Thirty Years of Safe Irradiated Fuel Transport Maintaining the Record

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Introduction.

Nuclear Electric plc is the generating company which has inherited the nuclear plant assets of the former Central Electricity Generating Board (CEGB) in March 1990. It currently operates two principal types of power reactor; the Magnox and AGR (Advanced Gas-Cooled Reactor). There is a total of 10 AGR and 14 Magnox type reactors in operation at nine locations with a total capacity in excess of 8,333 MWe, and providing 18.5% of all electricity generated in England and Wales. Transport of irradiated fuel is a service which is essential to the continued operation of the gas cooled reactors operated by Nuclear Electric.

The characteristics of the spent fuel arising from each reactor type require that two different designs of transport flask (or 'cask') are used for its transport to British Nuclear Fuels Limited (BNFL) Sellafield plant in Cumbria, North West England, for storage and reprocessing. The principal mode of transport is rail using special trains operated by British Rail (BR).

The paper reviews the evolution of the design of the Magnox and AGR flasks over 30 years and outlines Nuclear Electric's operational arrangements including its system for collecting and responding to reports on any operating difficulties found with the flasks, and also the Nuclear Electric administered emergency response plan for the provision of assistance at the site of any accident involving a flask in transit.

With the adoption of the 1985 edition of the IAEA Regulations for the Safe Transport of Radioactive Material by the United Kingdom Government there has been a requirement to install formal Quality Assurance (QA) systems. This paper also describes the Nuclear Electric systems and operating experience for all Irradiated Fuel Transport activities since the introduction of QA Programmes.

First Magnox Flask Design. (Mark M1)

This flask was first conceived and designed in the 1950s before any International Regulations were in place. (Figure 1) It was a development of a UKAEA design and started the concept of a massive cuboid steel box, water filled and with a bolted-on lid; the essential design requirements being shielding and internal heat transfer. The dimensions and handling features chosen at the time set the standard for all subsequent derivatives.

Sealing of the lid to body interface was achieved with a pair of 'D' cross section elastomer seals retained by an interference fit in the rectangular grooves in the lid. They functioned as a gasket and there was no attempt to allow space for expansion of the elastomer in a fire accident thermal transient. An interseal pressure test point was provided for carrying out a sealing check on these seals.

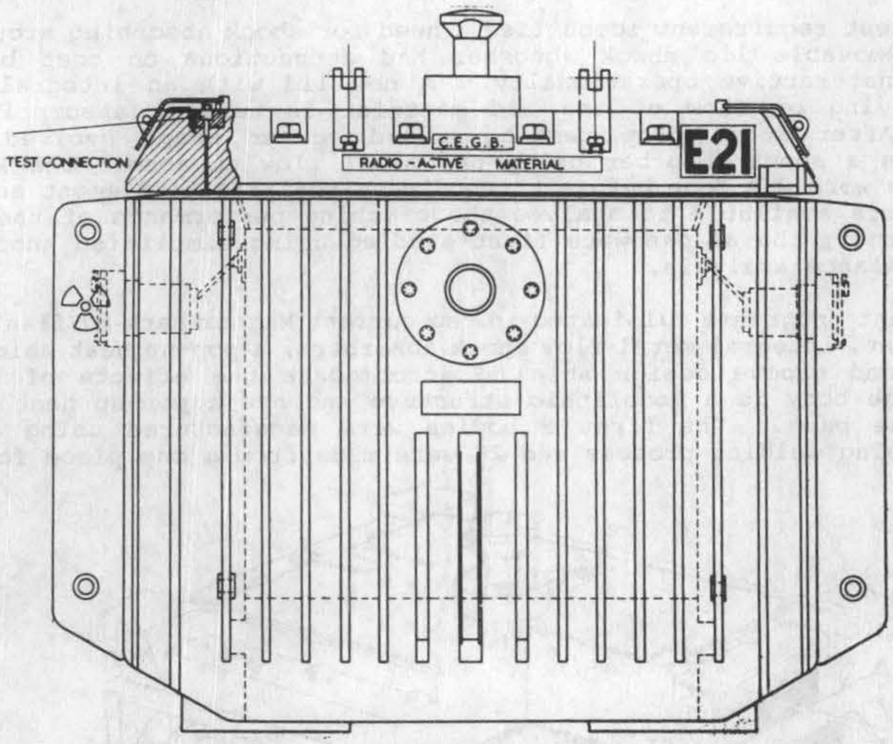

Figure 1. The Magnox Mark M1 Flask

The body of the Mark M1 flask was fabricated from five plates of mild steel 369 mm thick. The structural strength of the body was achieved by mechanical interlocking of the plates. The side plates used a unique 'jigsaw' interlocking joint; two of the base plate edges were keyed to the sides. Deep welds on the inside and outside edges of the plates provided the sealing and containment. Vertical fins on the four sides dissipated the internal heat. The lid carried a filter assembly through which the flask was continuously vented to avoid any internal pressure build up. Two valves were incorporated on opposite sides of the body to control the internal water level. The fuel elements were placed in a mild steel skip, essentially an open crate, the design of which is still used to this day.

Magnox Flask Development

With the introduction of the 1965 IAEA Regulations it was recognised that the Mark M1 Magnox flask would need modification to achieve full compliance and in 1976 the CEGB embarked on a development programme to identify and design an improved Magnox flask.

Freedom to introduce changes to the design was restricted by the requirement to remain within the existing cuboid shape and dimensions. It was not possible to go to a completely new flask design as all the cranes and remote handling plant at power stations and at Sellafield had been designed to fit the cuboid dimensions. Additionally, it was necessary that particular features such as the corner guides used for accurate positioning and the lifting points should be common to the old and new designs. The flask also had to remain inside the dimensions of the British Rail loading gauge limits when conveyed on the purpose built rail transporter.

Thermal stress analysis representing the 30 minute regulatory fire accident test identified a need for heat shielding on the top surface of the lid to reduce thermal distortion, consequent loss of seal compression and thus leakage. Also analysis and thermal testing of the main lid seal and groove configuration demonstrated that a complete redesign was necessary to accommodate seal expansion.

The 9m drop test requirement identified a need for shock absorbing around the lid. A removable lid shock absorber had attractions on cost but was considered unattractive operationally. A new lid with an integral shock absorber relying on flow of the lid material for energy absorption was proposed. After model drop testing a lid corner shape evolved which functioned as a shock absorber using the metal flow to absorb the kinetic energy. This work was done before three dimensional Finite Element analysis programmes were available to analyse the crushing performance of the shock absorbing corner; the shapes were first studied using simplified knock back and energy balance analysis.

The development programme culminated in the current Magnox Mark M2 flask. The lid has no vent, integral metal flow shock absorbers, a pop-up heat shield and a new seal and groove design able to accommodate the effects of a fire accident. The body is a monolithic structure and has a pop-up heat shield fitted to the base. The first 5 bodies were manufactured using a full penetration slag welding process and 25 were made from a one piece forging. (Figure 2)

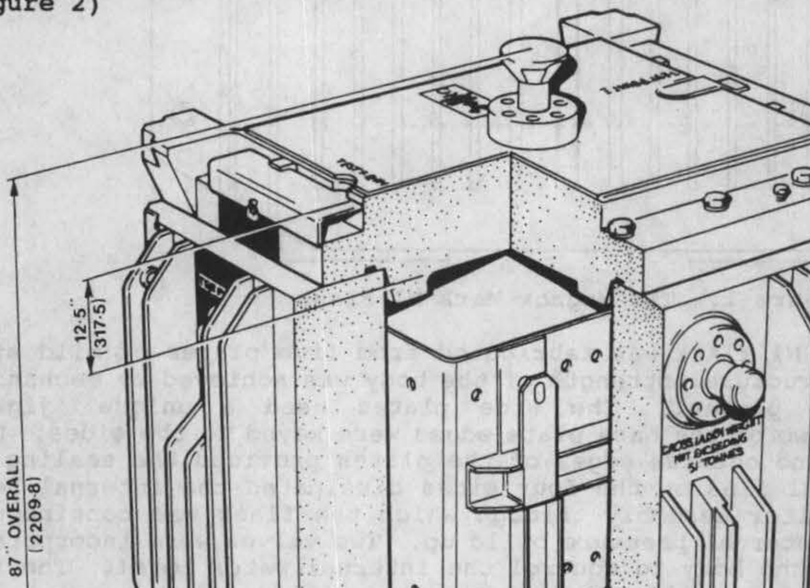

Figure 2. The Magnox Mark M2 Flask.

The Magnox Mark M2 flask design was introduced into service in the early 1980's. As a matter of policy the company has decided to seek to demonstrate full compliance with the 1985 IAEA Regulations, rather than to rely on the "grandfathering" provisions included in those regulations. A full review of the design, and of QA arrangements for design, manufacture and procurement has been undertaken. As a result, a programme of minor modifications to the sealing system has been drawn up and will be commenced shortly.

AGR Flask Early Designs

The first AGR flask came into service in 1977. (Figure 3) It has similar appearance and dimensions to the Magnox flask and is a cuboid shape. The major difference is that the body is a composite construction. It has an outer containment fabricated from a 90mm thick steel plate and a 153mm inner lead liner. This is cast into a 12.5mm thick stainless steel skin and provides the major shielding.

A one piece steel lid is located with a spigot on to the steel body and retained by thirty two 50mm high tensile steel bolts to the body flange. Twin 'o' section elastomeric seals are retained in seal grooves in the underside of the lid. They provide containment and enable pre-despatch seal performance of the sealed joint between the lid and body to be measured. 20 AGR fuel element assemblies are carried in a boronated stainless steel skip in a vertical attitude. Like the Magnox flasks, water is used to provide the internal heat transfer from the elements to the flask walls.

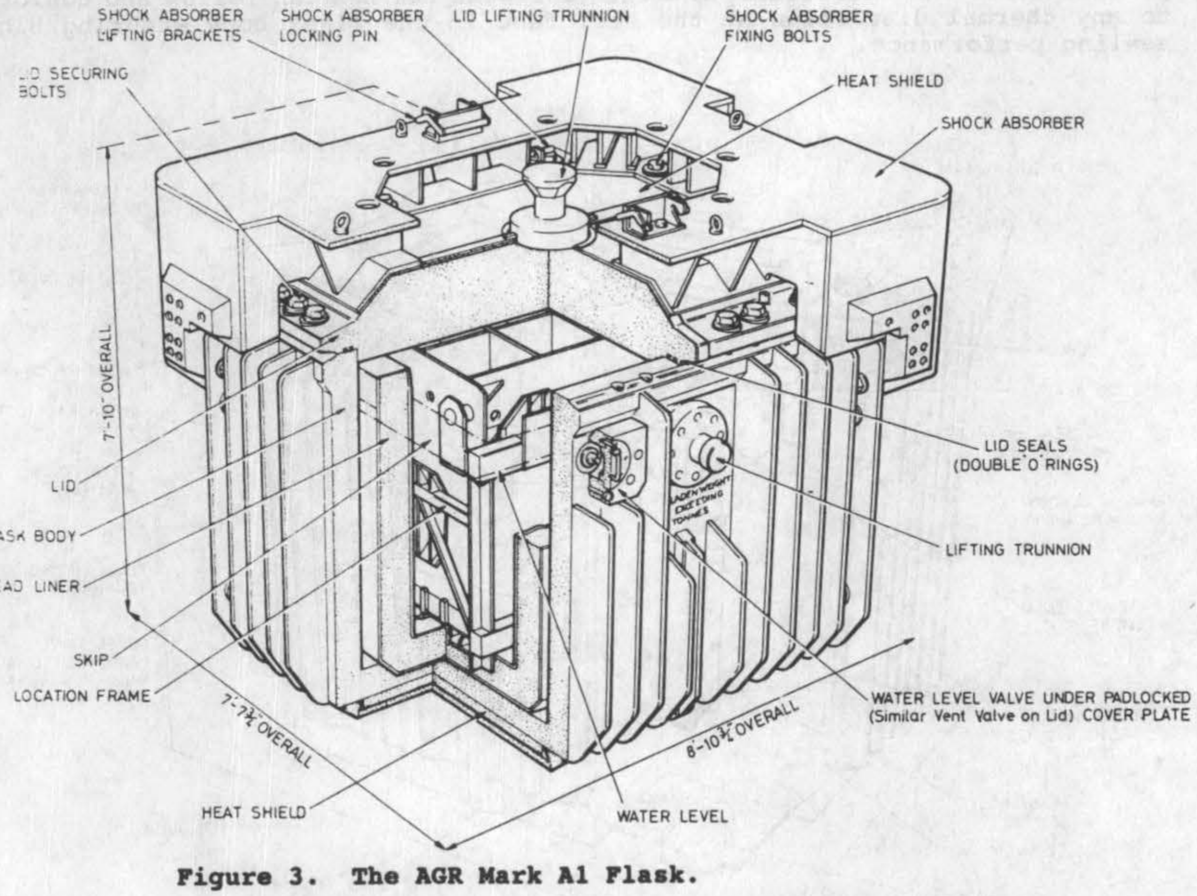

Figure 3. The AGR Mark A1 Flask.

Protection is provided to the lid and body sealing faces seals in the IAEA Regulatory impact and fire accident qualification tests by a detachable shock absorber. This is fabricated from 25mm thick aluminium alloy plate and is coated with an intumescent material which prevents the shock absorber from melting. The shock absorber also acts as a heat shield to the lid and seals.

AGR Mark A2 Flask

The commissioning of further AGR power stations necessitated additional AGR transport flasks. Rather than procure more A1 flasks the opportunity was taken by the CEGB to produce a flask which would provide continued operation for the next 30 years. This required that the flasks should be capable of carrying fuel arising from higher burnup fuel cycles being planned.

Design work on the AGR Mark A2 commenced in 1981 and the first of the new flask was introduced into service in February 1991. It represents the optimal design of flask incorporating features identified as a result of operational experience with irradiated fuel transport by CEGB gained since 1962. (figure 4) Once again, the new design had to fit into the existing A1 flask external cuboid envelope such that it fitted into the existing flask handling equipment at the AGR power stations.

The AGR Mark A2 flask has a monolithic steel body made from a single forging. The shield lid is inset into the body and retained by sixteen chocks (or wedges). Sealing and containment is provided by a lid seal member (LSM). This is a stainless steel flange and diaphragm fitted under the shield lid. Twenty eight bolts hold the flange of the LSM, together with its dual seals, to the flask body. The LSM isolates the flask sealing function from the disruptive effects of an impact or/and fire accident on the outer lid. Impact capability is provided by the inset lid design and integral shock absorbers. An impact on to a lid edge or corner of this flask simply bends the corner over to provide added lid retention. In a fire accident the LSM can follow and conform to any thermal distortion at the seal face in the flask body ensuring high sealing performance.

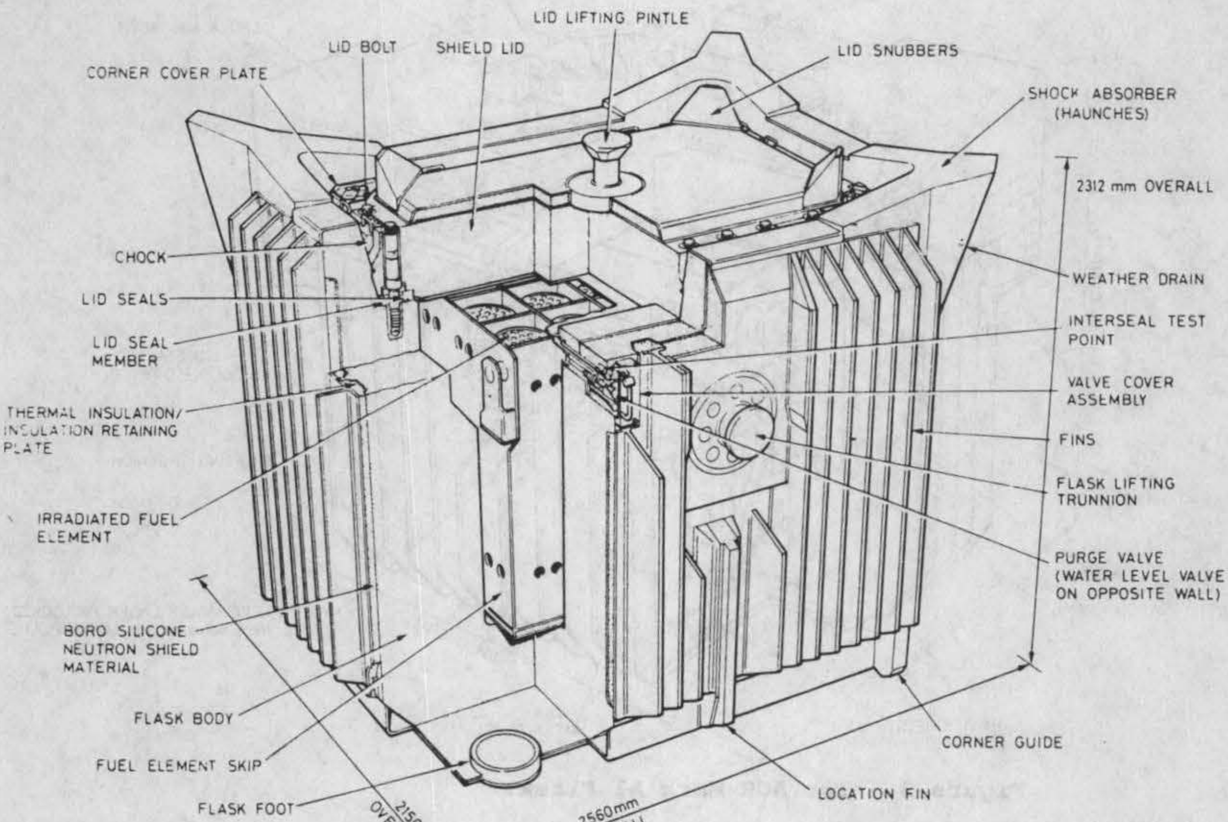

Figure 4. The AGR Mark A2 Flask.

As well as the shielding offered by the steel walls of the flask, additional neutron shielding is provided with the use of borosilicone injected in the hollow fins. The hollow fins also limit the heat flow into the flask walls in a fire accident. The irradiated fuel elements are carried vertically in a fifteen compartment stainless steel skip and are submerged under water. The separating grids in the skip are fabricated from stainless steel plate containing 0.7% boron. A more detailed description of this flask is given in Blythe R.A. and Wood I.A. 1989.

Flask Transport Operations.

In all but one station, irradiated fuel is stored under water at the power station in a purpose built 'pond'. Removal of the fuel from the ponds in most cases requires the immersion of the flask into the pond where the fuel transfer is carried out. The lid removal and replacement are also undertaken under water.

The preparation of the flask for transport includes decontamination of the outside surfaces. This is carried out using special cleaning compounds and in some stations power washing machines. The decontamination operation has been made easier over the years by the careful control of station pond chemistry and the development of the flask epoxy paint finish. The lid bolts are torque tightened using powered torque control equipment that provides a print-out of the torque values achieved. The pre-despatch leak tightness standard of the valves and the main lid seals is measured by pressurising the seal interspace and measuring the pressure decay over a fixed period of time.

The sealing integrity test has been the subject of much development and has resulted in the design of new semi-automatic test equipment to measure the sealing performance of the flask seals. This equipment is microprocessor controlled and takes all flask seals through a sequence of stages including excess water removal and seal drying before carrying out the leakage measurements. Temperature compensation for changes of interseal pressure during flask warm-up is also provided. A pre-despatch print out of the sealing performance is produced at the end of the test. The equipment, once started, releases the operator to do other tasks as it requires little intervention. A programme to install this new equipment at the power stations will commence during 1992.

Nuclear Electric and Scottish Nuclear operate a combined in-service fleet of 30 Magnox Mark M2 flasks, 12 AGR Mark A1 and 24 AGR Mark A2 flasks. Nuclear Electric is at present transporting an average of 16 loaded flasks per week from its power stations to the reprocessing plant. This represents approximately 750 movements or 950 tonnes of fuel transported per year. In most cases the flask is first transported by road to a purpose built railhead, close to the power station, where it is transferred to a purpose built rail vehicle. Road and rail vehicles are fitted with a ventilated sliding cover to reduce flask cleaning operations. At some of the newer power stations the rail line goes right into the power station thus avoiding the road journey.

Nuclear Electric operates a company train system with British Rail whereby only flasks are carried on a train. The rail journey is the responsibility of BR who marshal the flasks into trainloads. The journey from the power station to the reprocessing plant is completed in less than 24 hours. Nuclear Electric maintain a flask operating database which is updated at each stage of the journey. It provides an instant knowledge of the situation of each flask at any time together with an operational lifetime case history of each flask, skip and rail wagon.

The logistics of the flask transport operation are based on each station's fuel arisings and planned pond stocks being combined into an annual flask allocation plan. This plan is the target for the year but three monthly and weekly programmes are also used to ensure the day to day operation is optimised. Difficulties can occur at any time at any location in the operation and careful management of the operation ensures high levels of fuel movement at minimum cost.

Flask Operating Experience Reporting System

In order to control the operational state of the flask fleet a computerised reporting system was set up in 1985 utilising the Nuclear Electric main frame computer. This database (FLASK2) is used to record and monitor the operating problems and analyse the performance of its fleet of flasks. Each flask operating site has on line access to the NE mainframe database (FLASK2) and is required to enter reports when problems are experienced upon receipt or despatch of a flask.

The Database Administrator monitors all reports daily and enters them into the database. Each report is given a subject category in the database according to the type of problem experienced. Categories include valves, seals, paint, debris, bolts, locks etc. Where the Database Administrator is made aware of a event which will require repair or maintenance, advance notice is given to BNFL to take remedial action upon receipt of the flask from the reporting power station.

Analysis of the database reports is carried out to identify trends. These are brought to the attention of the designers and in some cases have resulted in a design change and flask modification. The database also enables all power stations in the company to share operating experience.

This database forms part of the NE QA arrangements in ensuring that its flask fleet meet the requirements of the Approval Certificate issued by the UK licensing authority The Department of Transport.

Flask Maintenance.

Planned maintenance is carried out on each flask in order to ensure its operating performance does not deteriorate from that defined in the Package Design Safety Report (PDSR). This work is carried out by BNFL under contract in a purpose built active workshop at Sellafield.

Magnox and AGR flasks are withdrawn from service for a short period to enable a formal inspection to be carried out every 12 months (approximately every 25 trips). The areas of the flask inspected include the condition of paint, lid bolt retaining threads, lid bolts, Seals and Sealing faces.

In addition planned biennial maintenance is also carried out on all flasks. The work carried out is much more extensive and can take up to 3 months. The flask is thoroughly decontaminated. The sealing faces and other stainless steel clad areas are protected, before grit blasting (inside and outside) to remove the paint and reveal bare metal. Where necessary, standard repairs are carried out. These have been demonstrated to the regulatory authority not to compromise the flask performance as defined in the PDSR. They include replacement of a bolt insert in a flask body, the repair of a damaged seal face by building up with weld metal and remachining, etc. Valves and main lid seals are replaced. The flask is finally repainted, checked out and returned to service.

Transport Accident Emergency Plan

The Irradiated Fuel Transport Flask Emergency Plan for England and Wales (IFTFEP) is administered by Nuclear Electric and provides rapid response by the public emergency services and health physicists to the scene of any irradiated fuel transport accident irrespective of consignor. It is regularly exercised by all participants. As well as providing training for all participants, exercises have identified aspects of the plan for improvement which has been undertaken.

The essential feature of the plan is the communication chain whereby the train guard or driver activate alerting arrangements which first bring the fire service, police and ambulance to the scene. The nearest nuclear power station is also alerted and takes over the role of coordinating the response to the emergency. Once alerted, this Nominated Power Station sends to the scene health physics support and an emergency team with a knowledge of the flask features who can carry out any remedial action. In accordance with the Plan, other organisations ("Agencies") may also be called to send out health physicists if they can get to the scene before the power station health physicist.

The identification and alerting of the nearest power station and in some cases an Agency health physicist is carried out by a central Alerting Officer located in the BR headquarters.

Quality Assurance

Each management unit with responsibility for flask design, procurement and operation within Nuclear Electric has a quality assurance document system comprising, QA programme, Procedures, QA Plans and Working Instructions. The Irradiated Fuel Transport Quality Assurance Programme for overall control of the flask fleet calls for the provision of a quality system for the handling and despatch of irradiated fuel on each site.

British Standards Institution Standard BS5882 has been adopted by Nuclear Electric as the basis for operational QA systems for nuclear power stations. The QA Programme for Irradiated Fuel Transport therefore adopted the same standard for operational activities and BS5750 for flask design and procurement activities. The specification for flask handling, preparation and testing and despatch are provided in the form of a Package Operations Manual, derived from the Package Design Safety Report.

The power station quality plans for flask preparation and despatch are prepared from the Package Operations Manual, power station operating instructions and power station quality assurance programmes.

Public Relations

Nuclear Electric's policy is one of openness so that members of the public are aware of our activities, any fears are eliminated and they have confidence in the safety of the operation. Visitors are welcome at our power stations, all but one of which have visitor centres where information is available on irradiated fuel transport. Company representatives spend time talking to interested parties such as clubs, societies, learned bodies, councils or any member of the general public if there is a question or request to provide information about Nuclear Electric irradiated fuel transport operation. Members of local councils etc. are invited to observe exercises of the flask emergency plan, and the media also normally attend.

The most effective demonstration of the adequacy of the accident requirements of the IAEA regulations, and the integrity of a flask designed to meet them, was the full scale crash of a locomotive travelling at 100mph into a Magnox flask. Although it was carried out in 1984 it still speaks more effectively than words as the most convincing demonstration to the general public of the safety of the Nuclear Electric irradiated fuel transport operation. (I.Mech. E. 1985)

Conclusion.

Nuclear Electric is a leader in the field of irradiated fuel transport having transported fuel successfully without significant mishap, and without any accident involving the release of radioactivity, for 30 years. Over 21,000 tonnes of spent fuel, in about 13000 loaded flask movements, over 4 million flask miles. Nuclear Electric is proud to acknowledge CEGB's achievements and to be its successor.

Nuclear Electric flask designs have been developed to maintain the highest standards of safety and compliance with the IAEA Regulations. Its second generation of flask designs should be adequate to meet the lifetime needs of the gas cooled reactor programme.

References.
Blythe, R.A., and Wood, I.A. "Mk A2 AGR Irradiated Fuel Flask, A New UK Flask Design", PATRAM 1989.
I.Mech.E. seminar, 1st May 1985. "The Resistance to Impact of Spent Fuel Transport Flasks"