. The activity in the TRUPACT-I cavity that is available for release is carried by the flow of cavity gases. Much of this activity is filtered from the gas flow by the filtered vent or by the leak holes. The analysis conservatively calculates the release from the filtered vent assuming that all flow occurs through the filtered vent, calculates the release from the leak holes assuming that all flow occurs through the leak holes, then adds the two releases together. Gas flow would actually occur primarily through the filtered vent.

3.1 Model for Release of Activity Through the Filtered Vent

The model for release of activity through the filtered vent conservatively assumes that the pressure differential of 30.3 kPa (4.4 psig) is completely relieved during the one-hour (normal conditions) or one-week (hypothetical accident) time period for evaluation, thereby allowing 30 percent of the air in the containment cavity to pass through the filters. A conservative calculation of the fractional activity release rate through the filtered vent ($R_{F/V}$) is given by

$$R_{F/V} = (0.30/t)\ (RF)\ (MPE)$$

where RF = total release fraction as discussed above,
MPE = maximum filter penetration efficiency of the filtered vent,
t = time period for evaluation (one hour or one week).

For typical filters the penetration is maximum at a specific particle size, usually in the neighborhood of 0.3 µm [3], and rapidly decreases for either larger or smaller particle sizes. The MPE for the filters in the TRUPACT-I filtered vent is specified to be 5.0×10^{-5} at a flow rate of 20 L/min (corresponding to a minimum collection efficiency of 0.99995).

3.2 Model for Release of Activity Through Hypothetical Leak Holes

The cumulative fraction of activity released from the cavity is given by

$$CAR = \int_{t_o}^{t_f} \left[\sum_{i=1}^{N} TAAP_i(t) * EFF_i(t) \right] * FTMR(t)\ dt$$

where the activity release is assumed to be proportional to the air mass released and

CAR = cumulative fraction of activity released from containment through the hypothetical leak holes,

FTMR(t) = fraction of the total air mass released in a time increment Δt at time t,

$TAPP_i(t)$ = total aerosolized fraction of activity for particle size i,

EFF(i) = filter penetration efficiency of the leak hole for particles having size (i),

N = total number of particle sizes used in the analysis,

t_o = initial time

t_f = final time (1 hour for normal transport and 1 week for accident conditions).

The aerosolized fraction of activity, TAAP(t), is reduced from TAAP(t=0) by the activity that has already leaked out of the containment cavity and by the activity carried by larger particles that have settled out and are no longer aerosolized (considered only for the hypothetical accident case). Particle settling velocities are calculated using Stokes Law.

The fraction of the total air mass released in a time increment Δt at time t, FTMR(t), is given by

$$FTMR(t) = \frac{P(t-\Delta t) - P(t)}{P(t-\Delta t)}$$

The pressure at time t, P(t), is given by

$$P(t) = \frac{P(t-\Delta t)V_{TRUPACT} - Q\Delta t}{V_{TRUPACT}}$$

where $V_{TRUPACT}$ = internal void volume of TRUPACT-I (cm^3),

Q = volume flow rate from TRUPACT-I between times $(t - \Delta t)$ and t ($atm\text{-}cm^3/s$).

The EFF(i) are obtained from the decontamination factor for the leak hole (DF = 1/EFF), calculated from the following equation [4]:

$$\log_{10} DF_i(t) = 0.0867 + (203.2)\frac{\mu d_i L^2}{\Delta P D^4}$$

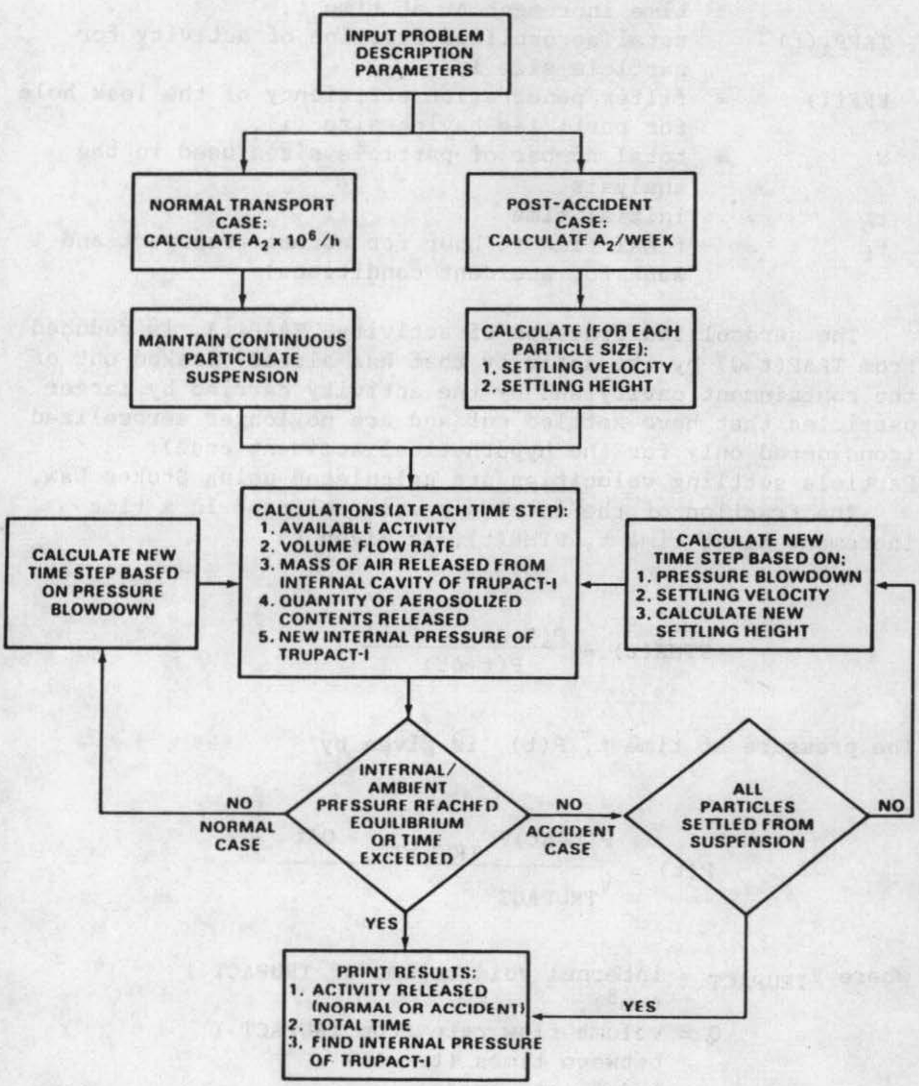

FIG. 1. Simplified flowchart of activity release calculated for a specified leak hole size.

where μ = absolute viscosity of air (atm-s)
d_i = diffusion coefficient for particle size i in air (cm^2/s)
L = leak hole length (cm)
P = pressure drop across the leak path (atm)
D = leak hole diameter (cm).

Gas leakage through small holes for laminar, transitional, and molecular flow modes (from 10^{-7} to 10^{-2} atm-cm^3/s) is estimated by the following equation [5]:

$$Q = 3810 \left(\frac{D^3}{L}\right)[323\left(\frac{D}{\mu}\right) (P^2_{TRUPACT} - P^2_{ambient}) + \sqrt{\frac{T}{M}} (P_{TRUPACT} - P_{ambient})]$$

where T = gas temperature (K)
M = gas molecular weight (amu)
and the other variables are as described above.
$P_{TRUPACT}$ = pressure inside TRUPACT-I (atm)
$P_{ambient}$ = ambient pressure (atm)
μ = absolute viscosity of air (cP)

The filtration efficiency of a flow path increases with decreasing leak hole diameter and increasing number of turns in the flow path. Particles will plug small holes more readily than one large hole of the same total size. The analysis conservatively considers one equivalent-size hole and a straight leakage path.

Fig. 1 shows a simplified flowchart for the computer program CONLEAK which calculates the activity released through leak holes of different sizes for normal or hypothetical accident conditions. The program also prints the total air leakage from the hole during the release evaluation period.

The gaseous leakage rate for the TRUPACT-I seal is specified to be no greater than 1.0×10^{-2} atm-cm^3/s under standard conditions of ANSI N14.5 [5] (a flow of dry air at 25°C from a pressure of 1 atm abs to a pressure of less than 1.0×10^{-2} atm abs).[1] Corresponding to this leakage rate and a leak hole length of 1 cm (the thickness of the seal); the equivalent leak hole diameter is 35 µm.

4. ALLOWABLE ACTIVITY PER TRUPACT-I FROM CONTAINMENT ANALYSIS

The total fraction of activity potentially released is calculated to be 5.0×10^{-13} for normal transport and 4.3×10^{-7} for accident conditions. When compared to the

[1] 1 atm = 1.013 25 × 10^5 Pa.

regulatory release limits, these fractional activity releases result in a conservative limit on the activity transported by TRUPACT-I of 2.0 x 10^6 A_2 Ci (7.4 x 10^7 A_2 GBq).

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