The European strategy for Fast Reactor core static mechanics studies

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1 INTRODUCTION

The European strategy for Fast Reactor core static mechanics studies has been formulated and agreed. It identifies the outstanding work in addition to current national programmes, which is needed in support of the three reactors to be built collaboratively under the inter-governmental agreement. It also identifies the new facilities which are needed.

A fast reactor core has a large number of sub-assemblies, with hex-agonal wrappers, nested together. Each wrapper is separated from neighbours by spacer pads located above and/or below the active core. Clearances are needed for thermal expansion, void growth, dilation and bow of the wrappers. Restraint is provided "naturally", as in SPX2, or by a surrounding barrel as in CDFR or by any intermediate style. Restraint causes interactive loads, which are offset by creep.

The magnitude of the loads and displacements varies widely with the choice of wrapper material and the style of restraint. Uncertainties in predicting them can be separated into those caused by variance in the swelling and creep of the wrapper material and those arising from mechanical processes of large arrays.

The economics of fast reactors must be improved for them to compete with PWR's and fossil fuelled power generation. This requires higher burn-up and longer dwell. It calls for low swelling wrappers which tend to give a slack core with attendant problems of vibration or rattling of sub-assemblies. Flexible design is required so that a gradual change can take place from the use of swelling materials initially, to low swelling materials ultimately.

2 OBJECTIVES

The strategy is designed to meet the needs of participating European countries by achieving the following objectives:

- to provide generic information and data on the static mechanics of all styles of core of interest, validate codes and optimise new designs.
- to endorse specific features of SPX2 and SNR2 designs.
- to provide the new facilities which are needed.
- to present the programme of work required and timescale.

3 UNCERTAINTIES

In designs with light restraint, vibration may cause frictional restraints to become negligible. The importance of friction may vary considerably, depending on the style and the tightness of restraint. If frictional forces are zero, variance between calculations and reality results only from approximations in input data and assumptions which simplify the codes.

If friction is significant, then the calculation of core loads and displacements is much more complicated and expensive. Friction permits excess elastic-strain energy, above the minimum, to be stored in the core. This can be released, by any transient event or reduction in the friction coefficient. There are no unique solutions. The restraint system must prevent excessive deviations from prediction.

4 BENEFITS

Benefits sought from the proposed work are that:

- increased assurance will come from validation of codes, and measurement of variances from predicted loads and displacements.
- scope for less conservative design and improvements in safety margins can be exploited.

5 NATIONAL PERSPECTIVES AND PROGRAMMES

5.1 France

The french development programme, initially based on SPX2 project, will be extended to advanced reactors studies, which exploit core design options.

The HARMONIE code system, together with modules such as FORCEZ for core-handling machine interaction and HARMOREA for calculating reactivity effects, now includes detailed models of core mechanics.

The French rig for large arrays studies, R106E, simulates the naturally restrained core in SPX1 at full scale. It has been used to support the SPX1 design and to validate HARMONIE for this core style. The rig has been extended to meet SPX2 requirements by including a central island of 7 short-spike S/A's. A new device to simulate charge discharge operations completely, with a parametric representation of the real handling machines stiffnesses, has just been installed on R106E. It will enable an extended validation of FORCEZ to be made.

Some limitations in the capabilities of R106E, are too fundamental for a complete validation of recent HARMONIE developments, such as geometrical non linearities and the friction model, and from a more general point of view, for reducing significantly the uncertainties for different core styles. These features will be obtained in the new CHARDIS IIC rig.

Code validation from in-air tests is complemented by measurements obtained from reactor operation and compared with a very fruitful, but difficult code simulation. The operation of Phenix, and now of SPX1, has produced, and will produce, a large amount of data. Handling forces are systematically recorded on the two reactors and most of the S/A's distortions are measured in Phenix by PIE.

5.2 Italy

ENEA activities in core static mechanics are directed primarily to qualification of the PEC core design including assessment of all mechanical, structural components and thermal distorsion effects.

The main Italian objectives comprise development and validation of HARMONIE code including SISCO (developed by ENEA) and a new code to predict forces throughout handling operations.

5.3 Germany & Belgium

The German experience is based on operation of KNK II and on the experimental programme performed in support of SNR-300 in co-operation with Belgium. For SNR2, the need for handling tests with arrays of at least 7 full scale sub-assemblies is emphasised. They will cover the range of possible geometrical variables, simulation of refuelling movements with bowed and dilated sub-assemblies and tests of initial core loading without dummy sub-assemblies.

For the core mechanical design and for the treatment of problems such as fuel management, the 2d-code FIAT as well as the 3d code system DDT is available at Interatom. For detailed fuel assembly wrapper tube mechanical design and analysis the 3d-code STRAW developed by Belgonucleaire is used within the German-Belgian collaboration.

5.4 UK

The development programme described in succeeding papers in this session will remain based on CDFR until a new reference design is available. Continued study of core mechanics is needed to arrive at an optimum style of restraint. The code CRAMP is the basis of core design and of PFR core management. It will be extended to calculate interactions with the handling machine throughout refuelling operations and to include spike clearance.

Experiments with the charge-discharge rig CHARDIS I showed reasonable agreement between the axial load to charge or discharge a sub-assembly, but not for individual loads. CHARDIS II provides more accurate and comprehensive data. It will soon have a generic and adaptable handling machine. Data produced will be used to study mechanical interactions of core operation and refuelling and to validate CRAMP for barrel restrained cores.

Test sections have been designed to expose all guidance and locating features to the full range of reactor duties in the sodium components test facility at Risley and at reactor operating conditions. The effective friction coefficients will be measured throughout. In the "Monkey's Paw", a section of dilated wrapper will be extracted from neighbour sub-assemblies.

6 FACILITIES FOR TESTING LARGE ARRAYS

Existing facilities are listed in Table 1. None of them could yield the information with large arrays of sub-assemblies needed to validate the codes used for SPX2, SNR2, CDFR or successors. The European view is that a single new facility is needed to meet both current and future requirements, which is easily adaptable to changes in styles of restraint or handling machine design. The best way to meet this need is to replace the existing rig by CHARDIS IIC. This uses modified dummy SPX1 sub-assemblies.

7 PRINCIPLE FEATURES

CHARDIS IIC retains the basic principle that the boundaries of the array of sub-assemblies are adjusted in a pre-determined manner to represent the displacement of the corresponding imaginary boundaries within a real core. These displacements and the resulting loads are measured at the boundaries and at all spacer pads surrounding the central sub-assembly. The principle applied to simulation of "natural" restraint is illustrated in Fig. 1. It requires an increase in lattice pitch (of 9%) to provide room for adjustment of sub-assembly bow and dilation, attaching load measuring pads and use of a tilting chandelle. All S/As have a joint at the core mid-plane which can be preset and clamped to any required bow. All have detachable spikes with adjustable clearance and stiffness.

The new features of CHARDIS IIC are:

- A diagrid replaces the bottom plate of CHARDIS II. It locates tubes (representing chandelles) which can be tilted to simulate bow.
- Two stiff frames are provided at restraint planes. They can be moved vertically to represent different styles of restraint.
- Rams with large displacements are provided at each restraint plane. Transducers measure the load and displacement of each ram.
- A charge machine guide tube of larger diameter, with a grab to suit, will be fitted.

To use the rig, the procedure is:

(a) Calculate loads, gaps and displacements for a reactor core through one or more runs and shut downs.

(b) Calculate a matching set of rig adjustments.

(c) Measure actual initial conditions.

(d) Calculate the expected consequences of applying (b).

(e) Measure them and compare.

To simulate refuelling, set up the shut-down conditions, as above, then with constant displacements convert each ram from its stiff mode to a flexible mode. Springs within the ram then carry the load and

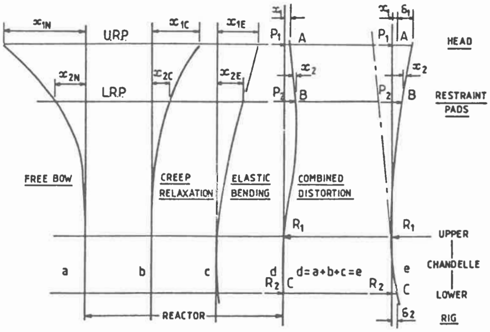

FIG 1. Representation SPX2 Restraint

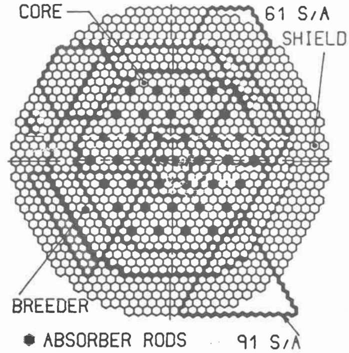

FIG 2 Core Locations & Boundaries

represent the remainder of the core. The central (distorted) S/A may then be discharged and an undeformed S/A may be inserted.

8 SIZE AND SHAPE OF ARRAY

A key question is how can we be sure that large arrays will behave as predicted and without unpleasant surprises? The authors and their colleagues judge that the best value for money and time will come from using hexagonal arrays of 61 S/As. Fig. 2 shows how they may be used to represent various regions of the core. After a few years work, any doubt about the subtleties introduced by the shape of the core boundary, could be resolved by tests with 91 S/As.

9 OTHER FACILITIES REQUIRED

The French R106E is being adapted to test 7 SPX2 S/As in an array of 54 SPX1 S/As. A representative charge machine is being added. This will meet the French need for a rig with standard S/As to study handling problems and contribute to code validation.

Each other country constructing one of the "European" reactors will require a simple rig with 7 standard S/As and a handling machine.

Italy has a facility for testing SPX2 spike/chandelle components in air and water. Mulinox is used for tests in sodium on PEC spikes.

The UK has constructed SOD 1 to test the spike/support tube/diagrid bush interactions in CDFR. It can be adapted to test specimens similar to the SPX2 spike and chandelle. SOD 2 has been designed to study the friction and wear of spacer pads. It can also perform Monkey's Paw extraction tests.

10 PROGRAMME

Handling tests in R106E with bowed S/As for SPX2 and with distorted S/As and variable grab stiffness for SPX1 will be made in 1987. Tests with 19 S/As in CHARDIS and of the PEC spike and socket in MULINOX will be completed. Code development will include introducing friction and clearance in HARMONIE and development of FORCEZ. DDT will be verified and endorsed.

By 1989, it is planned to complete CHARDIS tests with 61 S/A's, CRUPER tests with 91 S/A's (to study loading mode, pad area, high friction) and to complete construction of CHARDIS IIC. By this time, CRAMP will be validated for barrel restrained cores and extended to cover spike clearance and refuelling; DDT will include multi force pad flexibility. Generic tests of CDFR spike/support tube/diagrid in sodium will be completed and tests to evaluate the durability and friction of contact faces will be in progress. It is envisaged that the whole programme will be completed by 1993.

11 CONCLUSION

The European strategy recognises the valuable contribution of existing national programmes, and the common need for improved validated codes for core static mechanics and refuelling load calculations.

In the European view a single major adaptable rig is required. It will be used to study the behaviour of large arrays of sub-assemblies and of interactions with the handling machine. This rig should be a new version of CHARDIS II known as IIC. It will have an initial complement of 70 sub-assemblies made from SPX1 dummy core sub-assemblies used in arrays of 61.

France already has the R106E rig. Each other country constructing a new reactor under the inter-governmental agreement, will require a simple rig with 7 standard sub-assemblies and a handling machine replica.

The programme includes tests in sodium rigs to endorse the durability of guiding features and bearing surfaces and also to establish the best values for and variability of the friction coefficient.

The SPX2 design will be endorsed in 1987.

The programme shows that the new work identified in the strategy will provide soundly developed and validated codes with the complimentary mechanical design information needed by 1993.

TABLE I

Existing core static mechanics rigs

Medium	Rig	Country	Remarks
Air	CHARDIS II	UK (UKAEA)	Represents 'barrel' restrained cores with a generic charge machine.
	CRUPER	UK (NNC)	Single plane of 91 S/As.
	R106E	France (CEA)	7 SPX2 S/As and 54 SPX1 S/As with fully representative charge machine.
	CHARLIE	France (CEA)	Measurement of bending stiffness.
	PROMETHEE	France (CEA)	Measures pad elastic and thermal creep distortion at operating or fault temperatures.
	FOOT/ CHANDELLE	Italy (U of PISA)	Mechanical test of Foot to Chandelle hard facing.
Sodium	SOD 1	UK (UKAEA)	Tests Spike/Support Tube/Diagrid bushes.
	SOD 2	UK (UKAEA)	Tests spacer pad and head surfaces.
	SOD 3	UK (UKAEA)	SOD 2 for Monkey's Paw Tests.
	EXPRESSO	Italy (ENEA)	Thermal Shock + dwell.
	CEDI	Italy (ENEA)	Thermal Shock + dwell.
	RSB	Germany (INTERATOM)	Tests reactor handling mechanisms.
	AKB	Germany (INTERATOM)	Tests core components.