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PRELIMINARY RISK ASSESSMENT FOR THE TRANSPORT OF REACTOR DECOMMISSIONING WASTE IN THE UNITED KINGDOM

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Abstract

PRELIMINARY RISK ASSESSMENT FOR THE TRANSPORT OF REACTOR DECOMMISSIONING WASTE IN THE UK.

It has been decided to decommission the UKAEA Windscale Advanced Gas-cooled Reactor (WAGR) to a 'green field' site to provide information on procedures and costs. This paper describes a risk assessment for the transport to a suitable repository of 200 large concrete packages containing about 700 t of resulting waste material. The packages are cubic with external dimensions a little over 2 m. Prototypes have been drop tested from heights of 0.65 m and 5 m and they sustained insufficient damage to impair the containment and shielding significantly. An impact equivalent to a 15 m drop was calculated to be necessary to expose the package contents. An event tree approach was adopted to determine the frequency of severe mechanical and thermal loading during road and rail transport. Collisions with a second vehicle or fixed object, falls from bridges, serious fires and crane failure during unloading were considered. The frequency of rail accidents sufficiently severe to expose the package contents was calculated to be about 5×10^{-7} per year. The frequency of these severe impacts in conjunction with a serious fire was found to be two orders of magnitude smaller. The package weight would limit the vehicle speed on UK roads and no accident which could expose the package contents was considered plausible. Preliminary calculations indicated that the consequences of a transport accident (increased gamma radiation and dispersion of flammable waste by fire) would be relatively minor. It was concluded that transport risks should not present obstacles to the decommissioning of the WAGR.

1. INTRODUCTION

The Windscale Advanced Gas-cooled Reactor (WAGR) was a graphite-moderated, carbon dioxide cooled, prototype reactor built by the UKAEA at Sellafield on the north-west coast of England. It had an electrical output of about 30 MW and, after 18 years of successful operation, was finally shut down in 1981. Prior to that, it had been decided to decommission the reactor itself (but not the ancillary buildings) to a 'green field' site to provide valuable information on procedures and costs.

The reactor core (graphite with steel supporting structure and restraints) is located inside a steel pressure vessel (protected by an internal thermal shield of steel plate) which, in turn, is located within a thick reinforced concrete biological shield. This, together with four large heat exchangers (also contained within reinforced concrete biological shields) are located within a steel containment.

Nearly 90% of the total mass to be demolished is inactive. About 1800 t has some activity, of which about 700 t will require special disposal, either at sea or by shallow land burial. In either case the waste will require packaging and transporting from the site. The materials to be disposed of consist mainly of mild and stainless steels, reinforced concrete and graphite of which, in terms of mass, mild steel forms the greatest part. The packaging operation is scheduled to commence in about three years' time.

2. WASTE PACKAGES

2.1 Description

The Disposal Box design which was assessed is almost cubic with sides a little over 2 m in length [1]. Five sides of the Box are constructed from reinforced concrete 230 mm thick, clad on the outside with 12 mm mild steel plate. The waste material is packed inside and concrete grout is poured in to fill all the remaining space. The top of the Box is then completed with reinforced concrete and the top steel plate is welded in position. Equipment to cut up remotely the waste material and to carry out the packaging behind shield walls has been designed.

The sides of Boxes containing the more active waste will be constructed from "Super-Shot" (high density) concrete and various combinations of waste materials and concretes give expected total Box weights ranging from 28 to 50 t. The contents of each Box will vary considerably as shown in Table I.

The Box is designed to meet the IAEA requirements for industrial packages carrying LSA III material [2]. The most onerous test it must satisfy is a free drop from 0.3 m onto an unyielding surface with no loss of radioactive contents and no more than a 20% increase in radiation levels. The structure's response to more severe impact loading is of interest to the transport risk analyst, and the full scale tests performed so far are described in the next section.

TABLE I. CONTENTS OF DISPOSAL BOXES

Waste material	Type of shielding O = ordinary concrete S = Super-Shot concrete	Payload (t)	Activity (TBq)
Stainless steel	S	0.7	70–220
Stainless steel and mild steel	S	2.4–11	60–120
Stainless steel and mild steel	O	15	12
Mild steel	S	0.6–15	40–60
Mild steel	O	5–18	0.6–30
Graphite	S	5	3
Graphite	O	5	1
Reinforced concrete	O	8	0.7–1

2.2 Testing

Full scale drop testing of prototype Boxes was carried out at the UKAEA site at Winfrith, Dorset. The outdoor facility there includes a 150 t crane which is capable of raising loads of over 90 t to a hook height of 30 m [3]. The target consists of a 700 t concrete block faced with 150 mm steel plate.

Four prototype Boxes were constructed weighing 40 t and containing steel plates to simulate sections of the WAGR thermal shield [4]. Drops in four orientations were conducted, i.e. onto a base, edge, corner and lifting lugs. The IAEA regulatory drop height of 0.3 m was increased to 0.65 m for the first series of tests to compensate for the mass of the prototype being less than the proposed maximum and for possible variations in material properties. This greater height incorporates a large measure of conservatism. Information was recorded using high speed cameras and accelerometers, and in addition a gamma source was inserted into specially prepared channels before and after the drops to check for any changes in radiation shielding capability.

The results of the tests were very much as might be expected. The flat base drop gave the highest deceleration (150g) and the greatest deformation occurred in the corner drop. Damage in all cases was slight with no splitting of the steel envelope. Cores taken from impact regions later showed localised concrete cracking but no reduction in shielding properties was detected using the gamma source.

In view of the minor nature of the damage sustained in these tests it was decided to conduct four further drops from a height of 5 m (the limit imposed by the Winfrith drop test facility at that time), to provide further data about the impact behaviour of the structure.

A deceleration of 600g was recorded for the base drop with about 0.5 m vertical plate weld splitting at each corner. A small amount of crumbled concrete spilled out from these gaps, but insufficient to give a detectable reduction in shielding using the gamma source test. For the edge drop there was again a degree of weld splitting at two corners and a small amount of concrete wall was lost. The greatest crushing deformation occurred in the corner drop but the steel plate containment remained intact. The lifting lugs appeared to provide effective shock absorption in the remaining drop as little damage other than lug distortion was observed.

2.3 Failure

The prototype Disposal Boxes withstood severe impacts, much in excess of the regulatory requirements, with no significant damage, i.e. no loss of contents and no detectable loss of shielding capability.

In order to determine transport risks it is necessary to assess the ability of the package to withstand extremely severe (although most improbable) loading. It was decided to evaluate the impact severity necessary to remove, in effect, the outer 230 mm wall shielding by concrete crushing, thus exposing the core of waste and concrete grout. This was assessed using SRD computer modelling techniques [5] and the drop test data, to require an impact equivalent to a 15 m drop onto an unyielding surface.

3. TRANSPORT ROUTES

The Boxes were originally designed with sea disposal in mind. In view of the current moratorium on this option, land burial was also considered. Three potential transport routes were examined:

(a) by rail to the nearest convenient sea port (60 km)

(b) by rail to a potential land repository site (450 km)

(c) by road to the same land repository site (510 km).

The most direct major transport routes were chosen in accordance with current UK practice, with no attempt to, for example, avoid major centres of population,

It was assumed that 67 Boxes would be transported per year.

4. FREQUENCIES OF ACCIDENTS

4.1 Approach

Rail and road accidents considered were:

(a) collision with a second rail or road vehicle

(b) collision with a fixed object near the line or carriageway

(c) fall from a high bridge

(d) accidents involving a second vehicle carrying flammable cargo and resulting in fire

(e) crane failure during the unloading operation.

An event tree approach was adopted to assess the frequencies of significant Box damage.

4.2 Rail transport

It was assumed that the Box-carrying rail vehicles will travel at up to 100 $km.h^{-1}$ and that they may encounter other rail traffic travelling at speeds up to 200 $km.h^{-1}$. Historical rail data were used to assess derailment and collision frequencies (1.5×10^{-7} per vehicle.km for derailments) [6]. These were multiplied by probabilities determined for the important impact parameters such as speed, angle, Box orientation, impact energy absorption by vehicles, the number and nature of line-side hazards, and Box behaviour after impact. Where historical, route or vehicle data were inadequate, assumptions were made which were clearly pessimistic.

The Boxes will be transported either in dedicated trains or in mixed freight trains but without vehicles carrying flammable cargo. In addition, dangerous cargoes are segregated in

TABLE II. ASSESSED ACCIDENT FREQUENCIES

Route	Frequency of minor accidents (no radiological consequences) (a^{-1})	Frequency of superficial Box damage accidents (no radiological consequences) (a^{-1})	Frequency of Box contents exposure (a^{-1})	Frequency of impact to expose Box contents and subsequent serious fire (a^{-1})
By rail to notional land repository site	2×10^{-3}	3×10^{-6}	5×10^{-7}	4×10^{-9}
By road to notional land repository site	4×10^{-2}	7×10^{-6}	0	0
By rail to possible sea port	5×10^{-4}	3×10^{-5}	2×10^{-8}	5×10^{-10}

marshalling yards. Thus the chance of a Box being involved in a serious fire will be very small.

The most likely serious accident was found to be a derailment and subsequent high speed collision with a second train (about $5 \times 10^{-7}\ a^{-1}$). The only other event predicted to cause significant impact damage to a Box is a collision with a tunnel abutment (but at a frequency about two orders of magnitude lower). Damage to Boxes in collisions with bridge piers, after falls from bridges along the routes, and after falls during unloading operations was assessed to be less than the failure criterion given in Section 2.3, i.e. the effective exposure of the grouted waste. The results are summarised in Table II.

In addition, the frequencies of superficial damage accidents (equivalent to a 5 m drop onto an unyielding surface) and minor accidents involving no radiological consequences (such as derailment with no direct Box impact) were assessed (Table II).

4.3 Road transport

Current UK legislation would limit the road speed to 20 $km.h^{-1}$ (because of the package weight). Higher speeds (on motorways for example) could be permitted at the discretion of the police and the assessed maximum speed was increased by a pessimistic factor of three to allow for this and possible future speed limit increases. Other Heavy Goods Vehicles are limited to 100 $km.h^{-1}$ in the UK but again allowance for exceeding this speed was made. Injury road accident statistics [7] with a pessimistic factor for damage only events gave an overall accident rate (0.9-2.4 per 10^6 vehicle.km, depending on road class) although the majority of these incidents would be completeley inconsequential in the context of significant Box damage. Unpublished Department of Transport figures, route data, and assumptions where data were not available, were used to establish probabilities for bridge pier collisions, vehicle collision orientations and speed distributions.

Only fires involving tankers carrying flammable fluids were considered to have the potential to threaten the Disposal Boxes.

It was concluded that impacts severe enough to cause the Box wall failure described in Section 2.3 could not occur, principally because of the relatively low speed of the vehicle. For this degree of Box damage a direct Heavy Goods Vehicle/Box impact at over 120 $km.h^{-1}$ was estimated to be necessary. Whilst relative velocities this great could occur occasionally, it was considered that actual impact speeds would be less.

Frequencies for superficial damage accidents and minor accidents (such as collisions with a car) are also shown in Table II. The most likely accident giving rise to superficial damage was assessed to be a fall from an elevated section of roadway.

5. CONSEQUENCES

Following the analysis of accident frequencies, summarised in Table II, the consequences were assessed in three damage categories, namely, minor, superficial and significant.

Minor accidents would have no associated radiological consequences, although people, car occupants for example, could be killed or injured.

Superficial damage accidents also would have no radiological consequences. There would be no release of radioactivity and no significant increase in external radiation levels, but the Box might suffer noticeable damage.

Significant damage is specified in Section 2.3 as localised exposure of the grouted waste. This would lead to increased radiation levels from that portion of the Box but the inner grout would still provide shielding, and the components of the waste would furnish a degree of self shielding. The radiation level would vary a good deal depending on the nature of the waste being transported, but would necessarily be less than the regulatory requirement of 10 $mSv.h^{-1}$ at a distance of 3 m [2]. Such accidents would cause some disruption but it should not prove difficult to control exposure and make good any damage.

The most active waste material comprises activated steel components which are clearly not dispersible. Mechanical damage could release small quantities of powdered graphite, but this would not present a big problem as the specific activity is not high (at most about 3 TBq in a 5 t payload). The only feasible dispersion mechanism is the exposure of graphite by impact followed by a serious fire. However, the graphite would not ignite easily and the payload would only be partially exposed to the fire, so it is likely that only a small fraction of the total activity would be dispersed. Preliminary calculations considering the principal active components (^{14}C and ^{60}Co) indicate that individual and collective doses would not be great even if complete dispersion occurred.

6. FURTHER WORK

Changes to the Disposal Box design assessed here, which are currently being considered, include the removal of the outer steel plates on cost and superfluity grounds, alternative grouting mixtures to help ensure no air gaps remain, and modified lifting lugs to improve repository stacking arrangements.

SRD propose to develop their concrete package impact assessment techniques through programmes of scale model and full size drop testing and theoretical analysis.

7. CONCLUSIONS

Prototype Disposal Boxes for the transport and storage of radioactive decommissioning waste material have been designed, built and tested. A preliminary risk assessment for the proposed transport of these Boxes suggests that the frequencies of radiologically significant accidents would be extremely low ($<10^{-6}$ a^{-1}) and the radiological consequences of such accidents would not be severe. Transport risks should not, therefore, present obstacles to the decommissioning of the Windscale AGR.

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