THE CASE OF A LOSS OF VHLW CARGO AT SEA: TOWARDS A RISK ANALYSIS PERSPECTIVE

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Recently, the sea transport of vitrified high level radioactive waste (VHLW) between Europe and Japan has been a subject of public concern. Some anxiety and strong request for more information has been expressed by several en-route states, especially with respect to hypothetical accidents along the coasts, that might result in significant consequences. Namely, the safety of such shipments was questioned by state representatives, journalists and academists.

Although several factors have to be considered at the root of the public concern, the two of them addressed here are closely connected with the available scientific knowledge supporting the safety assessment of such industrial operations and with the way to inform the public of this knowledge. Namely, the public perception of risks may be twisted by :

- *catastrophic presentation of the safety case* ; a "worst case" scenario, well beyond design basis, can always be imagined without any consideration of probability : for instance ship collisions with consequent hypothetical waste immersion and huge dispersion of radionuclides into the sea ;

- *apparent or overemphasized discrepancies between published results* from different sources, that might suggest poor knowledge of the involved phenomena : for instance, between published evaluations of the potential impact of radionuclides associated with the dispersion into the sea.

Both sources of potential public distrust call for a well balanced and extended elaboration of scenarios, displaying the intervening features, events and processes, that will clarify the real significance of extreme hypothetical scenarios (i) and of residual scientific uncertainties (ii). In this perspective, it seems helpful to apply extended risk analysis approach and particularly to put into perspective the influence of the various assumptions adopted in the analysis of scenarios.

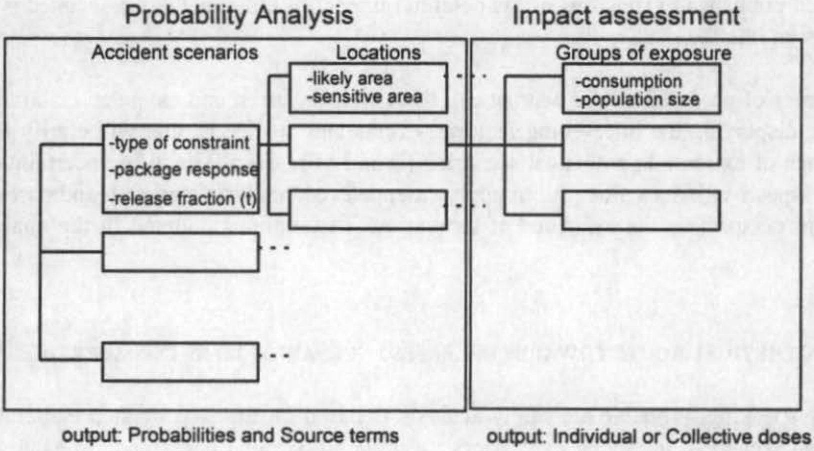
THE HYPOTHETICAL ROUTE TOWARDS RELEASES : SCENARIOS TO BE CONSIDERED

Generally speaking, probabilistic safety analysis is based on the step by step elaboration of conditional scenarios, involving event trees ; a probability value is assigned to each step. A given complete scenario leads to definite consequences, evaluated for instance as a collective dose to the public. The corresponding probability is obtained as the product of stepwise conditional probabilities. This approach brings several benefits ; let us mention

- the systematic investigation and accurate description of all possible series of events, out of which the most pertinent can be selected for the assessment of consequences,
- a consistent framework encouraging risk quantification as far as possible,
- the final presentation of all scenarios on a probability/consequences diagram, providing a unified perspective and a useful decision tool in relationship with a predetermined domain of risk acceptability.

It is beyond the scope of this work to estimate the overall probability of a series of events causing the breach of containment and the release of radionuclides from the glass canisters. This question has been investigated by SANDIA National Laboratories (1) and is currently thoroughly investigated within a IAEA coordinated research program. Here, the discussion will be restricted to the tree of events following an assumed serious ship collision, including ship wreckage and transport cask sinking into seawater.

Accident scenarios are defined, from the one hand, by the type of accident (fire, collision, etc.) harmful enough to breech the package and to lead to a radioactive release with respect to the features of the ship devoted to the transport of RAM, and, from the other hand, by the location of the accidental event. Risk analysis related to marine transport of radioactive material is based on the evaluation of the frequency of occurrence of any realistic scenario combined with the set of individual and collective exposures. The first part of the risk analysis is devoted to the identification and the quantification (frequency and source term) according to their location, of accidental events. Release locations must be selected according to their likelyhood and to the sensitivity of the affected area (high population density, fishing practices,…). The second part consists in assessing the impacts associated with these scenarios. In the scope of marine contamination, the radiological exposure depends on the dietary habits in terms of the quantities consumed and their provenance as well as the dispersion processes and location of the release. The following figure illustrates the major steps of a risk assessment study.



One crucial assumption regards the cask integrity or failure after sinking. This assumption will govern the rate of release of radionuclides into the sea. Three alternate situations can be envisaged :

- The cask has not lost its integrity after collision and after sinking down to the coastal sea bottom ; the double O-ring seal resistance under 200 meter depth of water makes it possible.
- The only failure comes from leakage through the O-ring seal, at a low rate.
- The kinetic energy in ship collision is sufficient to breach the cask, so that seawater will rapidly invade the internal cavity.

There will be no release in the first case. In the other two cases the seawater will come into contact with glass canister ; after corrosion of the stainless steel envelope, it will start leaching of glass and will dissolve part of the radionuclide content. But the rate of release will widely differ between the second and the third case. In the second case, the thin gap between the O-ring and the cask body will only allow diffusion and natural convection to take place, limiting the rate of release outside the cask. Seawater inside the cavity will become saturated with radionuclides and the effective rate of dissolution will be substantially decreased. In the third case on the other hand, continuous circulation and renewal of seawater at the surface of glass will be possible, with practically no mass transfer resistance imposed by the cask itself.

Overall, even assuming the same chemical rate of leaching at the surface of glass, the actual rate of release *out of the cask* will be quite different between ii) and iii).

Another key assumption is the real place where the waste will have sunk, determining the local hydrodynamics for the dispersion of released radionuclides.

Finally, since a cask sunk on a continental shelf can be located and recovered, the total released quantity of radioactivity will be determined by the assumed timelength until the recovery of the package is achieved.

PUBLISHED EVALUATIONS : A VARIETY OF SCENARIOS

Illustration of the variety of scenario assumptions can be drawn from published studies (2), (3), (4), (5), all related to the sea release of radionuclides from vitrified high level waste in case of immersion.

- R.D. KLETT (2) considered the wreckage of a ship carrying vitrified HLW in the North American coastal waters, resulting in cask sinking onto sea bottom, 100 meter deep. He examined the release from one canister, by seawater circulation in the cask and glass leaching at constant rate. The assumed rate of glass leaching was not specified, but an overall fractional release of 0.001 per year was indicated. As examples, the rates of release calculated for the first year were :

  ⇒ Cs 137 = 4.9 TBq/year
  ⇒ Am 241 = 0.19 TBq/year
  ⇒ Cm 244 = 0.47 TBq/year

- OECD/NEA report on the subseabed HLW disposal project (3) considered a similar situation, but with different glass canister contents. The HLW canisters on board were contained in thick mild steel penetrators for disposal through seabed sediments. The assumed rate of glass leaching was 0.036 g/sq.m/d. The resulting estimated rates of release were :

  ⇒ Cs 137 = 2.3 TBq/year
  ⇒ Am 241 = 0.05 TBq/year
  ⇒ Cm 244 = 0.02 TBq/year

- A more recent study by CRIEPI (4) referred to a wreckage along the east coast of Japan, with a cask sunk 200 meter deep under water and 7 km away from the coast. As a main difference from the two previously mentioned studies, the assumed containment failure was limited to the seal damage, producing a 0.01 millimeter gap. This assumption is justified by the design of the TN 28 VT cask, complying with IAEA regulatory specifications ; one would have to imagine completely non credible situations to admit the breach of the cask : not only collision with huge kinetic energy, but also projection and crush of the cask against a stiff solid. Consequently, as explained previously, the calculated rates of releases to the sea were quite small, even though the assumed rate of glass leaching (2 g/sq. m/d) was relatively high :

  ⇒ Cs 137 = 0.0763 TBq/year
  ⇒ Am 241 = 0.000126 TBq/year
  ⇒ Cm 244 = 0.00112 TBq/year

- S.P. NIELSEN (5) did not indicate waste immersion scenario assumptions but only studied the consequences of a unit release of each radionuclide (1 TBq/year) in the European coastal waters, 20 meter deep.

Taking the example of Cs 137, it can be seen that the estimated rate of release varies from 0.076 to 4.9 TBq per year according to the author, that is depending on the assumed scenario. Clearly, the published evaluations of impacts from such accidental releases should be compared on the basis of unit quantities of release out of the cask, rather than out of the glass matrix itself. Otherwise, confusion would come from the assumed behaviour of intermediate containment barriers, i.e. the canister steel envelope and the cask.

IMPACT ASSESSMENT

For a given rate of release, the analysis of how much varying assumptions influence the evaluated impacts in the literature is rendered difficult, since detailed characteristics of the dispersion model are not always provided. The analysis presented here relies on a unique model.

The POSEIDON computer code [6] is designed to assess the collective and individual doses associated with a radiological release in European seawaters. Since risk assessment analyses are mainly focused on individual exposure, this indicator was retained and its variations among different groups of population were analysed. Using POSEIDON, an illustration of the wide range of exposures that can be observed is presented hereafter, assuming a unit release (1TBq over 1 year) of Cs-137 in West Channel.

A reference group of population is characterised by its consumption of fish, crustaceans, molluscs and seaweed, and by the provenance of these foodstuffs. For each release point, realistic population groups of sufficient size shall be defined. Several examples of reference groups and their characterisitics are presented on Table 1.

It is important to point out that other reference groups were retained in other studies according to the location of the release and characteristics of people living nearby. For instance, the CRIEPI (4) considers a fish consumption of 73 kg/year which reflects the Japanese dietary habits.

Table 1. Characteristics of the population groups and their size

Reference group Individual consumption (kg/year)	Average European	Average French	IAEA 66 reference man *	Fisherman
Fish	10.5	8.4	110	15
Crustacean	0.5	4	36.5	5
Mollusc	2	4.6	36.5	5
Seaweed	0.1	0.4	36.5	0
Fishing compartment	All concerned compartments of the model	All concerned compartments of the model	English Channel West	English Channel West
Population of concern	Few 10 millions	Few 10 millions	Few people	Few hundreds

* values selected to cover critical groups in all areas of the world according to current known dietary habits

Furthermore, it should be noted that the impact assessment is affected by the uncertainty on some biological parameters. In this respect, the distribution factor (modelling the interaction between water and organisms) can vary according to the location, specie or season. Thus, a sensitivity analysis was performed on distribution factors for which a wide range of values exists, as shown on Table 2 (Kd for sea products).

Table 2. Range of Cs-137 Kd published by IAEA (Bq/t/Bq/m^3)

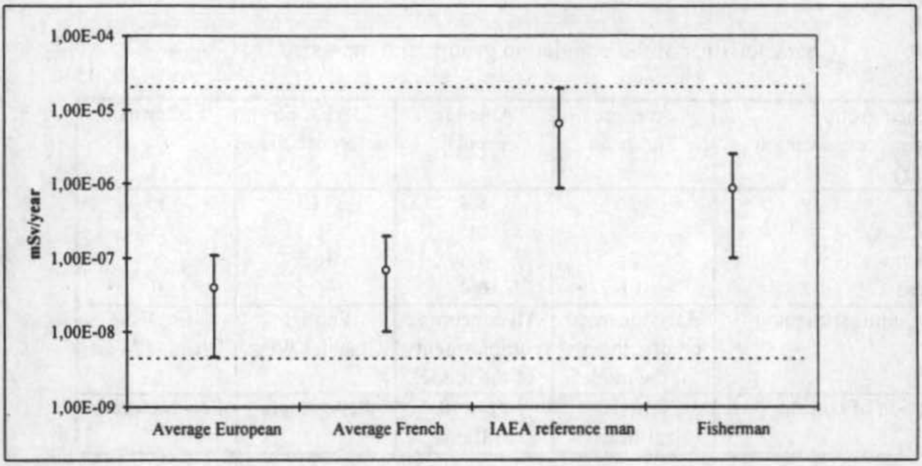
	Min	Max	Reference value
Fish	10	300	100
Crustacean	10	50	30
Mollusc	10	50	30
Seaweed	30	100	50

At this stage, it should be precised that these values are recommended by IAEA, different figures can be used according to the scope of the study. In this regard, Klett (2) considers different values (fishes: 80; Crustaceans: 9000 and Molluscs: 900) in accordance with the local characteristics of the seafood and fishing compartment.

According to the selected reference groups and to the range of distribution factors, the maximum annual individual doses were assessed (Table 3).

Table 3. Variation of the maximum individual dose (mSv/year)
(1 TBq within 1 year of Cs-137)

Reference groups	average	min	max
Average European	$0.4\ 10^{-7}$	$0.048\ 10^{-7}$	$1.1\ 10^{-7}$
Average French	$0.7\ 10^{-7}$	$0.1\ \ 10^{-7}$	$2.0\ 10^{-7}$
IAEA reference man	$65.\ \ 10^{-7}$	$8.8\ \ 10^{-7}$	$190.\ \ 10^{-7}$
Fisherman	$8.7\ 10^{-7}$	$1.0\ \ 10^{-7}$	$25.\ \ 10^{-7}$



The table reveals that the exposures can vary by more than 3 orders of magnitude depending on the reference group of population being observed and, with a lesser influence, from the adopted Kd value.

The objective of this analysis was to point out that major differences in impact assessments can arise depending on the population target being considered. Apparent discrepancies between studies originate from the large set of values that could be reasonably adopted.

A complete risk assessment study should take into account from one side all the realistic events that could lead to a contamination and from the other side all the exposure levels resulting from the release. On a graphical representation, each group of exposure should correspond to a probability -consequence curve. The number of people affected within each group of exposure should also be quoted in order to take into consideration the scale of consequences.

CONCLUSION

The importance of scenario elaboration and quantification for safety assessment has been emphasized and illustrated here. Probabilistic risk assessment brings a useful complement to the deterministic approach by design basis accident. It also means a wider scope. With such an approach, the worst case scenario and exposure will not be neglected, but properly put into perspective according to its likelyhood and extent.

Moreover, the comprehensive and accurate description of scenarios, coupled with quantified risk analysis, can be understood, checked and improved by scientific people from different origins. It will provide the best accepted basis for the selection of really credible and significant scenarios. It is claimed here that publicizing such a process can be the source of reinforced public trust.

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