# THE DEVELOPMENT AND STATUS OF TEST FACILITIES AT WINFRITH TO STUDY THE PACKAGING, HANDLING AND TRANSPORT OF RADIOACTIVE MATERIALS

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## ABSTRACT

The United Kingdom Atomic Energy Authority (UKAEA) in general and the Winfrith Atomic Energy Establishment in particular have specialized in safety assessments which have much in common with the steps involved in the development of a radioactive materials transport package. It is natural therefore for Winfrith to have built up considerable expertise on radioactive materials transport and related topics. This paper gives a broad review of the development and status of the test of facilities at Winfrith to study the packaging, handling and transport materials between sites. In parallel, there is a broad program of theoretical and practical work for commercial customers.

## INTRODUCTION

Winfrith Atomic Energy Establishment, one of the main sites of the United Kingdom Atomic Energy Authority (UKAEA) was set up in the late 1950s to carry out research and development in support of the emerging United Kingdom Nuclear Power Program. Plans for the site included locations for experimental and power reactors in satellite parks around a set of central facilities. In practice, two reactors have been built, the 20 MW(TH) DRAGON High Temperature Gas-Cooled Reactor, now shut down, and the 100 MW(e) Steam Generating Heavy Water Reactor (SGHWR) which supplies electricity to the National Grid. The work at Winfrith has expanded to cover most operational aspects of nuclear technology as well as a significant involvement in non-nuclear research and development, such as enhanced oil recovery. The wide-ranging nature of the nuclear program includes such topics as reactor physics, radiation shielding, criticality, reactor safety studies, heat transfer, control engineering and instrumentation as well as radioactive waste plant and process development. There is also a long term program of investigation into the behavior of power reactor fuels particularly from the UK nuclear program involving post-irradiation examination in large shielded cells.

The breadth of scientific and technical disciplines gives Winfrith a special position in the United Kingdom (UK) as a main center of expertise on radioactive material packaging and transport. Other establishments of the UKAEA have relevant experience which can be called on if needed. Although Winfrith is primarily a research and development center it also has the practical benefit of having an operational power reactor on site. This involves the transport of liquid and solid effluents including ion exchange resins and sludges from water treatment and reactor primary circuit decontamination.

## WINFRITH FACILITIES AND CAPABILITY

### Design

Winfrith design teams have been involved in the development of the site's transport test facilities as well as in studies of flask and package designs. A companion paper at this conference describes the development of an unshielded 500 litre stainless steel drum for the cement encapsulation, storage and disposal of what are known in the UK as 'intermediate' level solid and sludge waste(1). A study of large transport containers for decommissioning waste, partly funded by the Commission of the European Communities, has recently been completed. This was a joint enterprise carried out by Winfrith, the Windscale Laboratory (another establishment of the UKAEA) and Ove Arup and Partners. The main emphasis was on the design of large shielded industrial packages for decommissioning waste. In the UK, the cost of underground disposal is still somewhat uncertain, primarily because a national disposal site is unlikely to be operational before 2005. Under these circumstances, the package design which is most robust against disposal price increases is one where the payload is grouted with cement and provided with an outer steel shield for transport purposes. The bare package is the disposal unit while the steel shield is returned for reuse. The package is as large as can be transported on the UK rail system at 60/65 tons all-up weight and is cuboidal in shape.

### Manufacture

Winfrith has the capability of manufacturing medium-sized flasks (2). Units of up to 25 tons can be handled by the workshops. Such manufacture is subject to the quality assurance requirements of the 1985 edition of the IAEA Transport Regulations (3) allowing Type B(U) approval to be obtained.

### Shielding and Criticality

The UKAEA Shield Group is located at Winfrith where the members have been responsible for developing computer codes used to design and assess power reactor biological shield functions. The NESTOR reactor (a 30 Kw source reactor (4)) is used for realistic simulations of shield geometry and materials, so the computer codes are validated by comparison with well-instrumented experiments. A necessary consequence has been the development of sophisticated instruments to provide the sensitivity, accuracy and discrimination needed for such validation work (5).

The shielding codes have been developed in paralled with the reactor physics codes for reactor core analysis and design. However, the peculiar needs of shielding calculations, primarily the huge range of neutron and gamma ray fluxes to be accommodated within a single calculation, has led to the adoption of Monte Carlo techniques for the "best estimates" methods. The McBEND code (6) provides the most detailed geometrical capability coupled with point gamma energy date sets and a detailed treatment of neutrons coupled to provide secondary gamma sources.

Simpler, more efficient, codes such as RANKERN and FENDER (6) have been developed to provide data for the development of shield designs. Efficiency and economy of use are traded for modelling accuracy, so it is important to understand the limitations of such codes and the boundaries of the areas where they can be applied. A bench-mark exercise, organized by the OECD Nuclear Energy Agency, is currently providing comparisons between shielding codes from member countries (7). It is already apparent that the use of group cross-sections, and other simplifications such as the kernel method, introduce errors which are unacceptable at the extremes of assessment requirements (7).

Monte Carlo techniques are also used in criticality codes, notably the UK program MONK. Because of the similarity with shielding methods, the development of the code is also responsibility of Reactor Physics Division at Winfrith. MONK has unlimited capabilities to represent complex geometries and can be used with detailed point cross-section data or economical group data. It incorporates several novel improvements in computational efficiency, some of which are shared by the shielding codes.

The reactor physics methods developed at Winfrith for reactor core analysis incorporate valuable validation experience and nuclear date of known accuracy. The WIMS suite of codes (6) incorporates solution methods ranging from diffusion theory to collision probability and efficiency of these techniques, coupled with few-group data, condensed over appropriate neutron spectra, makes them very attractive for demonstration of subcritical multiplications far from unity where geometrical detail and accuracy are unimportant. They are also used to confirm more detailed MONK calculations where enhanced confidence is demanded.

These criticality and shielding codes are fully validated and subject to quality assurance. They are offered as a package providing access to the codes, advice on their use, and technical help for problems as a subscription service under the title ANSWERS. The codes can be provided to run on a variety of machines or access to the computers at Winfrith, Harwell and Risley may be chosen.

## Thermal Analysis and Fire Tests

Radioactive materials generate heat as a result of the radioactive decay. This heat dissipation is important for the highly active materials, irradiated fuel and vitrified wastes, for example, and may be of concern where large volumes of lower activity materials are stored in close proximity. Fire is generally a hazard, the results of which must be assessed for transport and storage situations.

Winfrith has a long history of practical tests on heat dissipation characteristics for transport flasks (9). This work is based on the simulate conditions in reactor cores and pressure circuits, both during normal operation and in accident conditions. There is therefore much experience with pressure circuits, fluid flow measurements, electrical simulation of nuclear heat generation and the associated instruments.

The practical program has included detailed study of many heat dissipation processes; in particular heat transfer from large finned surfaces, thermosyphon flow and evaporation/condensation cycles.

Computer codes have been developed to model both heat dissipation and fire test conditions. These are based on the general purpose, finite element code TAU (10), a purpose-built code FLUFF (11) for fin heat transfer and a dry pin array heat transfer code RIGG (12). Each of these has featured in a thermal benchmark exercise organized by the OECED Nuclear Energy Agency and reported in Ref 13.

The analysis of large pool fire experiments has shown that conditions within the flames are difficult to analyze and model (14). This is, in part, because "flame" thermocouples may respond to radiation emanating from a relatively large volume of flames, the flask surface and regions outside the fires. They do not necessarily represent local flame conditions. A variety of assumptions of flame temperature and flame and surface emissivities can be combined to reproduce the heat flux from the flames to the package surface. The variation of heat flux over the surface of a large body within a fire is difficult to predict with such semi-empirical models. It is clear that a more realistic model of a fire must be used with experimental data obtained from uniform and stable fires. This model should represent the distributed radiation source and the absorption of radiation by the flames and smoke. The current experimental program is aimed at improving the understanding of such fire test phenomena.

A pool fire test facility has been built at Winfrith (Fig. 1) to provide both fundamental data to improve our understanding of fires and a practical test bed for package prototypes.

Although a pool fire appears to be a relatively simple concept, the practical situation is much more complex. A series of tests to establish stable and uniform flame cover has been completed. Even with zero external winds, the fire will draw in large volumes of air generating local winds which, with even minor differences around the fire, will introduce significant asymmetries. A box-type wind-break greatly modifies the characteristics of the fire which are very sensitive to the size, shape and location of vent to introduce air to the box. A preferred option is to arrange cruciform or cross-over walls beneath the flask which reduce the transverse flow of air and therefore minimize the asymmetry without modifying the air supply.

The IAEA Transport Regulations (3) specify the fire test in terms of the geometry of the fuel pool. This provides a relatively simple objective for practical tests. In contrast, the NUREG fire test is specified in terms of a thickness of flame cover. This is both difficult to achieve without the possibility of measure as evidence of a successful test. Directional Flame Thermocouples have been developed at

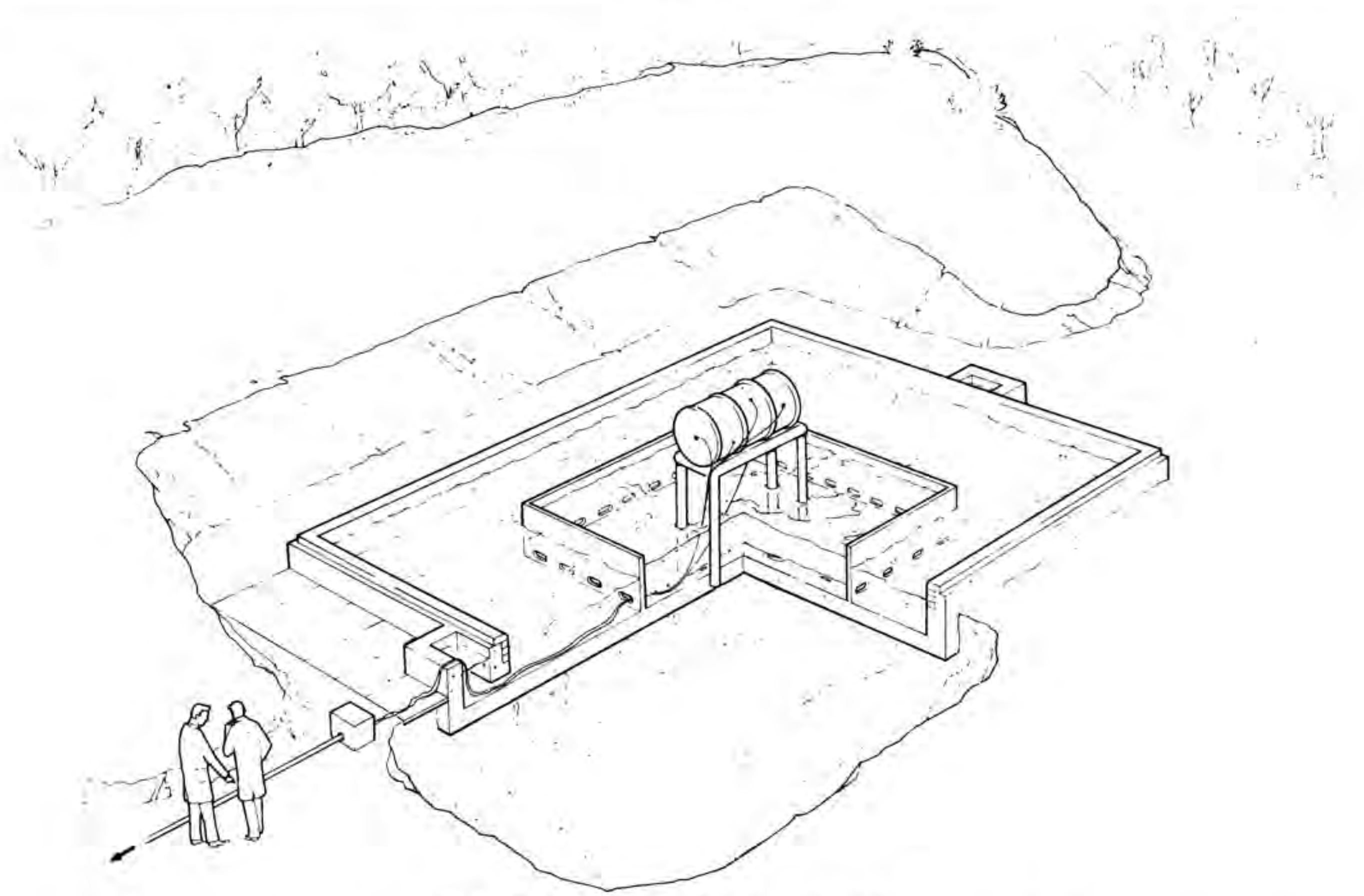

Fig. 1. The Winfrith Pool Fire Test Facility.

Winfrith to provide data the analysis of which enables an effective flame thickness to be derived.

It is sensible to design type B transport packages to survive the most stringent interpretation of the IAEA fire test with confidence that a "failure precipice" is not approached when allowance is made for uncertainties in calculations. A good model of a practical fire, with data validated by experiment, is required for such design work and for subsequent design assessments. The object of the basic experimental program is to provide such evidence as validation for the computer models and justification for boundary condition assumptions.

Currently an extensive program of work, with the Harwell Laboratory of the UKAEA, to study the behavior of waste packages is under way jointly funded by UK NIREX Ltd and the Commissions of the European Communities. The accent, in contrast to most other non-nuclear fire test work, is on what happens within the fire. The drum provides the containment for cemented ILW during the transport, storage and, ultimately, the disposal conditions. While overpacks may provide both shielding and impact protection during the transport, the containment function of the drum will remain important.

<u>Impact Testing and Analysis</u>

The IAEA Transport Regulations (3) define tests to simulate accident and other conditions to ensure that no realistic situation will increase the risk to the public significantly. These include impact, penetration, crush and immersion tests. The US NUREG requirements extend these, particularly for air-transportable packages, to include dynamic crush and spear tests. Each of these can be performed at Winfrith using a range of facilities capable of all conceivable impacts at either full- or small-scale.

Simple drop tests are performed at an outside facility with a 700 to target and a 150 to capacity crane capable of drops from up to 65 m. Concrete waste packages destined for disposal of decommissioning waste from the Windscale Advanced Gas-Cooled Reactor weighting 40 te have been subjected to regulatory drop tests for Industrial Packages. It has also been demonstrated that a drop from 5 m, such as might occur during a handling mishap, will not destroy the package functions. Another type of regulatory test involves dropping under free fall conditions at -40°C, the lowest ambient temperature for a Type B(U) package. Such a test has been successfully carried out on a 23 te accommodate 500 kg models with drop heights of up to 24 m of which 28 m can be guided (Fig. 2)

The Horizontal Impact Facility (HIF, Fig 3) (15), brought into operation in 1987, extends this capability, particularly for scale models of larger flask design. A compressed air gun can supply 2 MJ of kinetic energy through barrels of 0.5, 1.0 or 2.0 m diameter. A 1000 to steel-faced, prestressed concrete target may be used for regulatory


**Fig. 2. A 40 te Prototype WAGR Concrete Waste Package Prepared for a Flat Base Drop Test.**

impacts, but alternative targets may be interposed using the mass of concrete to provide inertia. Scale modelling is used to demonstrate the integrity of package designs and can also be applied to the extended NUREG requirements for air transportable packages. Thus HIF can be used to impact 2 te models, (representing 138 to prototypes), at 45 m/s (100 mph) or smaller masses (up to 50 kg) at near sonic velocities. As with fire testing, a main object of the impact work is to study the margins to failure.

The impacts are recorded by high speed cameras, viewing orthogonally, and a video camera. The models are instrumented with strain gauges and accelerometers typically providing 40 channels of transient data. Extensive facilities are available for post-impact inspection, particularly dimensional changes in the damaged areas. A variety of leak test methods is used to assess changes to leak tightness of transport packages, ranging from simple pressure loss techniques to helium mass spectrometry.

The HIF is currently engaged in a program of validation tests using 1 tone models of a typical monolithic flask with and without shock absorbers. The data obtained are compared with pre-test calculations using 3 finite elements codes, HONDO II (16), DYNA3D (17) and ABAQUS (18). Material properties are measured for each model and strain rate hardening is included in the calculations using data from Hopkinson pressure bar tests. A particular application

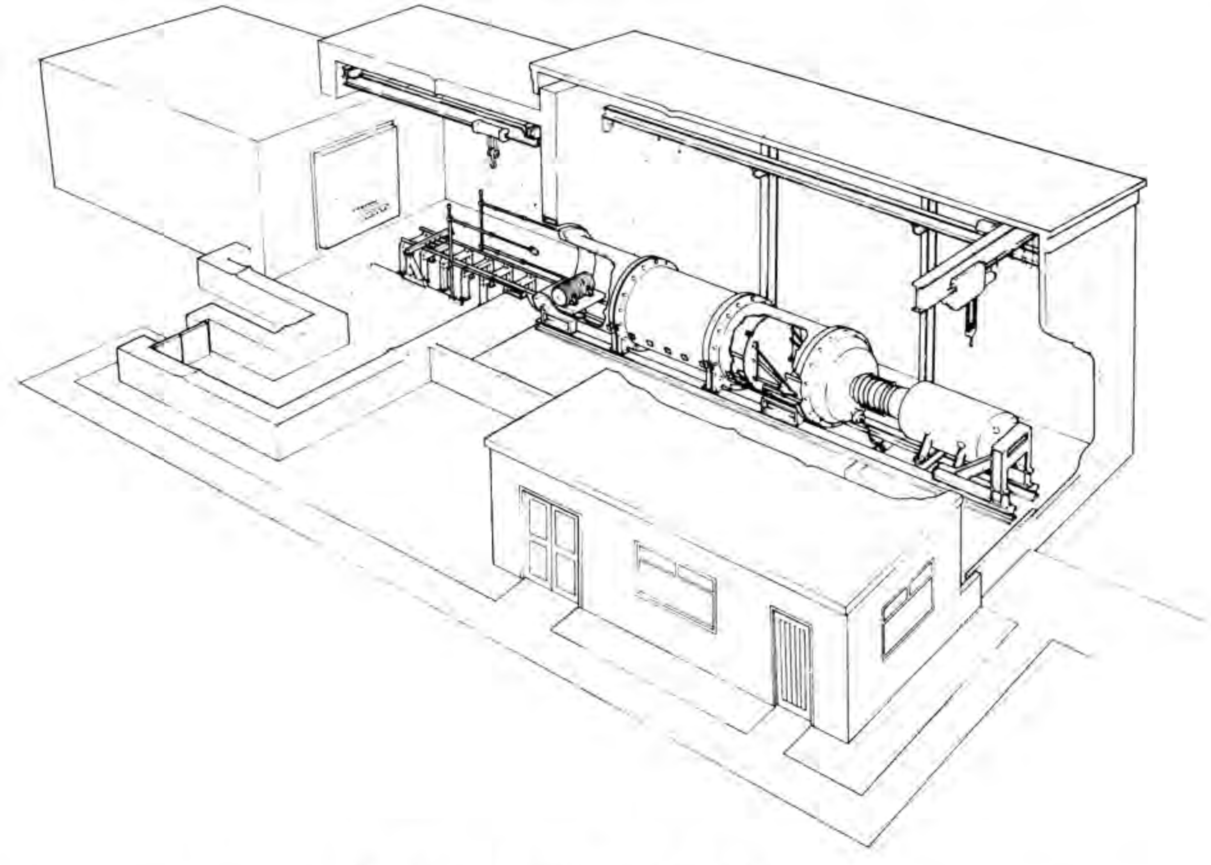

Fig. 3. The Horizontal Impact Facility.

is the validation of modelling techniques for balsa wood filled, shell-type shock absorbers.

The program has demonstrated that DYNA3D is capable of modelling the transient and residual strains resulting from extra-regulatory tests (typically 20 m drops) without shock absorbers. Even minor deviations of less than one degree from purely axial impacts with cylinders invalidate the use of axisymmetric codes such as HONDO II (19).

Frequently the impact test requirements for waste packages are set more by handling considerations than by the test conditions laid down in the IAEA Transport Regulations. Thus the 500 litre drums of cemented intermediate level waste to be produced from the Winfrith Radwaste Treatment Plant and to be stored in the Treated Radwaste Store prior to disposal should survive a 15 m free drop test.

**Immersion, Penetration and Crush Tests**

The test requirements of IAEA and NUREG transport regulations are all provided by facilities of varying sophistication. Small packages of linear dimensions up to about 2 m can be immersed in a water tank at Winfrith at up to 100 psi and there is access to other facilities to reproduce immersion at greater depths.

Penetration tests can be performed in a variety of ways ranging from drop testing onto a punch engineered to provide the maximum damage, in a NUREG test of conical shape, to spears dropped from heights of 50 m or more. The HIF can, of course, provide spear tests of much higher velocity than drop tests and the constraints of barrell size (up to 2 m diameter) are not significant.

A variety of masses in the form of steel slabs, obsolete flasks attached to plates and engineered devices is used for crush tests. The drop test facilities incorporate an engineering workshop which provides the necessary back up such as lifting and support structures to ensure correct orientation in impact and crush tests.

**Design Safety Reports**

The comprehensive nature of services ranging from design and manufacture, through testing and assessment, to operation and maintenance provide a thorough knowledge of the requirements of Competent Authority approvals.

The experience of thermal test on full scale flasks including non-standard conditions of operations has provided a firm basis for temperatures and pressure assessment. The effects of fire are now more predictable with validated calculation methods, so the pessimisms allowed for uncertainties can be minimized.

Practical experience with shielding codes and other design told provides increasing confidence in basic designs with the prospect of reducing development and testing in future. The use of novel materials makes some form of testing inevitable, however.

Experience with flasks designed, manufactured and tested with local resources provides greater confidence in new designs. This is now being exploited commercially.

Transport Technology Center

The unique combination of virtually all the resources and techniques required for the design, manufacture and testing of radioactive materials (RAM) transport packages at Winfrith has been recognized. A small organization has been established to market these skills to organizations transporting radioactive materials and other dangerous goods.

There are similar arrangements to offer other specialized skills which themselves form part of Transport Technology. The Shielding and Criticality work is offered as the ANSWERS service (6). Decontamination forms a separate technology center with an obvious contribution to the maintenance and decommissioning of transport flasks.

The Transport Technology Center contributes to the development of radwaste packaging and disposal options as transport inevitably features in the operations Similarly, decommissioning packages must be designed with transport in mind so interactions are needed at an early stage.

While the regulations for transporting other forms of dangerous goods differ from those for RAM, the techniques for testing and safety assessment are readily adaptable. With the continued high level of safety in RAM transport, it is possible that the requirements for other hazardous materials packaging and transport will be enhanced to match those for RAM transport.

## RADIOACTIVE MATERIALS TRANSPORT OPERATIONS

Although Winfrith is primarily engaged on research and development activities, the presence of a power reactor on the site and other radioactive facilities necessarily generates a variety of wastes. This practical edge to the work leads to about 300 movements each year including the transport of 900 m3 of low level waste to the national repository at Drigg in Cumbria. Such waste is disposed in shallow trenches in specially designed 20 foot long ISO containers.

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