ASSESSMENT OF THE CONSEQUENCES OF ACCIDENTAL BURIAL INTO SOFT GROUND OF A SPENT FUEL TRANSPORT CONTAINER

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SUMMARY

When it is accidentally buried into soft ground, a spent fuel package can lose its heat dissipation capability, as a result of the gradual drying of the ground into which it is buried. Overheating of sensitive components can result, notably those which contain the radioactivity.

The study focused on the transport of spent fuel by rail in France, taking into account derailment causing a package to fall into a marshy area.

The probability of a derailment, causing a package to fall into a marsh is low but not negligible and therefore, in accordance with the safety principles applied to nuclear activities (the concept of defence in depth), a deterministic study was carried out under upper bound conditions.

The results of thermal calculations indicate that partial sinking into this marsh, of less than half the package, will not induce overheating of the sensitive components and has no noteworthy effect on safety. Thus, action to extract the package, even if protracted, could take place without the use of special cooling facilities.

If, on the other hand, the package sinks completely, it may be necessary to introduce some means of emergency cooling, within a period of not more than two days. Studies are in progress to illustrate that the necessary means can be deployed within this time.

A study of this accident scenario effectively illustrates that the safe transport of radioactive materials depends on the following three factors:

- reliable transport systems, which reduces the probability of accidents,

- the design margins of the packages, which allow sufficient response time,

- the effectiveness and rapidity of the response.

INTRODUCTION

The spent fuel package burial scenario is not unrealistic. In 1987, at Lailly en Val, France, a spent fuel transport container partially sank when the contents of the trailer spilled out, and the package was not recovered until 48 hours later, corresponding to the time needed for the hoisting equipment to arrive on the scene. No radiological effects were observed.

The risk associated with this burial phenomenon arises from the loss of the heat dissipation capability of these packages, which leads to gradual heating of all the components, liable to result in the degradation of sensitive components, such as the sealing rings if they are made of elastomer, or in the melting of the lead, in the case of packages whose protective radiation screens are of lead.

This paper describes the study carried out to assess the risk of spent fuel package burial, the risk of overheating of sensitive components and the steps which have to be taken to guarantee the safety of packages subjected to such an accident scenario [1]. The study includes the assessment of the probability of a fall into marshland and then, taking into account the physical characteristics of the ground selected and the characteristics of the most adverse package, assessment of the depth to which the package sinks and the mechanism by which the temperature of the package components rises. In addition, the emergency measures taken to ensure that the package is maintained in a safe condition, in the event of an accident involving burial, are detailed in a Special Emergency Transport Plan, produced as part of this study.

TRANSPORT ACCIDENT SCENARIO

In view of the extent to which spent fuel is transported by rail in France, the accident scenario considered in this study is train derailment causing a package to fall down into a marsh.

ASSESSMENT METHODS

The general assessment approach consisted of dividing the study into successive phases, for which realistic but comprehensive assumptions were systematically chosen.

The following pessimistic choices were made:

- the package considered was that which had the greatest ground loading, so as to maximise its tendency to sink; the distribution of the load through the vehicle has been ignored; to assess the degree to which the package sinks and heats up, it is assumed to be detached from the vehicle,

- the characteristics of the ground chosen for the sinking assessment correspond to highly compactible peat and silt bog,

- the characteristics of the ground chosen for the heating assessment correspond to dry soil, maximising the thermal insulation characteristics and accelerating package heating, even though this situation is not coherent with the characteristics chosen for the ground to assess sinking.

ACCIDENT PROBABILITIES

The results of 1996 studies carried out by the SNCF [1] indicate that the incidence of derailment of a goods train travelling (in a straight line) at a speed of 30 km/hr or more is 8.6×10^{-9} derailments/truck.km.

Around 300 trucks of spent fuel circulate in France each year and the annual probability of derailment for a truck transporting spent fuel is therefore equal to 2.6×10^{-6} per km. As soon as the length of the marsh exceeds a few kilometres, the probability of derailment is sufficiently high as to justify deterministic assessment of the burial scenario.

To illustrate this probability, crossing a marsh 10 km long corresponds to one derailment every 40,000 years in the marsh, but the probability of a derailment causing a package to fall down into the marsh would be lower.

CHARACTERISTICS OF THE MARSH

The characteristics of the materials used in the model result from samples taken in a marsh considered as typical. These samples show that highly compactible substances (fresh peat and silt) with both a very high organic matter content (30 to 60 % on average) and a very high water content (70 to 90 % on average) are involved. The structure of the marsh selected and the characteristics of the materials are given in Appendix 1.

SPENT FUEL TRANSPORT EQUIPMENT

The French spent fuel packages equipped with a natural cooling system and transported by rail are TN12/1, TN12/2, TN13/1, TN13/2, TN17/2 and LK 100 M. Table 1 indicates the different characteristics of these packages, including the maximum loaded weight and the geometrical dimensions. These six packages are cylindrical and are fitted with two shock-absorbent end covers whose dimensions are slightly less than those of the body of the package. For sinking calculation purposes, they can be considered as cylinders.

The TN 12/2 package exerted the highest ground loading in the horizontal position and a loading in the vertical position which was close to that of the other packages; its thermal power was amongst the highest. For this reason, it was chosen as the upper bound package as regards the sinking risk. The sinking and heat exchange calculations were carried out using the characteristics of TN 12/2B, since this package has a neutron protection which constitutes an additional barrier against heat dissipation.

The thermal energy chosen for the heating calculations was 60 kW, but a higher energy case (76 kW) was also studied.

Special trucks are used to transport these packages; they are all of the Q7 type and are 20.7 metres long. The weight of the unloaded truck is 46.4 tonnes. It is capable of carrying twice the load of standard trucks, since it has 8 axles with 4 bogies, giving it greater stability. The maximum allowable load anywhere on the French rail network is 20 tonnes per axle, or 160 tonnes per truck, at a speed of 100 km/hr. When loaded, this truck weighs between 150 and 160 tonnes.

Table 1: Characteristics of French packages in use in September 1997, for the rail transport of spent fuels

Characteristics of the packages	TN 10/1 or TN 13/1	TN 12/1	TN 12/2	TN 13/2	TN 17/2	LK 100M
Loaded weight [t]	106	100.5	110	113	78.2	107
Cylindrical shape						
Overall length [m]	6.37	5.9	6.15	6.67	6.15	6.8
Overall diameter [m]	2.5	2.5	2.5	2.5	1.95	2.5
Ground pressure in the half-sunk position						
vertical [t/m²]	29	27	29	30	32	22
horizontal [t/m²]	6.7	6.8	7.1	6.8	6.5	6.3
Maximum transported energy(1) [kW]	38	70	64	77	46	55
Mean transported energy(1) [kW]	29	41	30	43	14	31

(1) *This refers to the maximum or mean energy transported by the package over the last three years (1994, 1995, 1996) [1].*

CALCULATIONS OF THE SINKING OF A PACKAGE INTO THE MARSH

Several accident scenarios were chosen. Since the ground pressure of the trucks was slightly less than one third of that of the packages, we assumed, to be conservative, that the package had become detached from the truck. Since it was not easy to model the general case where the package arrived at the surface of the marsh at an inclined angle, only the extreme positions (vertical and horizontal packages) were considered. In addition, three vertical package drop speeds onto the marsh were considered (0 m/sec, 5 m/sec and 10 m/sec), allowing for cases where the railway line is a few metres above the marsh.

The sinking calculations were made in two stages, the first consisting of determining the "initial" sinking due to the drop itself (rapid dynamic effect) and the second for determining the compressive consolidation of the soil, which is a slow effect, due to the draining of water from the soil. The calculations were carried out using elastoplasticity and high distortion values.

In all the drop cases considered, the calculations showed that the package has completely sunk within 15 days of dropping; in certain cases (horizontal position at a speed of 10 m/sec, vertical position at any speed), the package can reach the bottom of the marsh in a few days (when the depth is taken as being 10 m).

PACKAGE HEATING CALCULATIONS

The purpose of the thermal calculations was to evaluate temperature changes within the package containing spent fuel, before steps were taken *in situ* to cool it down.

The first sensitive components to be affected by a rise in temperature were the plug and orifice seals and the spent fuel rods. The Viton seals gradually start to break up from about 300°C. The maximum allowable temperature in the rods during normal transport is 500°C ; at higher temperatures, above 600°C, there is a risk of clad rupture. This phenomenon, which causes a large quantity of radioactive gas to be released into the hollow part of the package, can be tolerated as long as the package remains sealed, which is guaranteed only as long as the temperature of the seals remains below 300°C.

Five different configurations were studied:

- case n°1: package in a state of thermal equilibrium before burial, with a thermal energy of 60 kW,
- case n°2: package in the horizontal position sinks to 0.60 metre, with a thermal energy of 60 kW,
- case n°3: package sinks to 1 metre in the vertical position, plug downwards, with a thermal energy of 60 kW,
- case n°4: package sinks to mid-length at an angle, plug downwards, with a thermal energy of 60 kW,
- case n°5: package sinks completely, in any position, with a thermal energy of 76 kW.

The seal temperature never reaches 300°C in the cases of partial sinking chosen when the energy is limited to 60 kW; it reaches 257°C in case no. 4. In the case of complete sinking, regardless of the energy of the contents, the plug seal temperature always exceeds 300°C, within a minimum period of 46 hours for 76 kW [1]. This period is a direct function of the energy of the contents, as shown by table 2.

Table 2: Period during which seal temperature rises to reach temperature limit as a function of the thermal energy of the spent fuel content (for dry soil at 38°C) [1]

	30 kW	40 kW	50 kW	60 kW	76 kW
Initial temperature of the seal	85°C	94°C	103°C	111°C	125°C
Time taken to reach seal temperature limit	116 hrs	87 hrs	69 hrs	57 hrs	46 hrs

These times are conservative, in that they do not take into account, in particular, the time taken for the layer of moist earth around the package to dry out. In fact, if one considers the water which is present in the space between the package cooling fins (volume of 2 m^3), for peat with, for example, a 28% water content, the weight of the water contained in this volume is 574 kg, and for peat with an 82% water content, the weight of the water is 1682 kg. Between 5 and 13 hours are thus needed for the water to evaporate. Consequently, and in order to determine a reasonable order of magnitude, we shall consider a maximum response time of 48 hours.

In order to ensure the satisfactory resistance of the spent fuel rods in the package, a thermal calculation was carried out to determine the temperature of these rods when the seal temperature reaches 300°C, in the case of complete sinking.

The calculation was carried out for a thermal energy of 76 kW. The energy flow was assumed to be uniformly distributed within the shell. Any heat exchange between the package and the atmosphere was ignored.

The maximum temperature of the rods is 615°C. At this temperature level, there is indeed a risk of clad rupture, but containment is ensured by the sealing rings, as long as their temperature does not exceed 300°C.

RESPONSE PLAN

COGEMA and TRANSNUCLEAIRE are in the process of drawing up a Special Emergency Transport Plan (PPST). Like all Special Plans, it is divided up according to the sequence of events: alert, primary response and response by specialist personnel [2].

This Special Emergency Transport Plan applies to accidents which could take place in a marsh, during the rail transport of spent fuel packages.

This plan describes and structures the actions to be taken by industrialists to bring the package into a safe condition, in particular by setting up a pump for injecting water. Moreover, this plan includes response actions developed by the authorities.

The time taken to give the alert is estimated at 1 hour and the time required to locate the package may stretch to 24 hours, in an unfavourable case of complete sinking. The time to render the package safe, which depends on activation of the water-injection emergency cooling system, should be less than 48 hours in total after the accident. From the moment the package is placed in a safe condition, the freeing, lifting and removal of the package may be carried out without any time constraint. The response plan (PPST) must be rapidly implemented, in order to make the package safe before the package components ensuring containment of the radioactive materials overheat. Exercises are planned to determine these times more accurately.

CONCLUSION

The probability of derailment of a truck transporting spent fuel packages is $2.6.10^{-6}$ derailments/kilometre.year for the transport of 300 packages per year. As an example, crossing a marsh 10 kilometres long corresponds to one derailment every 40,000 years in the marsh but the probability of a descent into the marsh would be lower.

With respect to the depth to which a falling package can sink, several drop scenarios were considered, in a 10 metre-deep marsh consisting of peat and silt. For all the drop cases considered, the calculations show that the package sinks completely within 15 days of dropping; in certain cases, the package can arrive at the bottom of the marsh in a few days.

The first sensitive package components to be affected by limited heat dissipation are the sealing rings.

In the case of a partial sinking, for example, in a shallower or drier area of marshland, sinking of half the package at the most should not cause the sensitive components to overheat, provided that the visible surface is free from any impediment to heat dissipation.

On the other hand, if the package sinks completely, an emergency cooling system has to be implemented. The time available for installing the cooling system, before the package deteriorates, depends on the thermal energy of the package contents, the water content in the soft ground and the ambient temperature.

A response time of not more than two days is compatible with all the cases envisaged and allows the safe condition of the package to be guaranteed. The structure of the special emergency transport plan (PPST) devised for this type of accident should guarantee that the cooling system can be set up within a period of two days.

As soon as the package has been cooled, there is no limit to the time required to hoist and remove it.

With regard to the accidental burial scenario studied, the safe transport of spent fuels depends on:

- reliable rail transport, which renders this type of accident extremely rare,

- design safety margins of the packages, which allow their capacity for heat dissipation to be interrupted for several hours or several days,

- the effectiveness of the response, if an accident takes place.

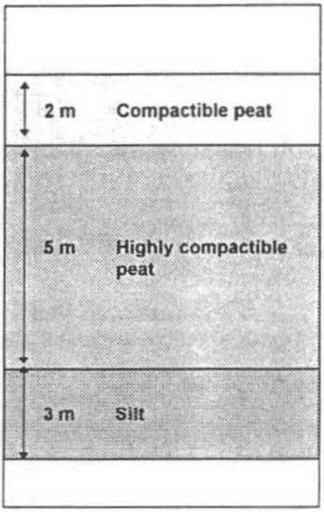
As in the case of any activity involving a nuclear risk, safety depends on the same three factors: reliability of operations, minimisation of risks at the design stage and the response effectiveness.

REFERENCES

1- Assessment of the risk of burial into soft ground of a spent fuel transport container. IPSN report ref. IPSN/DSMR-98/ (to be issued).

2- Memo concerning the production of a specialised departmental emergency plan concerning the internal transportation of radioactive materials. Circular NOR/INT/E/90/00092/C from the Ministry of the Interior, Civil Security Department, 16 March 1990.

APPENDIX 1



CROSS-SECTION OF THE GROUND SELECTED FOR SINKING CALCULATIONS

Soil	E (kPa) Dynamic Young modulus	ν Poisson coefficient	C_{uu} (kPa) Cohesion	φ_{uu} Internal friction angle	ρ (Kg / m³) Voluminal mass of moist soil
Compactible peat	680	0.33	12.5	0.5°	1 120
Highly compactible peat	680	0.33	12.0	3.0°	1 060
Silt	5 000	0.33	16.0	3.0°	1 800

CHARACTERISTICS OF THE GROUND SELECTED FOR SINKING CALCULATIONS