CRITICALITY ASPECTS OF BNFL IRRADIATED FUEL STORAGE FOR DISMANTLED CAGR FUEL

P D Clemson and R T H Mayson
British Nuclear Fuels Reprocessing Engineering Division
Risley, Cheshire, UK. May 1985

Extensive criticality survey calculations have been carried out to investigate the nuclear safety of dismantled CAGR fuel storage. The surveys considered fuel enrichment, storage can diameter, number and configuration of pins within each can, and configuration of storage cans within the fuel storage SKIP. The SKIP itself is contained within a secure outer container, which is stored in an array of similar units in a storage pond. The surveys were required to establish the criticality controls necessary for safe operation of the storage pond. Calculations were carried out using determininistic and Monte Carlo analysis techniques, and have been backed up by critical and sub-critical experiments carried out by the UKAEA in its DIMPLE facility. Results show that control can be achieved by limiting the diameter of the storage can, and by centralizing the cans in the SKIP compartments. No restriction on numbers of pins in each can, or their configuration inside the can, is necessary. The required controls are therefore achieved through engineering and manufacturing constraints, and do not require operational control on the plant.

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INTRODUCTION

Uranium oxide fuel irradiated in the UK Civil Advanced Gas Cooled Reactors (CAGRs) will be stored and subsequently reprocessed by British Nulcear Fuels at its Sellafield site. Following receipt from the reactors the irradiated fuel elements are dismantled and fuel pins stored under water prior to transfer to the reprocessing plant. This paper reviews the criticality aspects of this storage mode, and is based on design analysis work carried out by BNFL's Process and Technical Services (a design support and R&D department within the Reprocessing Engineering Division).

CAGR fuel elements (figure 1) consist of 36 steel clad oxide fuel pins in three annular rings, within a cylindrical graphite sleeve. The fuel pins are tyically 1 m long, 1.5 cm diamter, and unirradiated fuel enrichments are mainly in the range 1-2.5 $^{w}/o$ U235. In the reactor core these elements are stacked to form a "stringer" of eight elements connected be a central tie rod. Following discharge, the elements are disconnected and stored under water at the reactor site as individual units within a storage "SKIP".

The storage SKIP is a rectangular container divided into 20 square section compartments by a 0.6 $^{w}/o$ Boron Steel insert. Twenty irradiated fuel elements are thus stored in a fixed array with neutron absorbing steel compartment walls between adjacent elements. The SKIP is subsequently used as an inner container during fuel transport from the reactor site to Sellafield inside a transport flask (shipping cask).

At Sellafield, SKIPs are remotely removed from the massive shielded transport Flask and relocated inside a steel outer container closed by a bolted lid. These containers are then stored under water in a fuel storage pond. The containers form a large array in the pond, and may be stacked up to three containers deep. Subsequently, containers are to be taken from the pond into the dismantling facility. Here, fuel elements are removed, stripped of graphite and broken down into individual fuel pins. The fuel pins are then re-packed into cylindrical slotted steel cans for return to storage. Fuel pins from three elements (108 pins) are loaded into each can, and each can is returned to a storage SKIP compartment. Thus, for every three containers entering the dismantling facility, one is returned to pond storage with three times the fuel load, and two empty SKIPs and containers are free for futher duty. The SKIP containing dismantled fuel will be eventually transferred from pond storage to the Reprocessing plant feed ponds. The slotted cans are then fed through to shear and dissolution as the first stage of reprocessing.

CRITICALITY ISSUES

Criticality control is readily achieved for fuel in fuel element form by retaining each element within a boron steel absorber compartment. Constraining the SKIP within an outer container closed with a secure lid ensures that elements remain in their SKIP compartments during pond storage. The problem posed by dismantling the fuel is how to triple the fuel loading in each SKIP without compromising criticality safety. An added constraint is that any criticality controls imposed must not hamper plant operations.

It was established that the design of outer container ensured a sufficient water gap between adjacent fuel SKIPs in the pond storage container array to guarantee neutronic isolation. Attention could therefore be directed to the criticality parameters of a single SKIP, and the array of 20 cans within the SKIP.

In order to study the problem, a range of survey calculations were carried out to investigate the sensitivity of SKIP reactivity to the following parameters: fuel enrichment; can diameter; number of pins/can; configuration of pins within the can; configuration of cans within the SKIP.

METHODS AND DATA

The WIMS code [1] was chosen to carry out most of the survey calculations. This method (developed by UKAEA as a reactor lattice code) is cheap enough to permit extenstive studies, and being a deterministic method is well suited to investigating changes in reactivity. The DSN solution method within WIMSD4 was mainly used, but a few cases were repeated using a collision probability option to confirm the adequacy of the DSN treatment. The nucelar data used was derived from the UK Nuclear Data Library processed into the WIMS group energy structure [2]. An eight neutron energy group representation was sufficient for the surveys, this being confirmed by check calculations using 22 and 30 energy groups. As WIMSD requires annular geometry, the square SKIP compartment was "circularized" to give a lattice cell consisting of the compartment wall, the slotted can, and the fuel pins within a water moderator. Estimates of SKIP k-effective were generated by applying a buckling derived from the dimensions of the 20 compartment SKIP.

The WIMS survey calculations were followed by rigorous Monte Carlo analysis using the MONK[3] code. This allows a full 3-D representation of detailed geometry, but suffers from the stochastic limit to its precision common to all Monte Carlo methods which can obscure small changes in reactivity between similar systems. The nuclear data is based on UK Nuclear Data Library "point" energy and requires no processing into a group structure (as 8,000 neutron energy point values are utilized).

The combination of deterministic survey methods with rigorous Monte Carlo was used to advantage by using WIMS to find optimum (peak k-effective) conditions, followed by MONK analysis at the optimum.

RESULTS AND DISCUSSION

It became evident that in addition to fuel enrichment, the main control parameter would be the diameter of the slotted can holding the loose fuel pins. The can could be restrained within the SKIP compartment in the same way as the original element. The problem became one of finding the maximum permissible can diameter assuming; an optimum number of fuel pins at optimum arrangement inside a can, and an optimum position of the cans inside the compartments. (This avoided making the number of pins per can, or their configuration inside the can, criticality control parameters). Many survey calculations were carried out to find the peak reactivity condition given by optimising parameters simultaneously. An iterative approach was adopted which can best be illustrated by showing the change in the k-infinity of the lattice of compartments as major parameters varied.

The first major parameter, fuel enrichment, was set at the maximum unirradiated value anticipated (3.7 $^w/o$ U235). Although only relatively few elements may be manufactured at this enrichment (the vast bulk of fuel being at 1-2.5 $^w/o$ before irradiation) this assumption allows all CAGR fuel to be accepted by the facility without making fuel enrichment or irradiation an operational criticality control parameter.

The can diameter, and optimum number and configuration of pins in a can, proved to be mutually dependent. Table 1 shows the variation in system k-infinity as a function of can diameter. Table 2 shows the change in k-infinity by varying the number and configuration of pins in each can. The sensitivity to fuel pin configuration was particularly interesting. The optimum configuration was found to be a uniform Vm/Vu ratio throughout the can, with a "solid ring" of close packed pins around the inner surface of the can wall (see figure 2). The "solid ring" may be screening the remaining pins from the boron steel absorber at the lattice cell boundary.

The 216 mm diameter can was chosen as the reference design. As this is 20 mm smaller than the fuel element diameter, a further set of surveys was necessary to study the effects of can movement within the compartments. Figure 3 shows two such cases, which required MONK analysis to model the full SKIP geometry. The statistical uncertainty in the calculations made it difficult to calculate the difference in system k-effective with precision. Table 3 shows the estimated sensitivities.

The final optimised configuration was found to be 82 pins per can (arranged in annular rings of 1, 7, 14, 20, 40 pins) in a 216 mm ID can. The possible increase in system k-effective from "grouping" cans will be avoided by initially manufacturing a "centralizing" device on the can. This will ensure that cans cannot move from a central location in each compartment. The need for this device will be checked as part of the underlying experimental programme. Table 4 shows the k-effective estimate for the optimum conditions, and for the expected conditions which will normally apply.

OUTLINE OF UKAEA EXPERIMENTAL WORK

As part of its underlying generic work the UK Atomic Energy Authority carries out critical and sub-critical experiments at its Winfrith (Dorset) site. The DIMPLE research reactor[4] is being used to investigate UO_2 fuel storage configurations, and part of the UKAEA programme included cores of specific interest to BNFL. These cores were built inside an actual boron steel fuel SKIP, which had been mounted inside the DIMPLE core tank, and closely simulated the plant geometry.

This experimental work is of great value in validating the methods and data used in BNFL design analysis. It will also confirm (or hopefully remove) the need to centre cans within the SKIP compartments.

The current status of the experimental work is that the first phase - which included the cores of direct interest for the storage of dismantled CAGR fuel - has been sucessfully completed. The results are currently undergoing evaluation and further discussion is outside the scope of this paper. However, initial indications are that the methods and data compare favorably with the experiment.

CONCLUSIONS

The criticality controls which emerge from this work and the way they can be achieved in plant operation are listed below.

(a) Enrichment Limit.

Set at the maximum unirradiated value. No operational control required on plant (subject to future fuel designs staying within this maximum).

(b) Can Diameter.

Derived by calculation, checked by experiment, controlled by can manufacture. No operational control required on plant (only one can size to be manufactured).

(c) Can Centering Within Compartment.

Derived by calculation, to be checked by experiment, controlled by can manufacture. No operational control required on plant (all cans to be manufactured with centering device, unless experiments subsequently prove this is not necessary).

(d) SKIP Restrained Within Outer Container.

SKIPs are kept within outer containers at all times when under water. The secure container lid prevents fuel movement from the inner SKIP.

It will be noted that there is no criticality control on the number of fuel pins loaded in each can, or any restriction on the pin configuration within a can. This gives flexibility and avoids imposing a criticality control which would hamper operations.

It is apparent that all the required criticality controls have been engineered into the process operations and require no direct operator control. The design analysis shows that the most reactive condition achieved by optimising all the major parameters is safely sub-critical. It should be emphasised that the actual system k-effective in operation will be far below the most reactive condition, as shown in Table 4.

REFERENCES

1. J R Askew, et al., "A General Description of the Lattice Code WIMS", J Brit, Nucl. Energy Soc., 5, 564 (1966).

2. M J Halsall, C J Taubman, "The 1981 WIMS Nuclear Data Library" AEEW - R1442, UKAEA, Atomic Energy Establishment, Winfrith UK (September 1983).

3. UKAEA SRD, "MONK Code Users Manual", (1985) Safety and Reliability Directorate, Culcheth, Warrington, UK.

4. G Ingram, et all., "Critical and Sub-critical Measurements with 3% UO_2 Pins in a Boron Steel Walled CAGR SKIP", ANS Conference, Jackson Wyoming (1985).

Table 1. Sensitivity of SKIP Compartment Reactivity To Storage Can Diameter. (3.7 w/o U_{235})

Can Diameter mm	Optimised N° of pins/can	Compartment Lattice k∞	Reactivity Niles	Change $
229	90	1.02	+ 5.1	+ 7.8
216	82	0.97	0	0
203	60	0.92	- 5.6	- 8.6

Table 2. Sensitivity of SKIP Compartment Reactivity To N° and Configuration of Pins in a Can (3.7 w/o U^{235})

Pin Arrangement	Number of pins/can	Compartment Lattice k∞	Reactivity Niles	Change $
Figure 2.1	61	0.92	- 5.6	- 8.6
Figure 2.2	82	0.94	- 3.3	- 5.1
Figure 2.3	82	0.97	0	0
Figure 2.4	108	0.93	- 4.3	- 6.6

Notes: Reactivity changes quoted relative to 216 mm diameter reference case.

Reactivity change $\Delta\rho = {}^1/k_1 - {}^1/k_2$
$\Delta\rho$ Niles = $100\Delta\rho$
$ = $\Delta\rho / \beta$ where $\beta \simeq 0.0065$ (delayed neutron fraction for Uranium systems)

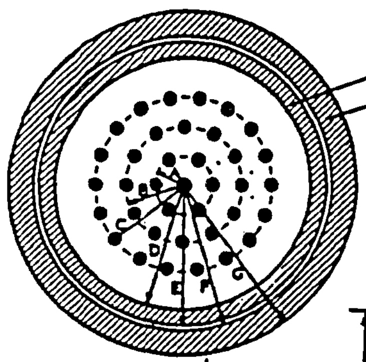
Table 3. Sensitivity of SKIP k-effective To Movements of Storage Cans Within Comparments (3.7 ^{w}/o U_{235})

Configuration	k-effective	$\pm\sigma$	Reactivity Niles	Change $
Optimum conditions, cans centred (As figure 3.1)	0.93	0.006	0	0
Optimum conditions, cans grouped (As Figure 3.2)	0.96	0.006	+ 3.4 ($\pm$ 1)	+ 5.2 ($\pm$ 1.5)

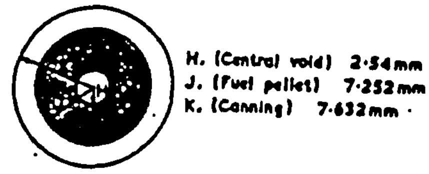
Table 4. Comparison Between SKIP k-effective at Optimum Condition and Routine Conditions.

Configuration	k-effective	$\pm\sigma$	Reactivity Niles	Change $
Optimum conditions	0.93	0.006	0	0
Routine conditions	0.70	0.010	- 35.3 ($\pm$ 1.4)	- 54.3 ($\pm$ 2.2)
Reactivity Changes:				
Enrichment, from 3.7 ^{w}/o to 2.5 ^{w}/o			- 3.7	- 5.7
N^o pins/can, from 82 to 108			- 4.3	- 6.6
Irradiation, from 0 to 18 GWd/t			- 27.3	- 42.0

Note: "Optimum condition" in Table 4 are the most reactive conditions which could apply within criticality control limits. "Routine conditions apply to the expected conditions inoperation (enrichment 2.5 ^{w}/o or less, 108 pins/can, fuel irradiated to 18 GWd/t or greater).



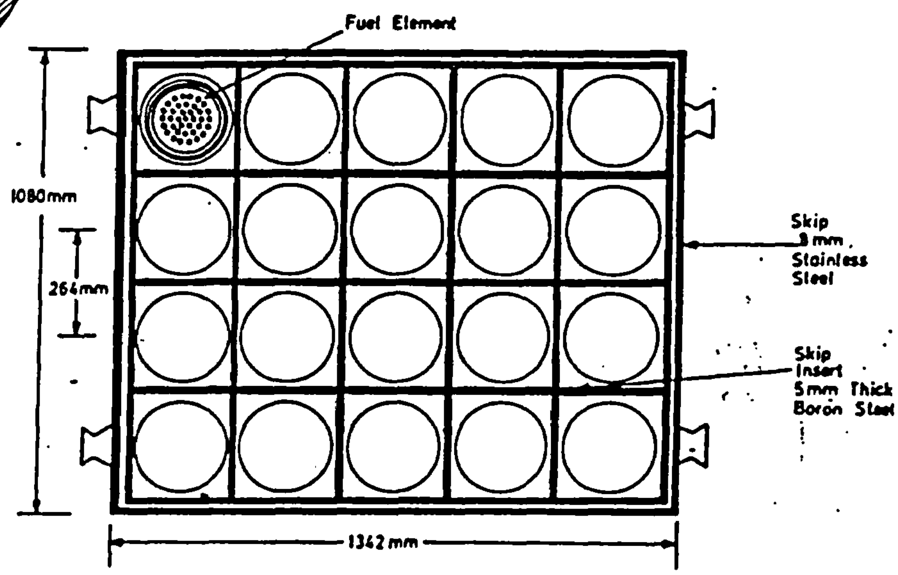
SECTION THROUGH FUEL ELEMENT



FUEL PIN

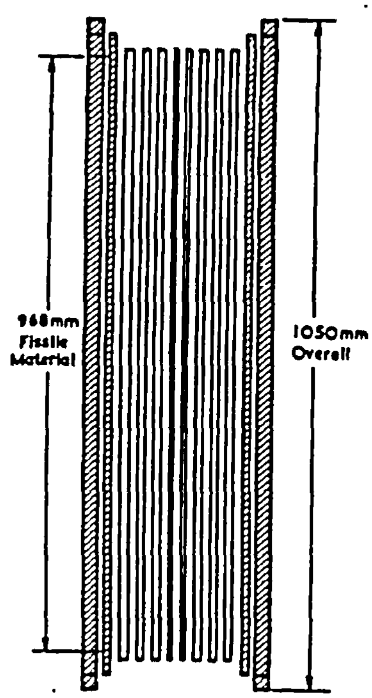
Dimensions

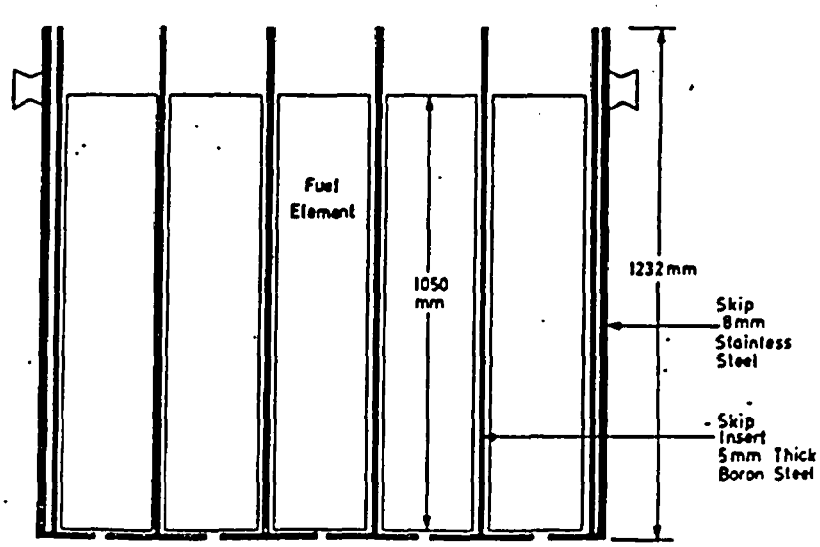
	Dungeness "B" (mm)	Other CAGR Stations (mm)
A	23·24	24·64
B	47·75	50·80
C	73·28	77·98
D	88·90	95·25
E	94·24	101·09
F	96·10	102·87
G	110·84	119·06
Tie-tube	6·85/7·75	7·61/8·06



STANDARD SKIP FOR CAGR ELEMENTS

FIG 1





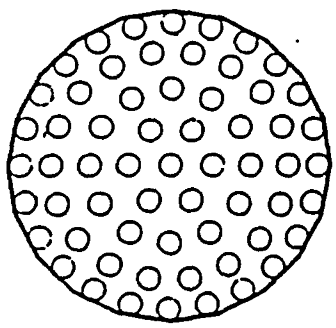


Fig 2.1 61 pins/can

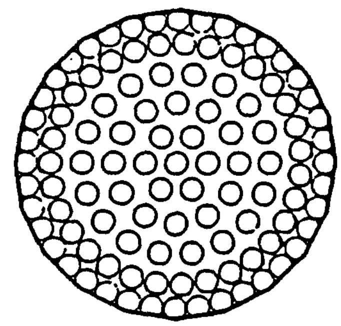


Fig 2.4 108 pins/can

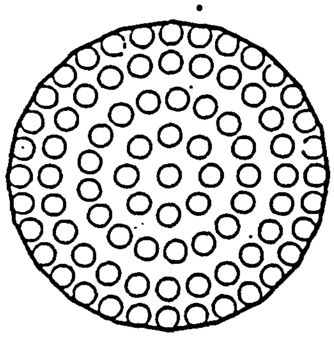


Fig 2.2 82 pins/can
Uniform Distribution

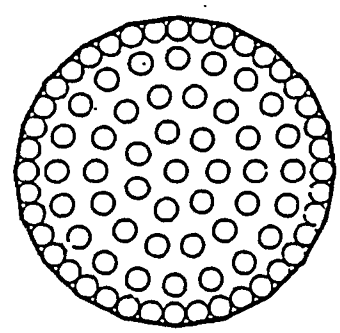


Fig 2.3 82 pins/can
Optimised Distribution

3.1

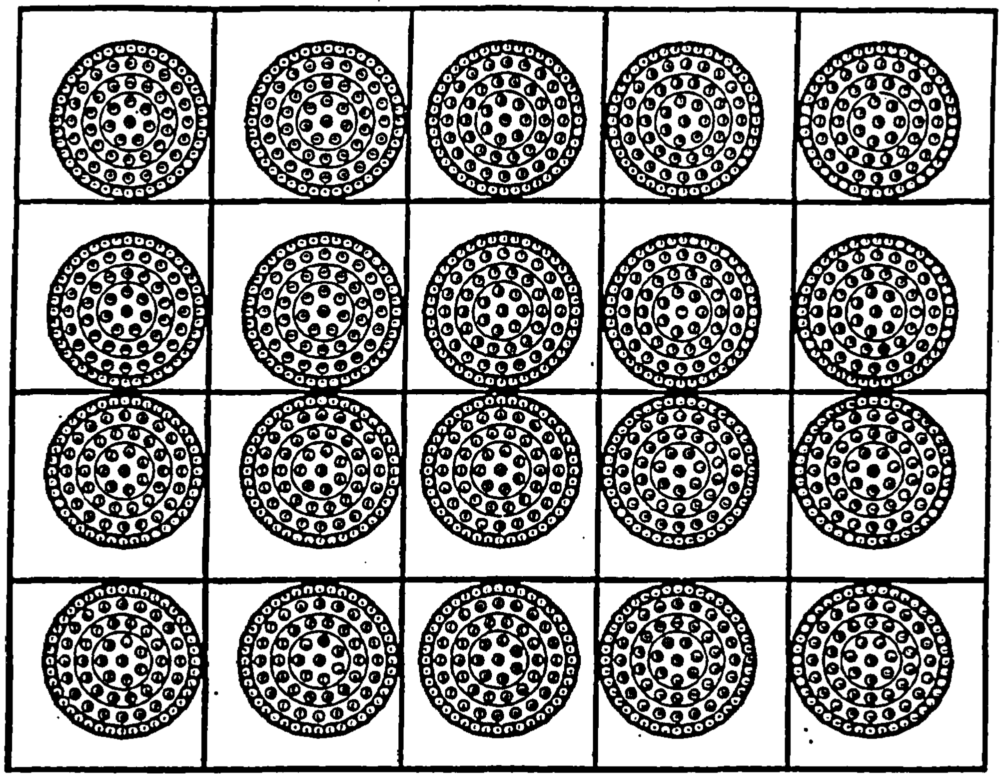


FIG 3

3.2