RISKS OF PLUTONIUM TRANSPORTATION

*A comparative literature survey**

K. TUNABOYLU, W. HUNZINGER, U. TILLESSEN
Motor Columbus Consulting Engineers, Inc.,
Baden, Switzerland

Abstract

RISKS OF PLUTONIUM TRANSPORTATION: A COMPARATIVE LITERATURE SURVEY.

Several risk analyses have been carried out in different countries to answer the questions: what are the risks of plutonium transportations and are they acceptable? Many of them are evaluated thoroughly in the paper and compared with each other, the different boundary conditions of each being taken into account. The main goal of this comparative survey was to estimate the risk of transporting plutonium within the total risk of nuclear energy generation and in comparison with other technical and natural risks. An additional goal was to work out the difference – if any – between the transportation risks of the two chemical forms (Pu oxide power and Pu nitrate solution). The most important results of this study are: (1) the potential risk of Pu transportation is less than 0.1% of the total risk associated with nuclear energy production with Pu recycling; (2) the chemical form of Pu has no significant influence on transportation risks; (3) the use of large transport containers for Pu nitrate solutions does not increase the transport risks; there are even several advantages; (4) the transport mode (rail or road) does not influence the transportation risks significantly; (5) risks of Pu transportation are several orders of magnitude lower than many other natural or technical risks and therefore can be considered to be acceptable.

1. INTRODUCTION AND BOUNDARY CONDITIONS

In the following study only the potential radiological risks of a possible accident during a plutonium (Pu) transport are examined. The potential gamma exposure of personnel and population during normal transportation (without accidents) is not considered. Also, the radiation exposure during remedial actions at the location of an accident has not been evaluated in the present study.

In several countries (such as the USA, the Federal Republic of Germany (FRG), the United Kingdom (UK), France (F)) and also in the European Community (EC) the risks of Pu transportation have been investigated according to the boundary conditions prevailing in each country concerned. The risks have been evaluated, together with their dependence on the chemical forms of Pu (solid

* This study was sponsored by the Federal Ministry for Research and Technology (BMFT), Bonn, Federal Republic of Germany and carried out in collaboration with MC Energy Consult, Stuttgart, Federal Republic of Germany.

as Pu oxide powder or liquid as Pu nitrate solutions) and the transport mode (road or rail). Air transport has not been evaluated in the present study.

Many of the studies reviewed date back as far as 1974, so that only transport containers of older types (satisfying the 1973 Revised Edition of the IAEA Transport Regulations [1]) have been taken into account.

2. METHODOLOGY FOR THE RISK ANALYSES

The probabilistic risk analysis method is necessary to evaluate the safety status of the components of a transport system, consisting of the transport containers, the transport mode, the traffic network involved, and the meteorological and demographic parameters along the traffic network. They are based on definitions of risk as proposed by Farmer [2] for the safety evaluation of nuclear systems. The Farmer methodology has been developed and was applied to NPPs by Rasmussen [3], who considered all possible event combinations that potentially could lead to an accident with radiological consequences on the environment and population.

In 1974, the Battelle Pacific Northwest Laboratories (BNWL) in the USA [4] further refined the Rasmussen methodology and adapted it to waste treatment and management systems. This method could also be applied to the analysis of the transport of radioactive material [5–7]. The risk analysis method of BNWL starts by identifying non-desirable accidental events and then identifies all possible event combinations that may lead to these accidents by using the 'fault-tree' method (deductive) instead of starting from the use of initiating events in 'event-tree' methods (inductive). Also, the probabilities of single events that lead to accidents with radiological consequences have been derived by using the 'fault-tree' methodology.

The most significant advantage of this method consists in its completeness. All later risk analyses concerning radioactive material transportations have used this BNWL method [5]. Therefore, all risk analyses which have been evaluated in the present study have been compared systematically on the basis of the BNWL method.

3. EVALUATION AND COMPARISON OF RISK ANALYSES FOR PLUTONIUM TRANSPORTATION

After a complete literature survey of risk analyses concerning plutonium transportation [8, 9], the most significant and representative studies up to mid-1984 (deadline for submission of this study to BMFT) for several countries with nuclear energy generation and Pu recycling programmes have been selected for a more detailed evaluation and comparison. These studies concerning the

risk of Pu transportation in both chemical forms (oxide and nitrate) are summarized with their main characteristics in Tables I and II. In all these risk analyses only the risks of Pu transportation on the road have been investigated. The risks of rail transportation of Pu have been studied by BNWL only [7]. A comparison of the results of both BNWL studies for Pu transportation by road [5] and by train [7] showed that there are no significant differences between the two [18]. Worldwide the majority of studies have been carried out for the transport mode 'road'. Therefore, attention has been concentrated in the present study on the risk analyses of Pu transportation by road.

Not all of these risk analyses have been carried out to the same depth and the results were not easily comparable. Also, some intermediate data required to evaluate important aspects such as radiological consequences were missing. Therefore it was necessary as a first step to evaluate all available data and to bring them to a common base from which it was possible to make comparisons. The main aspects of risk analyses for Pu transportation by road are evaluated, discussed and briefly summarized below.

3.1. Release of plutonium

3.1.1. Basic data for the analyses

Transport distances: In the French study CEPN-49 [12] and in the CEC report [11] the distances are not defined. For further evaluation the transport distance has been assumed to be 600 km, taking into account European conditions. This assumption has an uncertainty factor of 2, which is not significant for risk calculations.

Transport containers: With the exception of French [12] and British studies [13, 14] the majority of risk analyses considered the older generation of transport containers (Type 6M for Pu oxide powder and L-10 for Pu nitrate solutions). For these containers experimental tests have been made [19] to define the failure limits for each barrier (inner and outer containers, sample cans, heat insulation materials, etc.). In the case of French containers FS-47, FS-51/52 (for Pu oxide), British containers UK-250 (for Pu nitrate), Federal German containers GWK-Pu and 188 (for Pu nitrate), which represent the new generation of transport containers, there have been some experimental investigations. These show that the resistance of these containers to mechanical and/or thermal impact has been improved considerably in comparison with the older generation [20]. All these new containers are licensed in the relevant countries (F, UK, FRG and EC) according to IAEA Transport Regulations [1]. Some of them meet even the improved requirements of the revised edition of the IAEA Transport Regulations (1985) such as FS-51 for Pu oxide and 18B for Pu nitrate.

TABLE I. SUMMARY OF BASIC DATA AND RELEASE FREQUENCIES OF SEVERAL RISK ANALYSES FOR Pu TRANSPORTATION BY ROAD (ROUNDED VALUES)

	Plutonium oxide				Plutonium nitrate		
Studies / Parameters	– USA – (BNWL-1846) [5]	–FRG – (Battelle) [10]	– CEC – (EUR-6938) [11]	– F – (CEPN-49) [12]	– USA – (BNWL-1846) [13]	– CEC – (EUR-6938) [11]	– UK – (SRD-R-187) [13, 14]
Transport distance (km)	2400	400	600	(600) (a)	2400	(600) (a)	50
Pu amount per transport (kg)	100	100	240	~100	100	54	2 X 100
Transport container type	6 M	6 M-2	6 M-5	FS-51	L-10	GWK-Pu	UK-250
Dominant release scenario	puncture	puncture	puncture	mech. forces or criticality (c)	mech. forces and fire (b)	puncture and fire (b)	mech. forces (c)
Released portion of container inventory (g)	0.5 1275	1.0 2000	1.0 2200	(1.0) 2650	1.0 2000	1.0 2000	(1.0)
Airborne fraction of released portion	0.1/128 g 1600 Ci	0.1/200 g 2600 Ci	(0.1/220 g) (3300 Ci)	(0.1/265 g) 23 000 Ci	1.0 23 000 Ci	1.0 30 000 Ci	1.E-4/10 g 50 Ci
Accident frequency (km^{-1})	1.55.E-6	1.65.E-6 (0.92.E-6) (f)	3.52.E-6	0.9.E-6	1.55.E-6	3.52.E-6	
Release frequency per accident	9.E-5	3.E-5	9.E-5	1.E-4	(5.E-6) (d) (5.E-8) (g)	3.E-6 (3.E-8) (g)	

Parameters \ Studies	Plutonium oxide				Plutonium nitrate		
	– USA – (BNWL-1846) [5]	–FRG – (Battelle) [10]	– CEC – (EUR-6938) [11]	– F – (CEPN-49) [12]	– USA – (BNWL-1846) [5]	– CEC – (EUR-6938) [11]	– UK – (SRD-R-187) [13, 14]
Release frequency (km^{-1})	1.E-10 (2.E-10) (e)	5.E-11	3.E-10	1.E-10	(8.E-12) (d) (8.E-14) (g)	1.E-11 (2.E-13) (g)	2.E-9
Release frequency (GW(e)·a)	8.E-7	5.E-8	2.E-7	2.E-7	(5.E-8) (d) (5.E-10) (g)	3.E-8 (4.E-10) (g)	1.E-7

1 Ci = 37 GBq

USA: United States of America, FRG: Federal Republic of Germany, F: France, GB: Great Britain, CEC: Commission of the European Communities

( ): Values in brackets are either analogously derived figures for data which are lacking from other studies or values calculated by the present authors

(a) The transport distance is not given, therefore the same distance is used as in Ref. [12]

(b) Loss of heat insulation by mechanical forces and fire load on the inner container

(c) The mechanical forces are not described in detail, very likely it is crush

(d) Recalculated value (see Section 4.2)

(e) EPRI (USA) Study [15]

(f) According to PSE study 1985 [16]

(g) Under the assumption that the heat insulation does not fail (through better design and better heat insulation of the container)

TABLE II. SUMMARY OF BOUNDARY CONDITIONS AND RESULTS (CONSEQUENCES AND RISKS) OF RISK ANALYSES FOR Pu TRANSPORTATION BY ROAD (INHALATION AS EXPOSURE PATH WITH AN INTEGRATION TIME OF 50 YEARS OF INTERNAL EXPOSURE FOR LATENT CANCER FATALITIES OR 1 YEAR FOR SOMATIC FATALITIES (EARLY LETHALITY))

	Plutonium oxide				Plutonium nitrate		
Studies / Parameters	– USA – (BNWL-1846) [5]	–FRG – (Battelle) [12]	– CEC – (EUR-6938) [11]	– F – (CEPN-49) [12]	– USA – (BNWL-1846) [5]	– CEC – (EUR-6938) [11]	– UK – (SRD-R-187) [13, 14]
Release and exposure time (h)	<24	<24	<24	<24	<24	<24	<24
Release height and distance from the place of the release (m)	0–1 >100 m	0–1 0–25 km	0–1	0–1 0–10 km	0–1 >100 m	0–1	0–1 >500 m
Atmospheric stability classes and wind speed (m/s)	PASQUIL; B, D, E, F 1, 3, 5, 7, 10, 18	KLUG; I-V 1–10	KLUG; I (PASQUIL: F) (c)	DOURY	PASQUIL; B, D, E, F	KLUG; I PASQUIL: F	PASQUIL; F
Type of consequences (early or late fatalities)	late	early	late	early and late	late	late	late
Dose limits (road) for somatic fatalities (ref. organ: lung)		>6000: 100% 3000 –6000: 50%		>6000			
No. of exposed persons (km^{-2})	35 approx.	100–7000 (a)		500			
No. of early fatalities	not given	1–100 (b)	not given	>10	not given	not given	not given

Parameters \ Studies	Plutonium oxide				Plutonium nitrate		
	– USA – (BNWL-1846) [5]	–FRG – (Battelle) [12]	– CEC – (EUR-6938) [11]	– F – (CEPN-49) [12]	– USA – (BNWL-1846) [5]	– CEC – (EUR-6938) [11]	– UK – (SRD-R-187) [13, 14]
Collective doses (man·rem)	2.E.5 (2.E-4) (g)			1.4.E-6	2.E-5		1.E-5
Frequency of late fatalities/transport	3.E-8		5.E-8	6.E-8	8.E-7 (2.E-9) (d) (2.E-11) (f)	(2.E-9) (e)	1.E-8
Frequency of late fatalities/(GW(e)·a)	7.E-8		5.E-8 (c)	4.E-8	2.E-6 (5.E-9) (d) (5.E-11) (f)	(8.E-9) (e)	2.E-8
Risk man·rem/GW(e)·a	0.01 (0.001) (g)		<0.01 (c)	0.05	0.3 (0.01) (d) [<0.01] (f)	0.3	0.01

1 rem = 10^{-2} Sv

(a) Real population densities along the transport routes have been investigated in this study

(b) The extent and frequency of early fatalities are defined according to the corresponding transport routes

(c) Calculated using Ref. [17]

(d) Recalculated value (see Section 3.2)

(e) An approximate value (not given in original ref.)

(f) Under assumption that the heat insulation does not fail

(g) For an airborne fraction of 0.01 of Pu oxide powder [15] instead of conservative value 0.1 used in this table

Release scenarios: Containment puncture is defined as the dominant scenario for Pu oxide release in the US [5] and in FRG studies [10]. In the case of the French study [12] the mechanical failure scenario is not defined very clearly, but is very likely crush. Also, formation of a critical assembly of Pu containers has been assumed as a potential consequence of an accident under certain circumstances (such as for a van speed of >124 km/h). For Pu nitrate transport a combination of mechanical forces and fire load has been considered as the dominant scenario for release in the US and in CEC studies [12], whereas in the British studies [13, 14] the fire load has been assessed to be two orders of magnitude less likely than mechanical destruction (crush) of the big transport containers UK-250.

Release amounts and airborne fractions: Only the airborne fraction of the released amount of the total Pu inventory in a container is of importance for assessment of radiological consequences. In nearly all risk analyses represented in Table I the total Pu inventory has been assumed to be released after the accident (an exception is the BNWL study [5] where the amount is 1/2 of the inventory). Only 1/10 of the released portion of the Pu has been considered to be airborne within 24 h after a transport accident. These are of course conservative worst case assumptions. In reality (according to experimental experience) the airborne fraction is less [15].

3.1.2. Accident frequencies and release frequencies

Accident frequencies per kilometre can easily be determined in each country from police statistics of traffic accidents. There is a surprising similarity between the data in Table I. The uncertainty of about a factor of 3 for European conditions seems to be quite low.

Release frequencies can be calculated from the accident frequencies considered during accident scenarios. Through comparison of mechanical forces prevailing during an accident and failure limits of different barriers of a container during tests (such as IAEA recommended tests), it is possible to work out the **failure frequencies** of single barriers (outer container, inner container, sample can and thermal insulator) per accident. There is a good conformity between the failure probabilities of single barriers in several risk studies [5, 10, 11]. This can be attributed to the fact that later studies have taken over the frequencies of basic events (failure of single barriers) in the 'fault-tree' from the initiating BNWL study [5]. In the case of the French study with criticality as the release scenario [12] and the British risk assessment with crushing as the significant release mechanism [13, 14] the calculations of failure frequencies are independent of the BNWL study. Using the failure frequencies of single barriers the release probabilities per accident and finally per transport can be calculated (see Table I).

3.2. Consequences of Pu release and risks of Pu transportation

Boundary conditions for the estimation of radiological consequences and corresponding risks are summarized in Table II.

The average height of the potential release after an accident is assumed to be 0–1 m above the ground, which is very conservative, especially for the release of Pu nitrate under fire load.

Only the Federal German study [10] considers the real meteorological conditions along the chosen transport routes. All other risk analyses used averaged values, which are weighted over a year with corresponding frequencies for atmospheric stability characteristics and wind speeds.

Also, the demographic characteristics along the transport routes are averaged and weighted values for all studies with the exception of the Federal German risk assessment [10], for which real population densities along exactly defined transport routes have been used.

3.2.1. Radiological consequences and their corresponding frequencies

For both early (somatic) and late (latent cancer) fatalities inhalation has been assumed to be the dominant exposure path with <24 h exposure time. For the calculation of radiological doses an integration time of 1 year for early and 50 years for late (stochastic) fatalities has been used.

Only in Federal German [10] and French [12] risk assessments are early fatalities estimated using individual personal doses (rem). In all studies with the exception of the Federal German study the number of late fatalities has been determined using collective doses (man·rem) and cancer risk factors (5.E-5 rem^{-1} for USA, 1.E-4 rem^{-1} for ICRP and 2.E-4 rem^{-1} for France).

As can be seen from Table II, there is a remarkable conformity between the frequencies of the late radiological consequences per gigawatt (electrical)-year for Pu oxide transportation. This could be explained partially by the mutual compensation of the contrary effects of some parameters such as transport distance, gigawatt-year and population density in the USA and Europe.

The corresponding frequencies for Pu nitrate transportation are not very consistent with each other. Therefore, a recalculation of these frequencies has been performed by using the original frequencies in each risk study for all basic events that lead together to an accident with Pu release and taking into account the probability of radiological consequences. The results of this calculation are given in brackets in Table II with corresponding comments.

The new elaborated frequencies for late radiological consequences of potential accidents during Pu nitrate transportation are about one order of magnitude lower than the analogous values for Pu oxide. This can be explained by a 10 times higher airborne fraction and by a 100 times lower probability

for the release of Pu nitrate in the fire scenario with a loss of thermal isolation. The release frequency and consequently the probability of late fatalities would be reduced by one or more orders of magnitude by using improved transport containers for Pu nitrate with better thermal insulation and mechanical stability (such as the 18B container).

3.2.2. Risks of Pu transportation

To have a common base for comparison of the results of several risk studies it was decided to use the reference unit (man·rem/GW(e)·a) for collective radiological risks, for a quantity of Pu equal to that produced in an NPP of 1 GW(e). It is assumed that this amount will be recycled completely and therefore transported between reprocessing and fuel fabrication (MOX fuel) plants.

As can be seen in Table II (last line) the collective risk for Pu transportation amounts to 0.01–0.3 man·rem/GW(e)·a, whereas for Pu nitrate transportation 0.3 man·rem/GW(e)·a represents the conservative upper limit. After correction of the probabilities for the release and its radiological consequences the collective risk of Pu nitrate transportation has been reduced to 0.01 man·rem/GW(e)·a. Even this figure could be reduced to lower values using improved transport containers such as the 18B instead of the old version L-10 that has been considered. A similar reduction of risks for Pu oxide transportation could also be expected by using an improved container design such as FS-51. Both transport containers (FS-51 and 18B) fulfil the new IAEA design requirements and are licensed.

If the cumulative uncertainty of the collective risks is now set conservatively to be ±2 orders of magnitude, a maximum value of around 1 man·rem/GW(e)·a can be expected for the collective risks of Pu transportation, independent of the chemical form of plutonium.

A comparison of this risk for Pu transportation with the total collective radiological risk from nuclear energy production (with a total planned capacity of 25 GW(e)) in the Federal Republic of Germany [21] shows clearly[1] that the collective risk of Pu transportation contributes less than 0.1% to the total risk of nuclear energy production with Pu recycling. This result is confirmed by a US-EPRI risk assessment [15], in which the contribution of Pu transportation is even less (~0.01% of the total collective risk of nuclear energy production).

Parallel to the present study the risks of transportation of mixed oxide powder [2] (MOX powder) by train or by road have been evaluated thoroughly using real transport routes in the Federal Republic of Germany [16]. The work was completed at the end of 1984 and therefore could not be considered in this comparative survey of work up to mid-1984. However, a cross-check of the results from the two studies now shows a very good agreement between them.

---

[1] The total collective risk for a nuclear programme with 25 nuclear power plants (~25 GW(e) installed capacity) is: 6.6×10^4 man·rem/a.

[2] Includes up to 40–45 wt% Pu oxide.

According to PSE [16, Vol. 8], the collective radiological risk for MOX transport by road is 0.09 man·rem/14 GW(e)·a (or 0.0064 ≈ 0.01 man·rem/GW(e)·a). For rail transport the same risk is about half that from road transport.

4. CONCLUSIONS

Several risk analyses performed worldwide since 1975 show that the potential risks of Pu transportation in both chemical forms (oxide or nitrate) or as MOX powder are less than 0.1% of the total collective risk of nuclear energy generation with Pu recycling and can therefore be considered as negligible.

The chemical form of Pu has practically no significant influence on transportation risks. Despite this fact, the transport of Pu as nitrate solution may have some advantages. It allows easier handling both for transportation and MOX fuel fabrication, e.g. easier ^{241}Am separation after long storage periods.

The use of large transport containers for Pu nitrate solutions does not decrease transport risks; there are even several advantages such as:

- reduction of the transport frequency by increasing the net transport weight for Pu per container
- reduction of fire load as a result of much higher heat capacity of the armoured outer container
- reduction of the potential risk for diversion (better physical protection)
- easier handling due to a smaller number of operational steps.

The transport mode (rail or road) does not influence transportation risks significantly. Rail transportation has a slightly lower risk than road by a factor of about 2–3 for the same amount of Pu [7, 16, 17]. But this difference cannot be distinguished within the uncertainty limits of such risk analyses. Road transport has the advantage of greater flexibility in selecting more suitable routes. Also, the diversion risks for Pu can be kept lower by road transportation.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Materials – 1973 Revised Edition, Safety Series No. 6, IAEA, Vienna (1979).

[2] FARMER, F.R., Reactor safety and siting: a proposed risk criterion, Nucl. Saf. 8 (1967) 539.

[3] RASMUSSEN, C., Reactor Safety Study, Rep. WASH-1400, USAEC, Washington, DC (1974).

[4] SMITH, T.H., et al., A Methodology for Risk Analysis of Nuclear Waste Management Systems, Rep. BNWL-SA-4899, Battelle Pacific Northwest Labs, Richland, WA (1974); CLARKE, R.K., et al., Severities of Transportation Accidents; Motor Carriers, Rep. SLA-74-0001, Sandia Natl Labs, Albuquerque, NM (1974).

[5] McSWEENEY, T.I., HALL, R.J., et al., An Assessment of Risk of Transporting Plutonium Oxide and Liquid Plutonium Nitrate by Truck, Rep. BNWL-1846, Battelle Pacific Northwest Labs, Richland, WA (1975).

[6] SMITH, T.H., et al., A Risk Based Fault Tree Analysis Method for Identification, Preliminary Evaluation and Screening of Potential Accidental Release Sequences in Nuclear Fuel Cycle Operation, Rep. BNWL-1959, Battelle Pacific Northwest Labs, Richland, WA (1976).

[7] DAVIS, D.K., et al., An Assessment of the Risk of Transporting Plutonium Dioxide and Liquid Plutonium Nitrate by Train, Rep. BNWL-1996, Battelle Pacific Northwest Labs, Richland, WA (1977).

[8] POLKE, H., SPINDLER, H., Risikoorientierte Untersuchungen für die Stationen des nuklearen Brennstoffkreislaufs, Rep. GRS-A-873, Gesellschaft für Reaktorsicherheit, Cologne (1983).

[9] Packaging and Transportation of Radioactive Materials, Proceedings of International Symposia: Miami Beach, 1974, Union Carbide Corp., Nuclear Div., Oak Ridge, TN (1975); Las Vegas, 1978, Sandia Natl Labs, Albuquerque, NM (1978); Berlin West, 1980, Bundesanstalt für Materialprüfung, Berlin (West) (1980); New Orleans, 1983, Oak Ridge Natl Lab., Oak Ridge, TN (1983).

[10] HARTWIG, S., et al., Schwachstellen und Risikoabschätzung beim Transport radioaktiver Materialen; Bericht für BMI, Rep. BF-R.62891-1/2 (Vol. 2: Revision 1981), Battelle-Institut, Frankfurt am Main (1978/1979).

[11] ANSPACH, W., SCHNEIDER, K., Environmental Impact of Plutonium Transportation in the Event of Accidents – Estimation of Potential Releases, Rep. EUR-6938 EN, Commission of the European Communities, Brussels (1980).

[12] HUBERT, P., PAGES, P., Risk Analysis of the Transportation of Plutonium Dioxide, Rep. CEPN-49, Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire, Fontenay-aux-Roses (1981).

[13] LOCKE, J.H., et al., The Transport of Plutonium in the Form of Nitrate Solution between Dounreay and Windscale: A Safety Assessment by the Nuclear Installations Inspectorate, Rep. NII-R/39/78, Health and Safety Executive, London (1978).

[14] CHICKEN, J.C., Summary of the Risk Assessment Mode of the Transportation of Plutonium Nitrate, Rep. SRD-R-187, UKAEA Safety and Reliability Directorate, Culcheth (1980).

[15] ERDMANN, R.C., et al., Status Report on the ERPI Fuel Cycle Accident Risk Assessment, Rep. EPRI-NP-1128, Electric Power Research Inst., Palo Alto, CA (1979).

[16] Projekt Sicherheitsstudien Entsorgung (PSE), Vols 7 and 8, Hahn Meitner Institute, Berlin (West) (1985).

[17] A Plutonium Recycling Scenario in Light Water Reactors: Assessment of the Environmental Impact in the European Community, Rep. EUR-7768 (1982).

[18] RHOADS, R.E., JOHNSON, J.F., Risks in transporting materials for various energy industries, Nucl. Saf. **19** (2) (1978) 135.

[19] MISHIMA, J., et al., Release of Pu from Heating Plutonium Nitrate, Rep. BNWL-931 (1968); Release of Pu from Heating Pu Oxide Powder, Rep. BNWL-786 (1968); and Some Experimental Measurements of Airborne Uranium (Representing Plutonium) in Transportation Accidents, Rep. BNWL-1732, Battelle Pacific Northwest Labs (1973).

[20] YOSHIMURA, H.R., et al., "Extended testing of modified plutonium nitrate shipping container", PATRAM 80 (Proc. 6th Int. Symp. Berlin (West), 1980), Bundesanstalt für Materialprüfung, Berlin (West) (1980) 1230.

[21] FEDERAL REPUBLIC OF GERMANY, Ministry for Research and Technology, German Risk Study for Nuclear Power Plants, TÜV Rheinland, Cologne (1981).