THE ADDITION OF AIR-COOLED DRY VAULT STORAGE

FACILITIES TO OPERATING NUCLEAR PLANTS

D. Deacon, C. J. Ealing, B. R. Cundill
GEC Energy Systems Ltd.,
Whetstone, Leicester, England

B. K. Agarwal
FW Energy Applications Inc.,
Livengston, New Jersey 07029

ABSTRACT

Natuarl thermosyphon, air-cooled dry vault storage offers a passive, economical, operator-friendly, minimum footprint method of extending irradiated fuel storage facilities at a fully operational nuclear power installation. The concept permits the location and integrity of each fuel assembly to be clearly and continuously monitored. Proven, safe and reliable irradiated fuel handling techniques permit easy, routine reception of fuel assemblies into store, and transfer as or when desired to an off-site repository or reprocessing plant.

Experience in the successful design and construction of air-cooled irradiated fuel storage vaults on twin 590 MWe nuclear power plant is reviewed, together with the subsequent 14 vault years of operating experience.

Factors involved in the adaptation of the above experience and development of the concept to suit US light water reactor fuel storage regulatory requirements are examined.

THE MODULAR VAULT DRY STORE (MVDS)

The on-site MVDS provides an economically attractive means of bridging the gap between the time when a given operating nuclear station storage pool loses full core reserve capacity and the time when the proposed Federal Monitored Retrievable Storage (MRS) facilities may be ready. The MVDS covers the circumstances where fuel which has already spent an appropriate period in an existing pool, may be required to be further stored up to several decades before being sent to an MRS. The MVDS can be built on a fully operational power station. It is also possible to add further storage modules as required, again without disturbance to the normal operation of the generating plant.

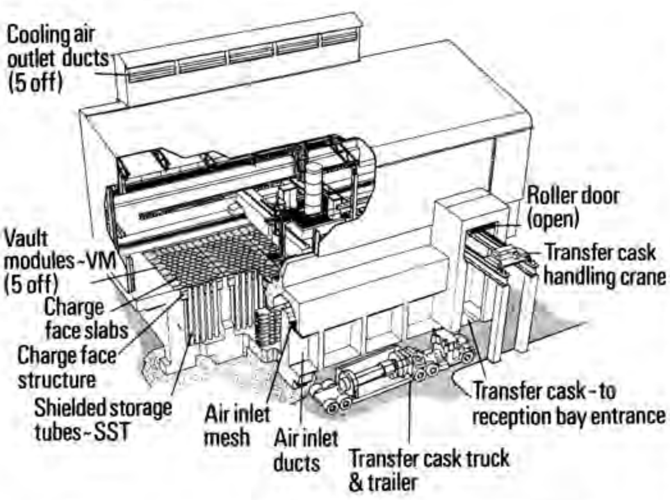

Fig 1. Modular Vault Dry Store Arrangement

The Store (Fig. 1) is designed for the vertical storage of irradiated fuel assemblies. The basic building comprises one or more storage modules with a reception/dispatch facility located at one end. The end remote from the reception/dispatch facility is designed to allow the addition of further storage modules.

Un-containerised irradiated fuel either in its original or consolidated form is stored within a bank of blind-ended tubes (Fig 2). Each tube is plugged and sealed at its upper end and is connected into a common manifold system composed of small bore pipework. The system forms a static, sealed primary containment envelope of high integrity for the stored fuel.

The MVDS design permits selection of either inert gas storage or air environment storage. If required a mode of operation can be adopted whereby the storage environment is changed from inert gas at a slight positive pressure to air at a slight depression when fuel decay heat values have decreased sufficiently to allow air storage temperature limits to be achieved.

Decay heat from the spent fuel is indirectly rejected to the environment entirely by highly reliable passive heat transfer processes. Primary heat rejection from the spent fuel to the sealed containment envelope is by radiation and convection. Secondary heat rejection from the outside of the containment envelope to the environment is produced by a self-regulating natural thermosyphon buoyancy-driven cooling flow using ambient air flowing over the outside of the storage tubes. This cooling air-flow is drawn by buoyancy forces from the outside of the nd vault, via ducting, and then across the tube bank before exiting to the atmosphere via the discharge ducts. The effectiveness of the cooling system is such that maximum fuel pin temperatures will be around 150°C for 5-year decay fuel assemblies.

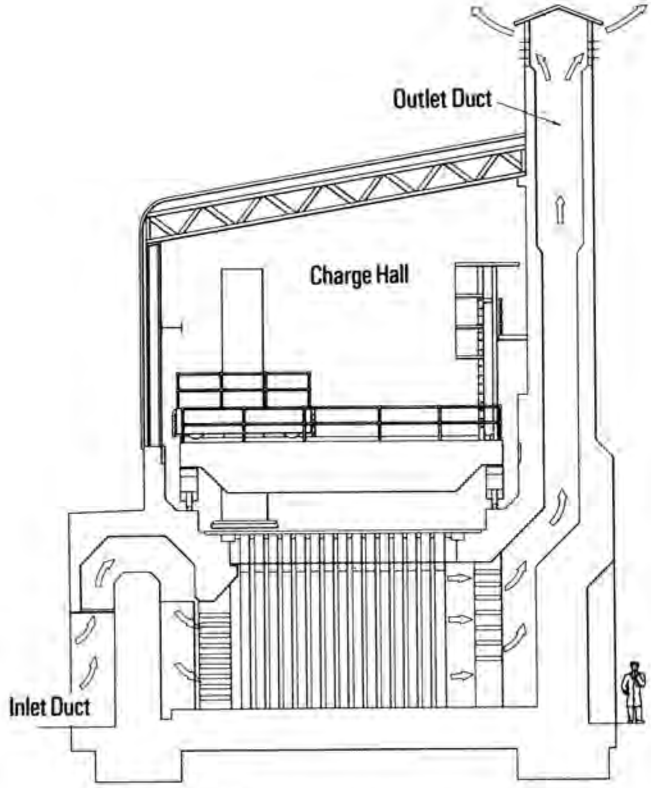

Fig 2. MVDS Natural Convection Cooling

Because the fuel is indirectly cooled there is no contact between the primary gas or air environment within the containment envelope and the secondary cooling air discharged to the atmosphere. Storage tube gas or air flow through the small bore pipework manifold system will be nominally zero in normal circumstances. Monitoring for flow can provide continuous monitoring of the leak-tightness of the containment envelope. Any discharge from the manifold system is filtered. In the unlikely event of degradation of a storage tube, the fuel can be removed at any time using the fuel handling machine, and the tube isolated.

The containment afforded by the storage tubes is surrounded by solid biological shielding. The structural properties of this arrangement, together with the system of storage tube support, also provides protection against extreme external incidents, eg, missile impacts, seismic disturbance, etc.

Irradiated fuel is remotely handled into and out of the storage tubes by a fully shielded handling machine (Fig. 3).

With the storage tubes removed, no permanent steelwork structures (or monitoring pipework) exist within the storage vault, which could be subject to long term *degradation* by corrosion.

The handling machine is capable of incorporating the necessary visual inspection and monitoring equipment so that the fuel assemblies in the tubes can be inspected when desired.

Remote viewing inspection equipment on the machine can visually examine any chosen assembly at any time, simply by visiting the chosen storage tube and hoisting the assembly into the machine. Gamma-ray spectroscopy can also be installed to gain some idea of radioactive inventory and hence irradiation history, burn-up etc. This facility can also provide individual characterisation for each fuel assembly, if required.

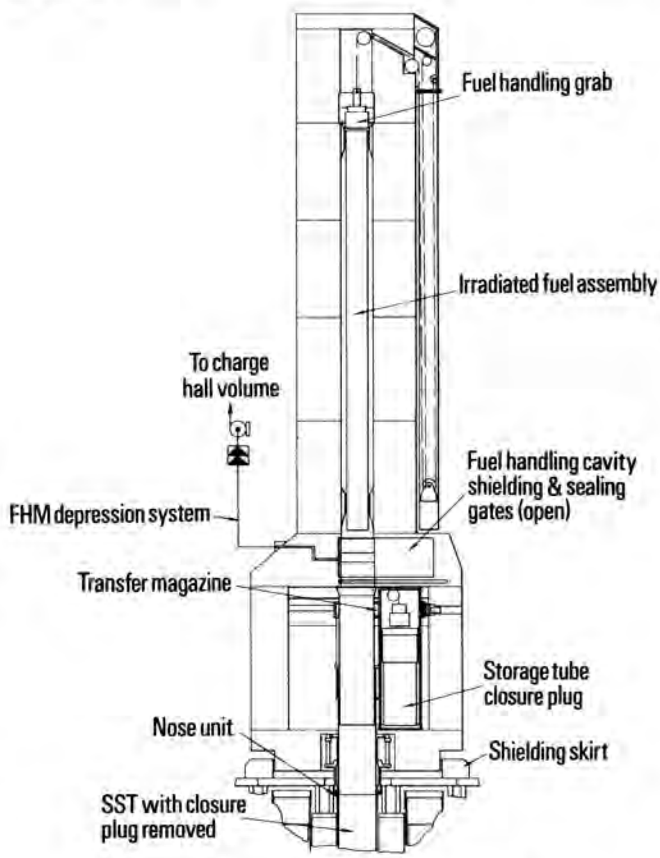

Fig 3. MVDS Fuel Handling Machine

DESIGN CRITERIA

The MVDS system has been designed against the following codes and standards:

- Direct radiation and radionuclide release are below the limits specified in 10CFR20 and 10CFR72 during normal and credible fault situations. The concept ALARA (as low as reasonably achievable) is also applied.
- The storage system and associated plant is designed to maintain the Irradiated Fuel Assembly in its received state and to inhibit the spread of contamination within the storage system.
- The design criteria of ANSI/ANS 57.9.
- The licensing requirements of 10CFR72.

THERMAL PERFORMANCE DEMONSTRATION PROGRAM

The design of the MVDS system has been underwritten by a thermal performance demonstration program to provide confirmatory experimental data to support licensing applications. The practical work has consisted of three main sections:

1. Fuel Temperature Program

Use of a standard PWR fuel assembly with electrical heaters in each fuel pin to demonstrate actual fuel pin temperature distributions over a wide range of normal and abnormal operating conditions. The electrical heaters simulated axial decay heat output profiles and an array of thermocouples measured radial and axial temperature distribution. The fuel assembly was housed in a storage tube which was itself thermocoupled to measure circumferential and axial temperature distributions. Horizontal air flow across the outside of the storage tube gave variable air and storage tube temperature conditions.

2. Store Performance Program

A 1/4 full scale model of store section was used to demonstrate air distribution and storage tube cooling for a range of store operating conditions, allowing direct correlation with the Fuel Temperature Program. An independently variable output electrical heater was located in each storage tube, which was thermocoupled to allow full axial and circumferential temperature distribution to be recorded.

3. Wind Tunnel Test Program

Scale testing in an environmental low speed wind tunnel has demonstrated that wind-induced air flow through a storage module will be from inlet to outlet under all wind conditions and directions.

The cooling air flow path replicated store conditions and the test arrangement allowed a wide range of flow conditions to be examined by using fans to drive the cooling flow. The model also permitted demonstration of natural cooling flow by the inclusion of a chimney.

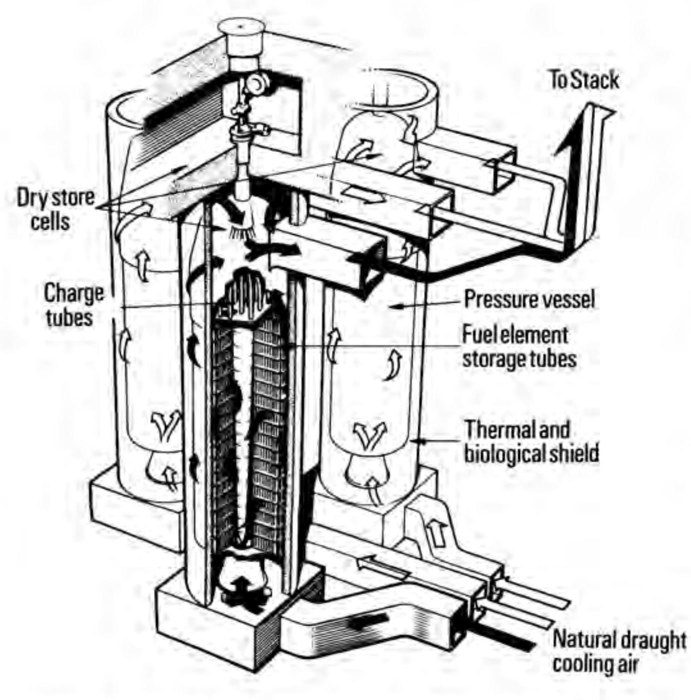

Fig. 4. An 83-ton Capacity Air-Cooled Buffer Store at Wylfa.

REGULATORY PREPARATIONS

The application of MVDS to the storage of either BWR or PWR fuel is the subject of a detailed Generic Topical Report currently being produced by GEC Energy Systems Ltd. in collaboration with FW Energy Applications Inc. for submission to the United States Nuclear Regulatory Commission.

DRY VAULT STORAGE EXPERIENCE

The concept of dry vault storage of irradiated fuel is not new. The 2 x 590MWe Wylfa magnox power station situated in North Wales was designed with three dry storage modules when construction commenced some 22 years ago. Each of these dry stores (Fig. 4) has a capacity of 83 tons and is cooled by completely passive means[1]. Irradiated fuel elements discharged on-load from reactors by a fuelling machine are stacked 12 high in tubes connected at the upper ends to a vessel containing the loading chute. This chute distributes the fuel from the central access standpipe to the tubes. The atmosphere within the tubes if CO_2 at a nominal pressure of 3 psig and a purity of at least 99.8%. The primary mode of decay heat removal from the fuel is by radiation to the tube wall, conduction through the tube and then by natural thermosyphon air cooling.

A CO_2 atmosphere was chose, because the limiting temperature for both uranium and magnox in CO_2 is about 600°C, whereas in air, the limiting temperature for uranium oxidation is 250°C. Very low concentrations of air, e.g. 0.2%, could result in the oxidation of exposed uranium, if it were present, at a rate approaching that of 100% air. Thus, a very high CO_2 purity is required in order to allow the cells to accept fuel direct from the reactors.

The operation and performance of these cells has been very satisfactory since they first came into operational service some 13 years ago. Owing to limitations in the throughput of the Sellafield reprocessing plant, in 1976 it was decided to increase on-site storage of irradiated fuel. Bearing in mind that the existing CO_2 cells can accept freshly irradiated fuel directly from the reactors, the original cells could be used as decay stores so that an air environment could be used for additional storage without exceeding fuel-limiting temperatures.

It was therefore decided to build two air-environment air-cooled storage modules, each with a capacity of 350 tons of irradiated fuel (Fig. 5). The additional modules (designated Cells 4 and 5) were designed and completed in 2½ years and 2 years respectively (Fig. 6).

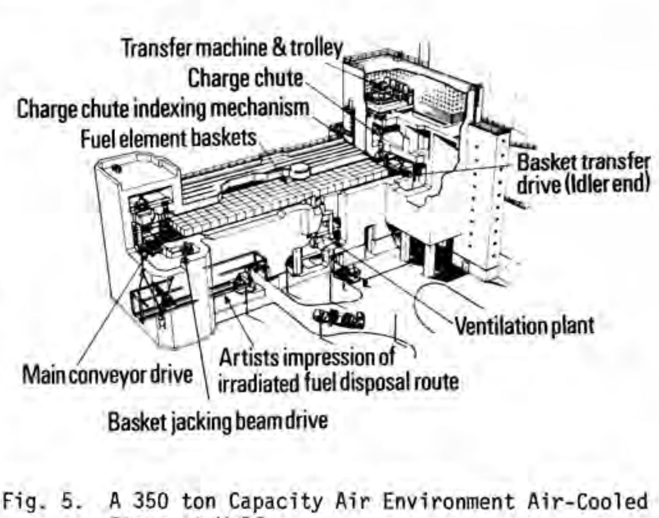

Fig. 5. A 350 ton Capacity Air Environment Air-Cooled Store at Wylfa.

Air inside the new modules is maintained at sub-atmospheric pressure to prevent the possibility of outleakage of any fuel contamination.

Natural thermosyphon was chosen for cooling the fuel within the store. An inherent advantage of natural thermosyphon cooling is that the cooling air does not need to be guided to the hot fuel. By deliberate design, the fuel draws cooling air according to its needs. The higher the heat output from the fuel, the greater the bouyancy head and hence the greater the cooling flow. The bulk heated air is then recirculated and its heat removed by a conventional fan and heat exchanger system embodying adequate redundancy. Five such fan/heat exchanger units are provided in each module, of which four are used for normal operation.

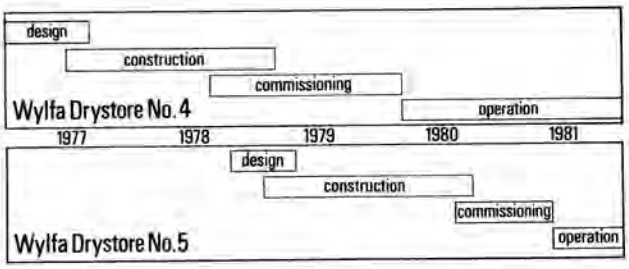

Fig. 6. Schedules Achieved for the two 350 ton Capacity Dry Storage Modules at Wylfa.

When freshly irradiated fuel is removed from the reactor (decay heat typically of the order of 1 kW) or 24 watts per inch length of assembly), it is stored in the CO_2 atmosphere cells for at least 150 days, so that the decay heat reduces to a level acceptable to the air-cooled dry stores. The heat output from a peak rated fuel element in the reactor, having decayed for 150 days, is approximately 46 watts including a 20% margin. The maximum normal temperature of a fuel element when resident in one of these stores is 150°C.

The irradiated fuel is adequately shielded during the transfer operations from the CO_2 modules to the air environment modules. Inside in the air cells the required thickness of reinforced concrete provides the necessary shielding.

The ability to meet the requirement to design equipment and components to prevent fuel element damage at all stages of handling and storage has been confirmed by excellent operating experience with over 200,000 irradiated fuel assemblies (Fig. 7).

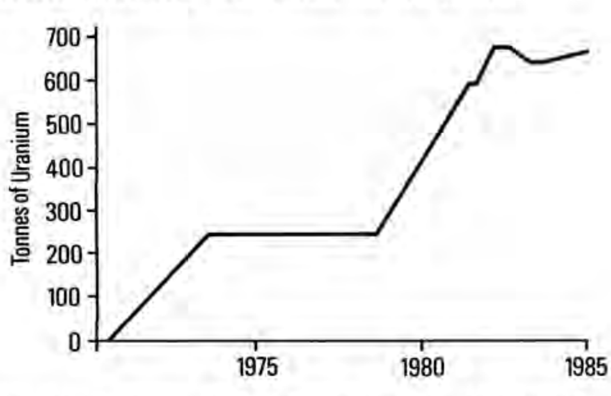

Fig. 7. Quantity of Irradiated Fuel in Air-Cooled Dry Storage at Wylfa.

An important aspect of the addition of the air-cooled storage modules at Wylfa was that the design and construction had to be closely integrated with the existing power station. The design and construction of the new stores was successfully carried out without any interruption to the operation of the existing power station, although the new stores are closely associated structurally and operationally with the original plant (Fig. 8).

The radiation level in operating and accessible areas is similar to the background radiation level ie. 0.0002 m Sv/hr (0.02 mr/hr). Similarly radiation and contamination levels found during routine maintenance (eg. of cooling fans) are typically background radiation level and 3.7 Bq/cm^2 (10^{-4} u Ci/cm^2) respectively[2].

The activity of the circulating air circuit is very low, typical values of gaseous and particulate activity being less than 0.3 Bq/ml (10^{-5} u Ci/ml) and less than 0.37 Bq/m^3 (10 pCi/m^3) respectively. The particulate activity of the filtered exhaust air being discharged to atmosphere is typically less than 0.37 Bq/m^3.[2]

CONSTRUCTION OF MVDS FACILITIES ON A FULLY OPERATING SITE

Based on Wylfa experience, normal operation of an existing nuclear power plant can be preserved during the construction and commissioning of an MVDS installation by arranging for the construction area to be completely isolated from the operational station. In other words, the "station fence" is rerouted if necessary to put the future MVDS on the outside, both physically and administratively. A new permanent site boundary is constructed around the new MVDS but is it only physically linked to the original boundary and the temporary access closed when the new installation has been raised to full nuclear clean conditions and all commissioning tests have been satisfactorily completed.

The layout and arrangement of the MVDS building permits further storage modules to be added to it at future dates, using a similar procedure. Construction of the additional civil works and extension of fuel handling machine crane rails can proceed "outside the

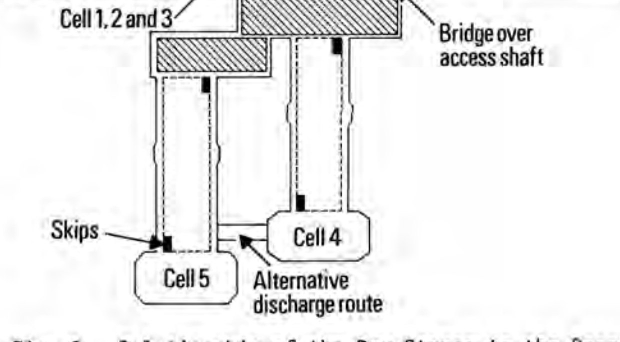

Fig. 8. Relationship of the Dry Stores to the Reactors at Wylfa Power Station.

fence". A temporary clean conditions sealed barrier is erected on the inside of the wall in the handling machine hall opposite to the reception bay end. Removal of this barrier after commissioning tests, brings the additional modules within the operational station boundary.

DRY FUEL HANDLING EXPERIENCE

The on-site MVDS is designed to permit reliable and safe movement of irradiated fuel in and out of storage, without requiring operator standards or expertise greater than those already available on existing plants. MVDS makes use of the proven high reliability on-load dry fuel handling technology used on gas-cooled reactors. GEC Energy Systems have been able to call on their extensive experience in the provision of a wide range of on-load dry refuelling machines, which over the past 20 years have successfully handled a total of over 1.8 million irradiated fuel assemblies.

REFERENCES

1. "Practical Developments on Modular Dry Storage Systems", C. J. Ealing, IAEA Seminar on Technical and Environmental Aspects of Spent Fuel Management, Madrid, Spain, September 1983.

2. IAEA Survey on the Storage of Spent Fuel, CEGB Response, December 1985.