CONSIDERATION OF SAFETY REQUIREMENTS FOR LARGE PACKAGES WITH Q SYSTEM

H. Suzuki
Mitsubishi Research Institute, Inc
2-3-6 Otemachi, Chiyodaku, Tokyo, Japan

H. Mochiduki
National Maritime Research Institute
6-38-1 Shinkawa, Mitaka, Tokyo, Japan

M. Hirose
Nuclear Fuel Transport Co. Ltd.
Japan

M. Uragami
The Kansai Electric Power Company, Inc
Japan

O. Sato
Mitsubishi Research Institute, Inc.
Japan

S. Nakanishi
The Kansai Electric Power Company, Inc
Japan

S. L. Turner
Science Applications International Corporation, USA

M. Aritomi
Tokyo Institute of Technology
Japan

ABSTRACT

A large component (e.g. a replaced steam generator) might be best categorized as a surface contaminated object (SCO). Paragraph 523 of “Regulations for the Safe Transport of Radioactive Material”, TS-R-I, states, “SCO-I may be transported unpackaged but SCO-II may not.” Regarding SCO-II level objects, competent authorities have reviewed the safety analysis reports on “internal surface contamination levels” and “free drop” incidents, and they have approved them as “Special Arrangement” transports. In this paper, we consider “What conditions are the same level as requisite standards of safety established by TS-R-1?” with regard to safety analysis reports for Special Arrangement. Under normal conditions of transport, a component might “fall off the platform of a vehicle” or be “dropped during handling” in minor mishaps. In most cases, the packages would be relatively undamaged and would continue their journey after these minor mishaps. Under the accident conditions of transport, fire and collision are also included as accidents. TS-R-1 requires little damage effect with contents limits for Type A and Type IP packages. As a simple example scenario, we find that if 10% of the internal activity is released from the component and 1% of particles are in the respirable size range, then the activity limit will be $10A_2$ for fixed and non-fixed surface contamination.

INTRODUCTION

Transport of a large component is approved as a “Special Arrangement” package in European countries and as “Special Permit” in the US. But “Special Arrangement” and “Special Permit” are not familiar in Japan. The transport of the used Reactor Pressure Vessel (RPV) of the nuclear ship Mutsu was the only instance in Japan. There are no cases where a planned series of multiple consignments were accepted for “Special Arrangement”.

Special Arrangement requires demonstrating satisfaction of the requisite standards of safety established by TS-R-1 [1].

For understanding Special Arrangement properly, we consider the safety requirements for large component transport with the Q system as established in TS-R-1.

Basic Safety Concept

The objective of TS-R-1 is to protect persons, property, and the environment from the effects of radiation during the transport of radioactive material. This protection is achieved by requiring: (a) containment of the radioactive contents, (b) control of external radiation levels, (c) prevention of criticality, and (d) prevention of damage caused by heat. A graded approach is applied to the performance standards in TS-R-1 that is characterized by three general severity levels: (a) routine conditions of transport (i.e. incident free), (b) normal conditions of transport (i.e. minor mishaps), and (c) accident conditions of transport.

Under the normal conditions of transport, a component might “fall off the platform of a vehicle” or be “dropped during handling” as minor mishaps. In most cases packages would be relatively undamaged and would continue their journey after these minor mishaps. Under the accident conditions of transport, fire and collision are possible accidents. For Type B packages, TS-R-1 requires the ability to contain the radioactive contents, control external radiation levels, prevent criticality, and prevent deterioration caused by heat under these conditions. For Type A and Type IP packages, TS-R-1 requires little damage effect with contents limits as shown in Fig. 1.

Release Model with Q system

In the Q system, which was developed to establish a radiological basis for TS-R-1, radiation exposure routes, i.e., external photon dose (Q_A), external beta dose (Q_B), inhalation dose (Q_C), skin and ingestion dose due to contamination transfer (Q_D), and submersion dose (Q_E) are considered. Amongst these the inhalation dose (Q_C) can be taken as a major exposure route under accident conditions of a large component, since most of the activity of the source is dispersed as surface contamination comes off surfaces of the component that is scraped or scratched during the accident. To assess the level of safety of transport of large components, therefore, evaluations of inhalation dose from surface contamination can be considered essential.

To maintain the same level of safety as in Type IP-2 package transport means that a large component without qualified IP-2 packaging should satisfy the design requirements for Type IP-2 package and comply with requirements and controls for Type IP-2 package transport. In addition, when the SCO is assumed to move in an accident and contamination is scraped off and released, an activity intake for a person in the vicinity of the accident should be approximately of the same level as that of SCOs or of Type A packages, which is considered as a value of 10^{-6} A_2. As shown in Fig. 2, Fig. 3, and Fig. 4.

An activity intake for a person in an accident is given by the following equation:

$$Q_{INT} = Q_{IV} \times F_{SCRAP} \times F_{RSUS} \times F_{REL} \times F_{INT} \quad \text{... (1)}$$

where,

Q_{INT} is the intake activity of radionuclides (Bq)

Q_{IV} is the inventory in a package or an object (Bq)

F_{SCRAP} is a fraction of surface area that is scraped in an accident

F_{RSUS} is a fraction of activity in a form of respirable aerosol freed from surfaces in an accident

F_{REL} is an activity release fraction from a package or an object in an accident

F_{INT} is a factor of activity intake for a person in the vicinity of the accident

And for a surface contaminated object an inventory is given as:

$$Q_{IV} = (C_{FIX} + C_{N-F}) \cdot A \times 10^4 \quad \text{.....} \quad (2)$$

where

C_{FIX} is a level of fixed surface contamination (Bq/cm^2)

C_{N-F} is a level of non-fixed surface contamination (Bq/cm^2)

A is a surface area of an object (m^2)

The "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, Safety Guide" [2] has an example for an SCO-II given in Para. 241.3 that assumes: 10 m^2 for A, 8×10^5 Bq/cm^2 for C_{FIX}, 400 Bq/cm^2 for C_{N-F}, F_{SCRAP} of 20 % and F_{RSUS} of 20 % and F_{REL} of 10^{-2} for fixed surface contamination, F_{SCRAP} of 100 % and F_{RSUS} of 20 % and F_{REL} of 100% for non-fixed surface contamination, and 10^{-4} for F_{INT}.For this case Q_{INT} is 0.2×10^{-6} A$_2$, which is well below the 10^{-6} A$_2$ level of safety for a Type A package.

In an approval of special arrangement transport of large components, every parameter in the "Release Model" should be examined and justified. Parameter A can be calculated form design drawings of the components. Distributions and radionuclide compositions of parameters C_{FIX}, C_{N-F}, and Q_{IV} throughout the component can be measured, or properly modelled for a series of components together with a verification measurement for representative points on each component. Parameters F_{SCRAP}, F_{RSUS}, and F_{REL} are sensitive, and should be demonstrated to be appropriate through the literature, tests, or reasoned arguments. Parameter F_{INT} may be a value of 10^{-4}, which is used in the Q system.

Release Fraction

Some analyses use a "release fraction" such as in US Steam Generator (SG) replacement cases. The value of the Release Fraction is 1 x 10^{-4} as shown in Table1. The European Union (EU) has developed an improved radiological basis and revised requirements for the transport of LSA/SCO Material. The large component would be categorized "Immobilised solids (non-combustible matrix)" and the value of release fraction is 1x10^{-4} as shown in Table 2. The US Department of Energy (DOE) has made a handbook on airborne release fractions/rates and respirable fractions for nonreactor nuclear facilities. The large component would be categorized as "Contaminated, Noncombustible Solids", and the value of release fraction is 1x10^{-4} as shown in Table 3. On the basis of these data, it would be appropriate to make a simple scenario where 10 % of internal activity is released from the component, and 1 % of particles will be in the respirable size range.

Results

In a case where values used in the SCO-II model would be justified for parameters F_{SCRAP}, F_{RSUS} F_{REL} and F_{INT}, inventories up to $10A_2$ for fixed surface contamination plus the non-fixed contamination on the inaccessible surface can be allowed to maintain the same safety level. For a simple scenario that assumes 10% of internal activity is released from the component and 1% of particles will be in the respirable size range, the inventory limits will be $10A_2$ for fixed and non-fixed surface contamination.

Care should be taken with regard to the radionuclide composition of inventory. In a case of β- and γ-emitting unknown radionuclides, an inventory limit of $10A_2$ corresponds to a total contamination of 0.2TBq and 4×10^3 Bq/cm^2 assuming a surface area of 5,000 m^2 (a typical internal surface area of a steam generator in Japan). This is almost two orders of magnitude lower than the contamination level limit on the inaccessible surface of a SCO-II, which is 8×10^5 Bq/cm^2. In the case where ^{60}Co is considered to be the only radionuclide existing in the inventory, the allowable level of inaccessible surface contamination increases to 4 TBq. And in the case of the SG inventory which is reported in the GNS study [12], the allowable level increases up to 260 TBq. as shown in Table 4.

CONCLUSIONS

For approval of a large package as "Special Arrangement", satisfaction of the requisite standards of safety established by TS-R-1 is required. The safety level should be demonstrated in routine conditions of transport (incident free), in normal conditions of transport (minor mishaps), and in accident conditions of transport. Regulations in TS-R-1 require little damage effect with contents limits for Type A and Type IP packages. As a simple example scenario, we find that if 10% of the internal activity is released from the component and 1% of particles are in the respirable size range, then the activity limit will be $10A_2$ for fixed and non-fixed surface contamination, assuming this model is correct.

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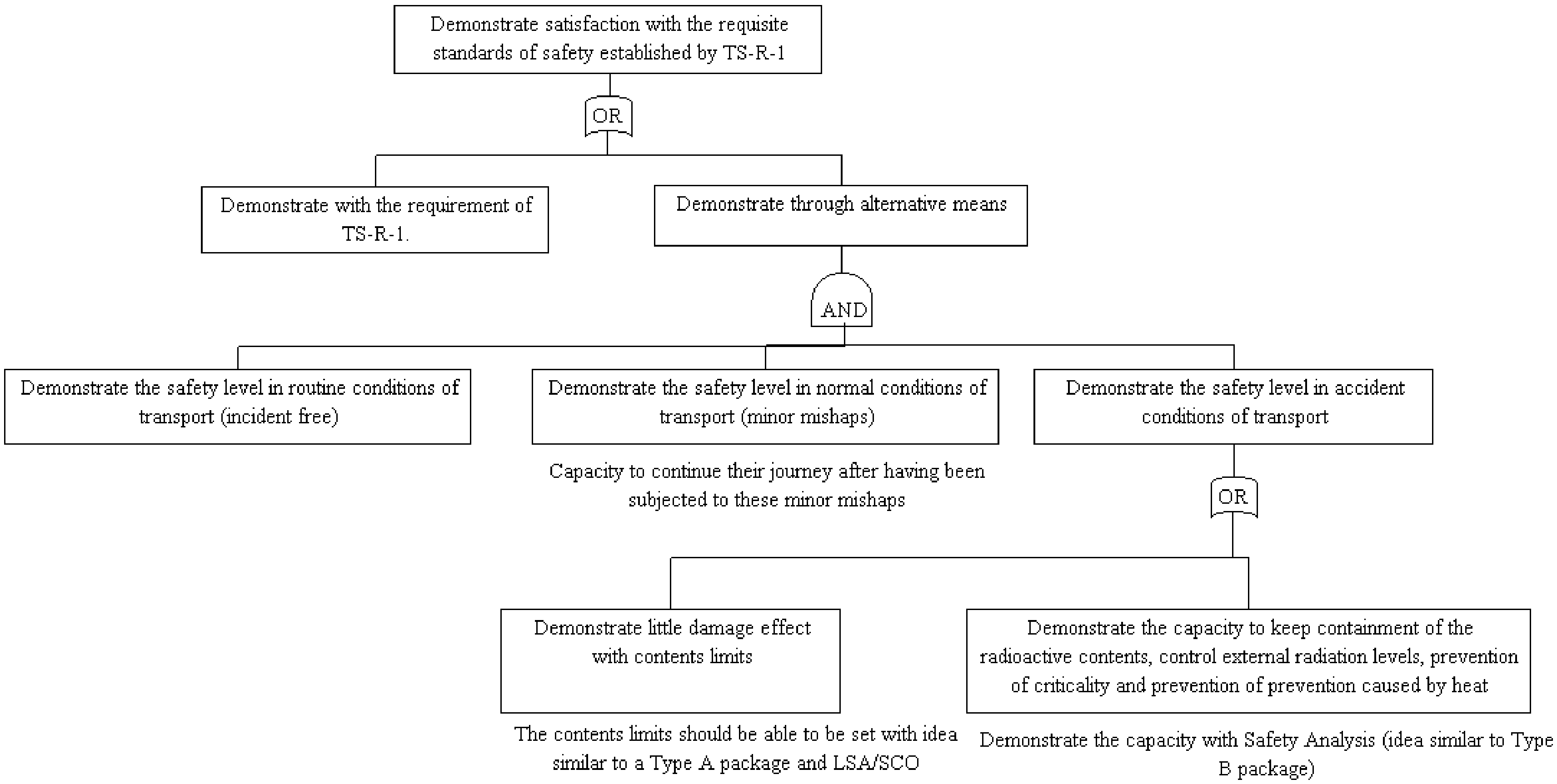

Fig. 1. Fault Tree on Safety Requirement for large component [1]

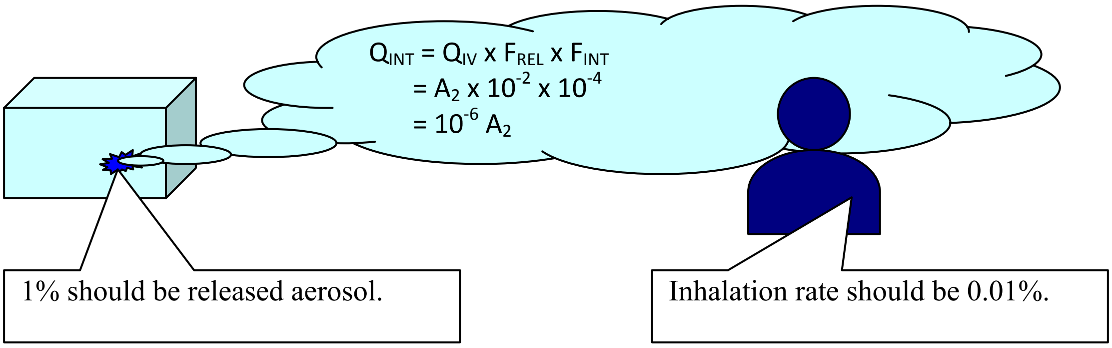

Fig. 2. Inhalation Scenario of Q system [2]

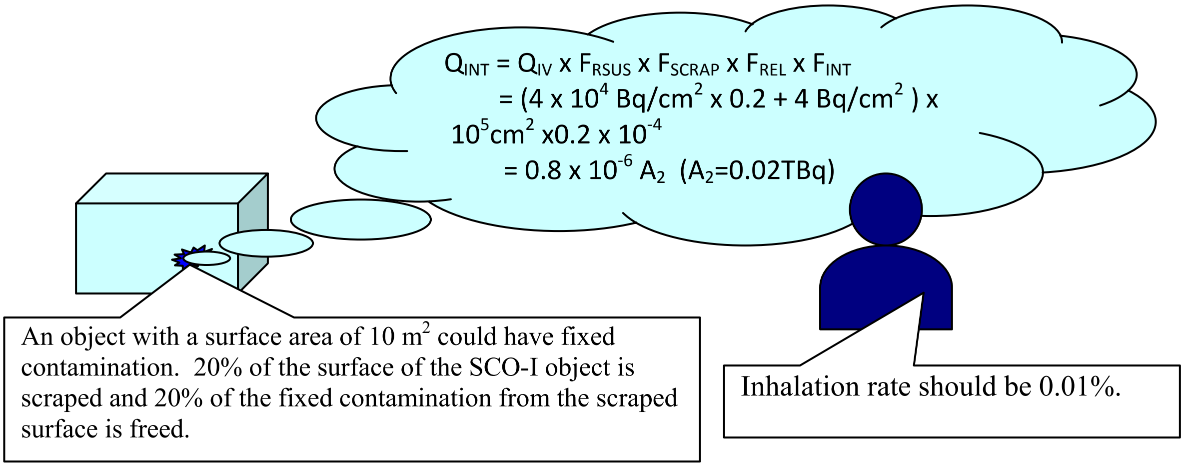

Fig. 3. Inhalation Scenario for SCO-I [2]

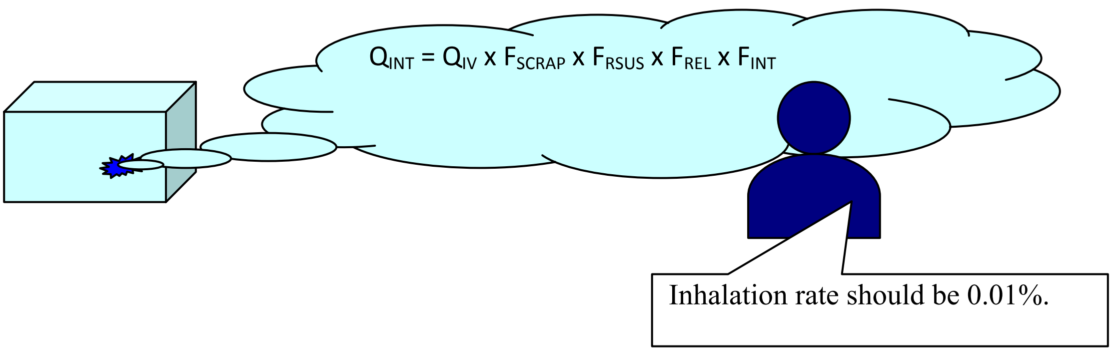

Fig. 4. Inhalation Scenario for Large Component (proposal)

Table 1. Release Fraction in US SG Replacement Cases

	H. B. Robinson [6]	Point Beach[7]	Surry[8]
	1983	1983	1978
Activity in Steam Generator	310 Ci	300 Ci	1400 Ci
Fraction of Activity Becoming Airborne	0.1	0.1	0.001
Respirable fraction	0.01	0.01	ND
Site Boundary χ/Q	1.7 x 10^{-3} sec/m^3	7 x 10^{-3} sec/m^3	1.6 x 10^{-3} sec/m^3
Lung Inhalation Dose Conversion Factor	ND	7.46 x 10^{-4} sec/m^3	7.46 x 10^{-4} sec/m^3
Breathing Rate	ND	ND	3.47 x 10^{-4} sec/m^3
Dose	67 mrem	268 mrem	0.6 mrem

ND = No Data

Table 2. Airborne Release Fraction in Study of Commission for the European Communities [5]

Material Type	Airborne Release Fraction on Mechanical Impact	Airborne Release Fraction in Thermal Accident
Gases	1	1(1)
Liquids	5 x 10^{-3}	1
Solids, easily dispersible, e.g. powder, combustible with melting point less than 300ºC	5 x 10^{-3}	1
Solids, not easily dispersible, combustible with melting point greater than 300ºC	5 x 10^{-4}	1 x 10^{-2}
Immobilized solids (non-combustible matrix)	5 x 10^{-6}	1 x 10^{-4}

NOTE: (1) This release fraction of 1 applies to gases and volatile elements.

Table 3. Airborne Release Fraction in USDOE Handbook [11]

	Free-Fall Spill	Impact, shock-vibration	Thermal Stress
Contaminated, Combustible Solids	No significant suspension	1x10^{-3}	Packaged Mixed Waste: 8x10^{-5} Uncontained Cellulosics:5x10^{-4} Uncontained Plastics: 5x10^{-2}
Contaminated, Noncombustible Solids	Most materials will not experience free-fall spill.	1x10^{-3}	6x10^{-3}
HEPA Filters	No applicable experimental data	Enclosed HEPA: 5x10^{-4} Unenclosed HEPA: 1x10^{-2}	1x10^{-4}

Table 4. 10A_2 Values

Type	Activity = 10A_2	Remarks
Mixed beta and gamma emitting fission products	0.2 TBq	A_2＝0.02 TBq
^{60}Co	4 TBq	60Co：0.4 TBq
Corrosion product or “crud” ^{60}Co：^{63}Ni：^{55}Fe＝14:85:1 [12]	260 TBq	A_2＝26 TBq ^{60}Co：0.4TBq, ^{63}Ni：30TBq, ^{55}Fe：40TBq