THE TRANSPORTATION OF RADIOACTIVE WASTE - A REVIEW

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SUMMARY

The paper reviews the present state and the future of the transportation of radioactive wastes, concentrating on Eastern Asia, Europe and North America. The types of wastes are defined and described and examples of the quantities of each type arising in various countries are given. The standards that apply to the transportation of the wastes are discussed as are the possible modes of transport. Current and proposed forms of the materials to be moved are described together with some of the designs of packaging for the various types of waste. Particular attention is devoted to high level waste and the packaging that is being developed now.

The vehicles which are being used, and those available, are discussed. Special attention is paid to the movement of wastes by river and sea, both for the transports to a land repository and for disposal at sea. Past experience in this field is depicted together with indicative costs of such transport. The problems of public relations are noted and some possible methods of progress are outlined. Finally the risks are examined, involving both the potential hazards and the probabilities of their occurrence.

The paper concludes that the transport of radioactive wastes presents no technical problems which cannot be overcome within the time available. Considerable operational experience of the movement of all types of radioactive materials already exists so a firm base exists for the future development of the necessary transport of radioactive wastes worldwide.

INTRODUCTION

Over 200,000,000 packages of radioactive material have been transported safely over the past 30 years. The quantity of radioactivity in these packages has ranged from the minute, small amounts of isotopes for hospitals and research work, to the very great, spent fuel from nuclear power stations going to reprocessing plants. In all these transports, so far as one can be certain, there has been no significant damage to the health of anyone.

Without the transportation of radioactive wastes nuclear power will be as dead as the proverbial dodo. Without such transportation wastes and spent fuel would pile up at every nuclear power station and wastes would stay where they are at every reprocessing plant and every fuel production plant. Obviously this is not a tenable situation. But over the past 30 years a distinct group of radioactive material has been transported - wastes - starting as a trickle it has now grown to a considerable size. By the end of this century it will be a major, if not the major, transport operation concerning radioactive materials. There will be a great range of radioactivity in the packages, from a drum of low level waste to a highly active waste cask containing as much radioactivity as a spent fuel cask.

This paper considers past experience, the job to be done and the means of doing it, and the main problems which will face an operator involved in the transport of civil, radioactive wastes.

THE MATERIALS TO BE TRANSPORTED

Waste Characteristics

Radioactive waste can take many forms, however as we are concerned with the transport of radioactive wastes this, in practice, limits the waste to the solid state. Solid waste is usually allocated to one of three main categories relating to its specific radioactivity. These are, broadly:

HLW, high level wastes, those wastes of high specific activity arising from the reprocessing of spent fuel, or any other waste with a comparable specific activity. These wastes generate significant quantities of heat, they are sometimes referred to as heat generating wastes. Spent fuel, if it was declared a waste, would be in this category.

ILW, intermediate level wastes, of a lower specific activity and heat output than HLW. They do not require heating to be taken into account in the design of storage or disposal facilities but still require shielding during handling and transportation.

LLW, low level wastes, which do not require shielding during normal handling and transportation.

Whilst there are differences between the categorisation of wastes by various authorities the above are in accord with the IAEA glossary for waste management. It should be noted that the USA has several classes of waste, and presently includes spent fuel in the HLW category.

Some nations have a further category - very low level waste (VLLW); in the UK this category is limited to wastes which are regarded as suitable for disposal with household refuse - they must be less than $0.1m^3$ of material containing less than 400kBq (10μCi) β/γ activity or single items containing less than 40kBq (1μCi) β/γ activity. As the quantities in this definition are so small such wastes are of little relevance to the nuclear power industry. Large quantities of such waste are treated as LLW, which in the UK must not exceed either $4GBqt^{-1}$ α ($0.1Cit^{-1}$) or $12GBqt^{-1}$ β/γ ($0.3Cit^{-1}$).*

Most nations who are producing, or intend to produce, HLW (as distinct from spent fuel) are planning to convert it either into a glass, the vitrification process, or into a synthetic rock-like material. These solids will probably be in stainless steel containers which are sealed by welding. The containers, arising from the French and UK vitrification plants, and probably from the Japanese and German plants, will be about 1.3m high with an outside diameter of about 0.4m and a wall thickness of some 5mm; the heat output of each will be up to 2.5kW at the time of production and the radioactivity content will be about 4×10^4TBq (1MCi). A typical canister will hold about 0.4t of HLW, corresponding to about 2tU of its original spent fuel.

The intermediate level wastes arise in several forms, for example: ion exchange material, sludges, fuel element debris and plutonium contaminated material (PCM). There will also be some miscellaneous wastes which may require considerable size reduction before they can be placed in a suitable package for transport. Much of the ILW will be fixed in some matrix, such as cement, prior to transport; this will help to reduce the dispersion, if any, of pollutants in the event of a transport accident.

Low level wastes also arise in many forms; those to be transported will usually be in the solid state, typically contaminated paper, clothing, laboratory or process equipment, concrete rubble and contaminated soil.

Spent fuel, if regarded as waste, is a special case of waste as, besides the high level of radioactivity associated with the fuel, it must be regarded as fissile material. Hence it is distinct from other categories of waste in that criticality is a major concern. Criticality will also be a consideration with PCM but it is not as significant a parameter as it is with spent fuel. The fuel will be transported from the power stations to a conditioning plant, probably at a repository, where it will be encapsulated in some way before disposal. Fortunately we have considerable experience in the transportation of spent fuel, for example Pacific Nuclear Transport Limited (PNTL) is currently moving about 500tU annually from Japan to Europe, about as far as one can sensibly move anything.

Both ILW and LLW may be conditioned prior to packing for interim storage and then transportation to a repository. The main methods in use and being developed are: incineration, compaction, cementation. Large items, such as might arise from the decommissioning of a plant, may require dismantling, or cutting, into smaller pieces before transportation. The volume reduction usually associated with conditioning is of great importance to the operators of the stores and repositories, it also simplifies the job of the transporter.

The Quantities to be Transported

Radioactive wastes are being produced throughout the world wherever radioactive materials are being used or processed in any way. The sources include hospitals, industry, educational establishments, power stations and fuel reprocessing plants. It should also be noted that the estimates of the volumes of waste to be transported are the subject of some uncertainty as methods of treatment are developed, undoubtedly these should lead to a reduction in the volume to be transported.

The amounts of LLW arising are considerable, for example present annual LLW arisings in Japan, UK, France and the USA are about 15,000, 30,000, 30,000 and $70,000m^3$ per year respectively. The EEC estimate that between 50,000 and $100,000m^3$ of LLW will be conditioned, transported and disposed of, each year, during the next 15 years within the European Community.(1) However this should not be a major transport problem as much of such waste is disposed of as it arises, hence stocks in store can be low, and disposal often takes place close to the major sources of arisings. For example, UK LLW disposal sites are at Drigg and Dounreay, both close to reprocessing plants; similarly the French LLW repository at Centre de la Manche is not far from La Hague and the Japanese repository will be at Rokkasho Mura, close to the reprocessing plant. Even when LLW has to be transported a considerable distance it is mainly a bulk movement problem, and probably a public relations problem, rather than a major problem in transporting radioactivity.

The ILW also arises in significant quantities and, at present, suitable repositories may not be available. Hence, besides current arisings there may be accumulated stocks in existence; for example the UK has some $40,000m^3$ of ILW in store with annual arisings of about $3,000m^3$. In France α-bearing wastes are not disposed of at their shallow land repository at La Manche, their waste management authority - l'Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA) - estimates that $75,000m^3$ of such waste will be produced by the year 2000. This can be compared with the amount of short-lived (less than 30 years half-life) β/γ waste which will be produced by the year 2000, some $800,000m^3$. Already ANDRA has disposed of about $260,000m^3$ of the latter waste at La Manche.(2) The EEC estimate of the amount of ILW which will be conditioned, transported and disposed of by the year

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*Throughout the paper activities and dose equivalents will be quoted in both the new and older, more familiar, units. The conversion factors are: 1Ci = 0.037TBq, 1rem = 0.01Sv.

2000 within the European Community is between 150,000m^3 and 300,000m^3.

High level waste, other than spent fuel, will usually be vitrified and it may be stored above ground for some considerable period before being transported to a repository. However the quantities involved are small; the UK expected to have about 1000m^3 and France about 3000m^3 of vitrified HLW in store by the year 2000. The volumes in other countries are unlikely to be significantly greater than these; however after 2000 there will be significant arisings in Japan as its reprocessing plants get into their stride and in the USA as the stocks of liquid HLW are solidified. The transportation of the HLW will be very much like that of moving spent fuel without the fissile material content and hence without the criticality problem.

The amounts of spent fuel to be transported in the USA are certainly significant. The inventory of LWR spent fuel assemblies in pool stores is about 65,000; by the year 2000 the number is expected to increase to about 150,000, corresponding to over 50,000tU. All of this fuel will eventually have to be transported to either a Federal Interim Store and/or to a Federal repository. "In the 25-year history of (US) civilian nuclear power, approximately 6000 spent fuel asemblies have been shipped. Beginning in 1998, the Department of Energy has the responsibility to ship the equivalent of 7000 spent fuel assemblies - per year - to disposal facilities". (3)

THE TRANSPORT ROUTES

The pattern of the development of waste facilities in the major countries with a significant nuclear power programme is illuminating. Japan has no repositories at present, a major store and repository will be built at Rokkasho Mura in northern Honshu. France has a repository for LLW at La Manche and is planning another, for LLW and ILW, which will be operational about 1990. The UK has repositories for LLW at Drigg and Dounreay and is seeking a further site for LLW which will be operational in the 1990s. Germany has used the salt mine at Asse in the past and is now seeking permission to use the Konrad mine for LLW and the Gorleben site for the disposal of all types of radioactive waste. The USA has no civil repository for HLW at present but efforts are in hand to have one operational before the end of this century, this will be used for the disposal of both HLW and spent fuel. However the USDOE operates some disposal sites for LLW on government-owned land, there are also a very few privately operated sites for the disposal of LLW.

Because of the diversity of the sources of radioactive waste it is apparent that the routes used for the transports will be many and various. This will be true even though the number of interim storage facilities and the repositories in each country may be small. Indeed it would appear that, during the next twenty years at least, the pattern will be much the same in each country, even those which are very large geographically - a few repositories being supplied by many sources.

There are two extraordinary routes which should be mentioned, one is in use now and the other is a potential route for the future. The first route is used to bring spent fuel by sea from Japan to Europe, eventually the return voyages will transport the waste, or possibly the equivalent radioactivity, from the reprocessing of the fuel in Europe, back to Japan. The route to Europe is firmly established with four ships continuously transporting spent fuel across the oceans. A fifth ship will join the fleet at the end of this year. Hence there will be both national and international routes for the transport of wastes.

The other route, using the word in a generic sense, would be that for the disposal of wastes at sea. Such routes have been used in the past by the USA and by several European nations; such routes are presently not in use but recent considerations of the best practicable environmental option indicate that the reopening of such disposal routes should not be precluded.

THE TRANSPORT REGULATIONS

Throughout the world, the laws governing the transport of radioactive materials tend to be based on the Regulations published by the International Atomic Energy Agency. These were first published in 1961 and have been improved by amendments and regular reviews over the years. These amendments and reviews arise from the work of international groups of experts in their particular fields. Hence the IAEA Regulations are improved continuously, based on the best technical advice and on over 30 years' operational experience. The Regulations are published in a concise format and are supported by the publication of explantory and advisory material on their technical requirements.

The Regulations cover both normal and accident conditions, the guiding principle being that the packaging should provide adequate shielding and containment en route. The aim is to ensure that when the radioactive material is in the appropriate packaging, and the carrier follows simple rules for stowage and segregation from persons, it can be transported as safely as other potentially dangerous goods that are continuously being moved around the world.

THE EQUIPMENT

The equipment necessary to transport radioactive wastes, in any significant quantity, is far from being insignificant. The casks for spent fuel and HLW are massive pieces of high quality engineering which require maintenance facilities. The ships used for the inter-continental transport of spent fuel and HLW are specially designed to carry the casks safely for the considerable distances involved. These systems will need railheads/parking regions, and marshalling and health physics survey areas at the power stations, reprocessing plants and at the repositories.

Packaging

The casks used for transporting highly radioactive materials are massive in order to provide adequate shielding, they range up to about 120t. The great mass also has the built-in ability to provide robust packaging which can be designed to withstand severe accidents. The packages for HLW and for spent fuel will be rather similar, the major difference being that there will not be the same requirement for criticality control in the case of a HLW package.

Four main types of packaging are specified in the 1985 IAEA Regulations: Excepted, Industrial, Type A and Type B. Excepted packagings are allowed to contain only relatively small amounts of radioactivity, hence the other packagings are of interest for spent fuel and wastes. Industrial and Type A packagings can be used to transport both LLW and ILW so long as the appropriate regulatory requirements on radiation levels, specific activity and total radioactivity content are met. Type B packaging will be used for the transport of spent fuel, HLW and some ILW; a Type B packaging is designed to retain adequate shielding and containment even in a severe accident.

Some transport casks for spent fuel and HLW are indicated in Table I; the Excellox 12 type is illustrated in Fig 1. HLW transport casks are presently at the design and development stage, however the designs becoming apparent tend, as expected, to be similar to the large spent fuel casks in overall dimensions and weight. Typical parameters are: a weight of about 100t, a capacity of some 20 canisters of vitrified glass giving a total heat output from the cask of not more than 50kW.

The transport systems for moving intermediate level wastes from, mainly, reprocessing plants to the storage or disposal sites are currently being designed and developed. Work by NIREX, the United Kingdom's organisation for dealing with ILW and LLW, suggests that, for ILW, there should be standardization in the UK on a nominal 500l unshielded drum. This drum could be transported inside large, reusable, shielded overpacks. The drum would be 0.8m in diameter and some 1.2m high. Several such drums could be carried in an overpack. The weights of the packages range up to about 60t depending on the particular characteristics of the ILW to be transported. The standard drums and their overpacks, might be supplemented by a range of reinforced concrete boxes with loaded weights of up to 100t. These would be available for large ILW items, the largest would be usually for items from the decommissioning of nuclear plants.

TABLE I

Some Excellox Transport Casks for Spent Fuel and High Level Waste. The laden weight is that on the crane after loading.

Contents	Type	Capacity, elements		Laden Weight	Cavity Length and Diameter,
		PWR	BWR	t	mm
Oxide Fuel	3/3A/3B	5	14	75	4674 x 864
	4	7	15	102	4886 x 914
	12	24	60	112	4559 x 1474
Vitrified HLW	21	21 canisters		107	4559 x 1626

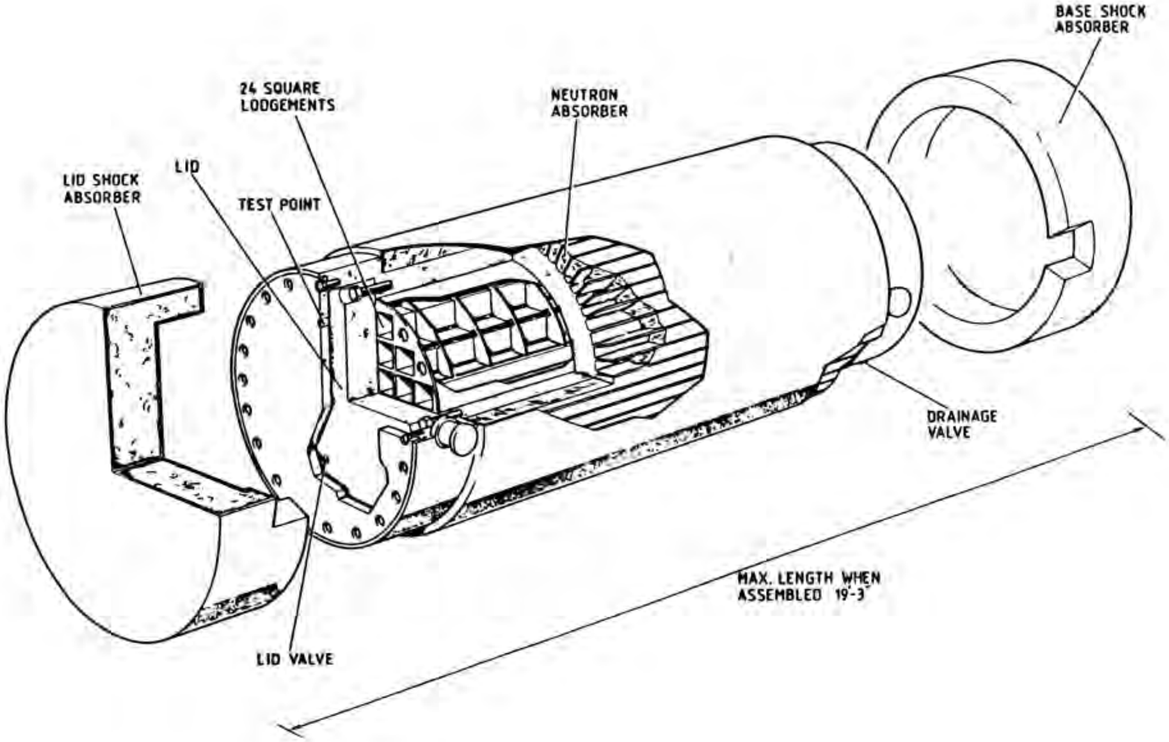

Fig. 1. Excellox 12 Cask for the Storage/Transport of Spent Fuel.

Most, but far from all, of the LLW in the UK can be stored and transported in 2001 drums; the rest will probably be transported in boxes of up to about 5m^3 supplemented by even larger boxes for bulky pieces of LLW from decommissioning operations. Similar arrangements can be envisaged for most of the LLW produced elsewhere in the world. However some repositories may not accept drums, for example Transnuklear have designed a range of steel or concrete boxes which will contain LLW drums, thus meeting the acceptance conditions of all the envisaged German repositories.

The Transport Vehicles

The vehicles used to transport spent fuel and HLW casks by road and rail are heavy units, but they are not extraordinarily different from those used for moving other heavy loads. The transport industry, in all developed countries, had considerable experience, prior to the advent of waste casks, in moving loads of the same order of weight.

If the carrier has a considerable business by sea then consideration will be given to ships built specifically for the carriage of radioactive materials. The first movement of spent fuel between Japan and the United Kingdom was in 1969. Now PNTL have four specially designed, wholly owned, radioactive material (RAM) carriers operating between Japan, France and the United Kingdom, see Table II, with a further ship on order.

The "PACIFIC SANDPIPER" is typical of this new class of ship, see Fig. 2. The size is limited by the characteristics of the Japanese reactor ports to about 3000 tons deadweight. The ships can transport spent fuel casks and/or HLW casks, they could also transport waste drums. Their main features are:

a. Two longitudinal bulkheads located one-fifth of the ship's beam from the main hull.
b. A double bottom structure over the ship's length, divided into tanks.
c. Transverse watertight bulkheads dividing the ship into five separate cargo holds and two machinery compartments. There is sufficient reserve buoyancy with any two holds/compartments flooded.
d. A second collision bulkhead located aft of the normal forward collision bulkhead and strengthening of the ship's hull.
e. Half of the hatch covers can carry a full cask weight during loading, they are immensely strong for their normal sea-going duties.

Other safety features include:

a. Twin engines with twin screws.
b. Bow thrusters for increased manoeuvrability.
c. Emergency hold flooding and extra fire fighting equipment.
d. Controlled discharge and monitoring of hold drainage water.
e. Personnel monitoring and decontamination facilities.
f. Additional navigation and communications equipment, using satellite communication systems, so that the ship, regularly and automatically transmits an accurate position report to headquarters.
g. Considerable spare equipment, so that the ship has a measure of self-sufficiency in the event of faults developing, or of damage, at sea.

It can be seen that the PNTL fleet is designed to a high standard. Nevertheless, in order to meet the objective of continuing but sensible improvements to all the transport equipment, there is a small, but real, development programme concerning ship operations. One example is the use of sensors in the ship which will allow remote, underwater interrogation, in the unlikely event of the loss of the vessel, from another ship, of the ship's orientation and the radiation levels on board. Developments elsewhere in control systems, engines and emergency responses are kept under review.

Fig. 2. A Pacific Class RAM Carrier at Sea.

TABLE II

Radioactive Material Carriers*

Motor Vessel	Operational	Carrier	Nominal Deadweight t	Capacity, casks		Draught, m	Length x Breadth, m
				LWR	Magnox		
Hinorua Maru	1978	NFT†	1300	4	-	4.20	77.5 x 12.2
Pacific Swan	1979	PNTL	3000	20	4	6.02	103.9 x 16
Pacific Crane	1980	PNTL	3000	24	-	6.02	103.9 x 16
Mediterranean Shearwater	1982	BNFL	1200	6	6	4.50	80 x 12.5
Pacific Teal	1982	PNTL	3000	24	-	6.02	103.9 x 16
Sigyn	1982	SKB**	2000	10	-	3.95	87 x 18
Pacific Sandpiper	1985	PNTL	3000	20	8	6.02	103.9 x 16.5
Pacific Pintail	1987	PNTL	3000	24	-	6	103.9 x 16.5

*These ships have the cargo lifted on and off by cranes, except for Sigyn which also has a roll-on/roll-off capability. The deadweight tonnage is a measure of the carrying capacity of cargo, fuel, stores and crew.

†Nuclear Fuel Transport, Tokyo.

**Swedish Nuclear Fuel and Waste Management Company.

Transport Terminals

At the end of each portion of the package journey, from its starting point to its eventual destination, there has to be a terminal. Road and rail terminals usually only need lifting facilities to get the cask on or off its transporter. Sea terminals are necessarily somewhat more complex, but the usual facilities of a normal port can often be used. BNFL and its associated companies have used over twenty ports in Europe in this fashion. PNTL use a private berth at the Port of Barrow as its United Kingdom sea terminal; this has a rail terminal and offices. A 150t crane is used to transfer the casks from the ship to the railway. Almost all the Japanese nuclear power stations have their own port which could, and presumably will, be used for transporting wastes from the station to the repository.

Maintenance Facilities

If a carrier has a significant number of packagings in use then he may find it desirable, and possibly necessary, to have his own packaging maintenance facility. This can be used for both routine inspection and for periodic major overhauls of the packagings, which will have been in contact, to some extent, with radioative materials. Their maintenance in good condition is a requirement of the IAEA Regulations.

These facilities will require resources, usually cranes, to move the packagings (some weighing over 100t) from workplace to workplace. The typical jobs to be done will be: decontamination, disassembly of the components, inspection of the components, any necessary modification or rectification, including the machining of the components, painting, assembly and testing. A storage region, which can be outdoors, will be necessary.

COSTS

The establishment of a first class transport system for wastes will require a considerable capital expenditure. An HLW cask, with any required ancillary equipment such as lifting tackle and a lifting frame, will probably cost about \$2M in 1987 money values. A RAM carrier of the "PACIFIC" class, with its great range, will cost about \$18M; waste carriers will in general cost less than this but not much less as the standards of equipment and construction will necessarily be high.

The cost of a port terminal with say two berths, a 150 ton crane, storage space, offices, good fire fighting facilities and good security arrangements may cost almost \$15M. The cost of a maintenance facility will depend on its capacity and location, if much of its services can be provided from an associated plant then these costs can be shared. However, even if it is co-located with an existing nuclear plant with land free, if it has a capacity of fully maintaining 50 packagings per year then the capital expenditure could be about \$20M.

The operating costs of such a system are not extraordinary. The operation of a maintenance facility will be to standards similar to other nuclear plants and it will require health physics support. The costs of other operations will be somewhat greater than for a normal transport operation due to the need for standing emergency schemes, health physics monitoring and, in the case of a shipping operation, the need for particularly skilled officers and ratings.

TABLE III

Preliminary Estimates of the Costs of Transport and Disposal in the UK, 1987 $\$/m^3$ (4)

Type	Transport by Road	Transport by Rail	Disposal
LLW	100	300	600
Short-lived ILW	600	1100	300
Long-lived ILW	1400	2200	3300

Notes:

a. The figures have been rounded.

b. The long-lived ILW was presumed to go to a deep repository, the short-lived to a shallow repository.

c. The volumes are those of the conditioned waste.

d. The average distance for the transport will be about 300km.

The costs of transporting ILW and LLW should not be great. Most of the capital costs will be associated with the packaging of the waste; it will be small for the majority of the LLW but could be significant for ILW packaging in total, nevertheless the unit capital cost should not be great. For preliminary assessments of the transport costs, for the movement of LLW from its various sites of origin to possible repositories in the UK, see Table III.

OPERATIONS

Experience

PNTL and BNFL ships, during 20 years of operations have carried spent fuel for nearly 16,000,000 cask-miles. During all these voyages no cask has been damaged other than minor bumps and scratches received during handling.

The casks travel by rail from the port to the reprocessing plant. Indicative of the standards that can be established, in this mode, is the experience of the UK Central Electricity Generating Board. Since their first consignment in 1962 there have been over 8000 cask movements of spent fuel to Sellafield. These amount to about 2,000,000 cask-miles, currently there are about 500 cask movements per year. The only recorded incidents have been minor derailments at slow speeds in marshalling yards. No accidents involving either damage to a cask or the release of radioactivity have occurred. However it should be noted that the pre-requisite of such a good transport record is a good railway system.

In the USA spent fuel has been moved to the AFR stores at the reprocessing facilities at Nuclear Fuel Services' plant at West Valley, NY and General Electric's plant at Morris, Ill; spent fuel has also been moved between the stores at the nuclear power stations. All movements have been either by road or rail, with an average over the last 20 years of about 300 movements per year. The safety record of these operations, which started about 1964, is also excellent. There have been no accidents which resulted in a release of radioactivity whilst spent fuel was being transported.(5) Transports of spent fuel by all modes used in Japan and in and from mainland Europe have also been without any releases.

Hence we have a fine safety record for the transportation of spent fuel. Good transport operations are, in themselves, a major safety factor. Standards of operations have been established which have not required the massive integrity of the casks to be called upon for protection. These operations have been perfectly safe, with a large measure of contingency available.

The operational record for the transport of wastes is also impressive. No significant quantities of HLW have been transported as yet, but considerable amounts of the other wastes have been moved. LLW has been transported in the UK from Sellafield to Drigg for over 25 years, as has LLW in France to Centre de la Manche since 1969. In Germany both LLW and ILW has been moved to the old salt mine at Asse; during the period 1967 to 1978 about 125,000 2001 drums of LLW and some 1300 drums of ILW were transported to this repository. There is also a considerable traffic in radioactive wastes in the USA, some 20,000 packages are transported annually, mainly by road. It is interesting to note that this number is about 0.02% of the total of movements of hazardous materials in the USA.

There have been no deaths or evidence of injury resulting from these waste movements. Indeed the transport of all radioactive materials has an outstanding record; in the last 35 years I estimate that more than 200,000,000 packages have been transported; there has been no accident with serious radiological consequences to the public.(6)

Security

It is almost incredible that any organisation would wish to steal spent fuel or radioactive waste, equally it is hard to imagine that anyone would attempt to sabotage casks containing such material. Such projects have many aspects unattractive to terrorists - the difficulty of moving the prize, the "hardness" of the casks, the poor results and the adverse publicity.

Emergencies

The probability of a serious cask accident, especially one that results in the release of significant amounts of radioactivity, is very small. Nevertheless a responsible organisation involved in the movement of radioactive materials has to prepare plans for emergencies, even though they are unlikely. Indeed the IAEA Regulations require that emergency procedures be established so that, in the event of an accident, human health and the environment are protected.

The overseas transport of radioactive materials presents extra problems with regard to emergency schemes, beyond those associated with one country. Hence arrangements have been made to move an expert team rapidly anywhere in the world where it could support work on a PNTL or BNFL or NTL package involved in an accident. Immediate response teams have been established by BNFL/PNTL in Europe and Japan, with about six emergency exercises being carried out, worldwide, each year. Arrangements have also been made, with a deep-sea salvage company, to provide emergency marine services worldwide.

RISKS

All activities have some associated risk, hence the transport of spent fuel and radioactive waste entails some risk. In order to conduct a sensible transport operation, and also to be able to deal reasonably with questions from the public, it is necessary to be aware of the magnitude of these risks.

One of the difficulties associated with all aspects of nuclear power, which has become apparent over recent years, is the considerable difference between the risk as perceived by some sections of the population and the risk as estimated by the best techniques available - the 'objective' risk. This section is concerned with the objective risk, but one of the goals of those who wish to see rational decisions made concerning nuclear power must be to decrease the differences between perceived and objective risks.

Normal Operations

Normal operations are those which do not involve accidents; hence the only hazard arising from these operations is the radiation exposure resulting from the contents and from any contamination on the outside of a package. Those exposed are the transport workers and the public along the route. Because of the stringent shielding requirements for the packages the radiation exposures are very small indeed.

A survey in the UK, by the National Radiological Protection Board (NRPB), indicates that the annual collective dose equivalent of all railway workers involved with the transport of spent fuel in the UK is about 5×10^{-3}manSv (0.5manrems).(7) This is approximately equivalent to the annual collective dose to two people in the UK due to natural radiation. The corresponding dose to all transport workers involved with the movement of spent fuel and LLW by road was less than 0.1manSv (9manrems). Similar low exposures have been reported from France and the USA.

The collective radiation exposure to the public in the UK from γ-radiation due to the transport of Magnox fuel (about 1000tUa^{-1}) amounts to about 0.02manSv (2manrem) per year.(8) The collective UK natural radiation exposure is some 10^5manSv. The amounts of oxide fuel transported in the UK are less than those of Magnox fuel, hence it can be seen that the exposure of the public in the UK is negligible.

All officers and ratings on BNFL and PNTL ships wear film badges when fuel is on board, whether or not their work takes them near the cargo. Periodically film packs are attached to positions throughout the accommodation. The radiation level for each cask is checked before it is placed on board; after the last cask is loaded a complete radiation survey of the ship is performed. The casks are monitored continuously, by eleven fixed monitors, throughout the voyage. Daily surveys are made by ships' officers to confirm that the fixed monitors are operating correctly. Records are maintained of all these measurements. The most realistic assessment of the annual radiation dose accumulated by the most highly exposed individual is less than 0.3mSv (30mrem) with the average dose being about 0.08mSv (8mrem). For comparison, the average annual radiation dose per person in the UK is about 2mSv (200mrem).

A preliminary analysis of the risks arising from the transportation of spent fuel and HLW to five potential repository sites in the USA has been reported by Marsden.(9) Each hypothetical repository was assumed to be in operation for 26 years, corresponding to about 15,000 shipments if all movements were by rail and to about 90,000 shipments if all were moved by road. The probable upper limits of latent cancer fatalities resulting were between 13 and 26 and between 6 and 13 respectively, from accident free operations, with the spread in numbers resulting from the different locations of the repositories. It was noted that in the same period the latent cancer fatalities from background radiation in the USA could be about 120,000.

Transportation Accidents

The events usually regarded as the precursors to serious accidents to packages are impact, fire and immersion in water or some combination of these three events. As has been noted above there has been no accident reported, worldwide, which has resulted in a release of activity from a cask transporting spent fuel. Further, so far as the author is aware, no cask transporting spent fuel or HLW has ever been involved in a serious fire, suffered a serious impact or been sunk.

Nevertheless, packagings are designed to withstand just such accidents. The prime design considerations are the attenuation of the radiation to acceptable levels outside the package, the exclusion of critical conditions and the provision of adequate cooling to ensure that the integrity of the contents is not diminished during transport. Further design requirements are that the casks can withstand the envelope of accident conditions stipulated in the IAEA Regulations; ie impacts, fire and immersion. These standards provide a higher degree of safety to the public than most, if not all, other transports of hazardous materials.

Womack has studied the rail transport of some 30ta^{-1} of fuel from the proposed PWR at Sizewell to Sellafield, a distance of 635km.(10) He estimates that the frequencies of severe impact and of severe fire are $1.5 \times 10^{-9}a^{-1}$ and $10^{-9}a^{-1}$ respectively. He emphasises that these very low frequencies are not those of a major breach in the containment of the cask. The only breach likely, if any, is a minor breach such as seal leakage. The consequences of the latter are negligible so far as the public are concerned, and minor so far as emergency services are concerned so long as reasonable precautions are taken.

The NRPB have considered the consequences of a postulated severe impact to a PWR cask followed by a severe fire (two hours at 1000°C) with the accident happening in London.(11) The NRPB results indicate that, even with no counter measures taken, the probability of fatal cancer to the closest individuals is about 2.5×10^{-4}, about one thousandth of the natural probability of fatal cancer, with two fatal cancers resulting in the UK. Noting that no counter measures were assumed, it can be seen that the results give confidence that the transport of spent fuel by train results in small risks.

Risk analyses of the transport of HLW by train have been made in Germany.(12) The transport system assumed was such that 1500t of heavy metal, in glass, were transported some 360km each year. This corresponds to the spent fuel discharged, to reprocessing plants, from a nuclear power plant capacity of some 50GW(e). The age of the HLW was assumed to be just over five years, with another age of 41 years assumed to test the sensitivity to this parameter. Risk was defined, as usual, as the consequence times the probability of occurrence, it amounted to 2×10^{-9} Sva^{-1} (2×10^{-7} $rema^{-1}$) for 41 year old HLW and to about 6×10^{-9} Sva^{-1} (6×10^{-7} $rema^{-1}$) for five year old waste. It is interesting to note that the most effective method of reducing the risk was by an adequate emergency response involving decontamination of the area involved.

The study by Marsden mentioned above also considered the probable accidents resulting from the transportation of the spent fuel and HLW to the various potential repositories. During the assumed 26 years of operations, it was estimated that if all the movements were by rail there would be a maximum of two fatalities; if all movements were by truck then there could be between 15 and 38 accident fatalities, depending on the location of the repository. These numbers can be compared with present accident rates: about 65,000 persons would die from truck accidents and about 32,000 would die from train accidents in a 26 year period in the USA. It is interesting to note that the estimated fatalities from the radiological effects of the accidents is negligible, the fatalities would result from the usual consequences of transport accidents.

The vast majority of spent fuel transports by sea take place in special RAM carriers, such as is shown in Fig. 2. These ships are extra strong, so that they can withstand more severe impacts than a normal ship of their size. They have extra fire fighting equipment and their crews are of a higher standard than is normal for cargo ships. Thus they have a significantly greater chance than average of surviving maritime hazards.

These hazards are: grounding, fire, collision and some combination of these, possibly with sinking. The nuclear fuel carrier has a further particular hazard in that a cask might be dropped on her in port. An assessment of such a cask drop on a ship of the Pacific class indicates that the cask would not be damaged but the ship's structure would be penetrated. Nevertheless, due to her compartmentalization, she would not sink.

The most severe hazard is a ship collision with fire on board. The frequency of such an accident to the PNTL/BNFL fleet has been calculated to be about $3 \times 10^{-5} a^{-1}$. The maximum collective dose, in the event of such an accident near a major city, has been estimated to be 300manSv (3×10^{4} manrem).(13) Thus, even in the event of such an improbable accident, the major consequence is likely to be the immediate danger, from fire or drowning, to the ships' crews involved.

PUBLIC ACCEPTANCE

Notwithstanding its fine record of safety, the transport of radioactive materials meets some opposition. A major part of this is presumably due to the concerns associated by some members of the public with nuclear power - their uncertainty about the long-term effects of radiation, a concern about the possibility of human error or over-confidence by scientists, the thought that there might just be a tremendous effect from an incident, possibly a feeling of risk imposition. Besides these concerns, which can be described as concerns about "tomorrow", there seems to be concerns which can only be described as concerns about "today".

These seem to be associated with the thought that technology is proceeding too rapidly for humanity to be able to control it adequately. This then leads to the hope or feeling that the advance of technology should be stopped or, at least, delayed. These concerns about "today" seem to be mainly associated with the relatively young. Hence, there is some tendency among young people to be against technology, hence against nuclear power and hence, to some extent, by association, against the transport of radioactive materials. There has probably always been opposition to progress and technology, there probably always will be; such opposition can, and possibly must, be left to the general future development of our culture.

However, it should be possible, indeed it behoves those in the industry to do whatever is possible, to minimise, or at least reduce, the concerns about "tomorrow". It will require a continuing effort to enlarge the public understanding of the advantages arising from the transports, the effects of radiation, the standards of personnel, the standards of operations that are maintained, the small probability of accidents and the almost negligible consequences of possible accidents. Above all it will require the maintenance of the present high standard of operation; no one can guarantee perfect safety, accidents will happen, but every effort must be made to maintain the present record.

The information presented will need to reach the general public as well as the public in the localities where they come into direct contact with transport operations. Also a continuing dialogue must be established with local officers and leaders of public opinion, especially on the regions of direct contact. The media will have to be kept well informed on events, developments and results. Debates in public will have to be undertaken as part of normal operations, training in such arts will pay dividends. Even the words used need to be chosen carefully, for example the "dumping" of waste is often mentioned, such an expression certainly does not induce visions of technical excellence!

CONCLUSIONS

Spent nuclear fuel has been transported, worldwide, for three decades. During these 30 years the Industry has had an excellent safety record and has developed so that it can cope with the present requirements. The transport of radioactive wastes is not as technically demanding, indeed such waste has been transported for over 30 years without any significant accident. Hence there is no technical reason why the industry cannot expand the volume and scope of its activities to meet the increased needs of the future.

It will be necessary to maintain a significant public relations effort so that the public, and decision makers, support its future development. Above all standards of operations will have to be maintained. If the Industry maintains the safety record, and informs the public of its activities, the transport of spent fuel and radioactive wastes should progress satisfactorily as an essential part of the production of electricity from nuclear power stations.

REFERENCES

1. S. ORLOWSKI and F. GIRARDI, "The Role and Results of the European Community's R&D Work on Radioactive Waste Management." Radioactive Waste Management & Disposal 1985, Edited by R. Simon, Cambridge University Press, UK (1986).

2. A. BARTHOUX and A. FAUSSAT, "Low and Medium Waste Storage in France", Nuclear Europe 3 (1986).

3. W. W. BIXBY, "DOE's Program for Transportation of Civilian High Level Waste - an Overview", Proc 27th Annual Meeting of the Institute of Nuclear Materials Management, New Orleans, USA, June 22-26, 1986 (1986).

4. W. A. WALDEGRAVE, Question Time in UK Parliament, March 6, 1986, Hansard, HMSO, UK (1986).

5. R. M. JEFFERSON, "Transporting Spent Fuel - Considerations for Safety", IAEA Bulletin, Spring, Vienna (1985).

6. "Safe Transport of Radioactive Material", IAEA, Vienna (1985).

7. K. B. SHAW, "Worker Exposures: How much in the UK?", IAEA Bulletin, Spring, Vienna (1985).

8. R. GELDER, J. S. HUGHES, J. H. MAIRS, K. B. SHAW, "Radiation Exposure Resulting from the Normal Transport of Radioactive Materials within the United Kingdom", NRPB-R155, National Radiological Protection Board, UK (1984).

9. M. M. MADSEN, "A Preliminary Analysis of the Risk of Transporting Nuclear Waste to Potential Candidate Commercial Repository Sites", Waste Management '84, Volume 2, Arizona Board of Regents, USA (1984).

10. C. J. WOMACK, Proof of Evidence to Sizewell Public Inquiry, CEGB, London (1982).

11. R. CLARKE, "Potential Consequences of Accidents", The Urban Transportation of Irradiated Fuel, Macmillan Press, London (1984).

12. K. A. SCHNEIDER and E MERZ, "Risk Analysis of Transporting Vitrified High Level Radioactive Waste by Train", Proc Patram '86 (1987).

13. Volume IV, Handling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Reprocessing Waste, SKB, Stockholm (1977).