5. PROTEUS EXPERIMENT PLANS

This chapter contains descriptions of the experiments carried out on each of the ten different HTR-PROTEUS configurations. The information is provided in table form for ease of reference. Table 5.1. contains a brief description of each of the configurations; this table is only intended for orientation purposes, more detailed descriptions are to be found in Section 7.2. The time periods spanned by each of the configurations is also given in Table 5.1. and represented graphically in Figure 5.1. In Table 5.2. a summary of the parameters investigated in each of these configurations is presented in the form of a “test matrix”. An explanation of the experiment identifiers appearing in Table 5.2 is provided below for each parameter, with reference being made to the detailed descriptions of the measurement techniques given in Section 6.

Since each configuration was planned with the investigation of one or more particular physics aspects in mind, the type of parameters measured varies considerably from core to core. A summary of the measurements made in each core is provided in Table 5.2 and brief details of each of the measurements referred to in the table is given below. Further details can be found in Section 6 of this report

Critical Loading

The measurement of the critical height of the core and/or the number of fuel and moderator pebbles loaded. Every effort was made to obtain critical configurations which were as clean as possible, especially with respect to control rod insertions, presence of start-up sources, temperature instrumentation etc. Operationally speaking, these critical loadings are not usually very convenient; for instance a low control-rod insertion implies a very small excess reactivity and often leads to problems during power raising. Therefore, the critical loadings quoted in the results section are often not the final operational states for that core.

The loading procedure is described in detail in section 6.1. This is arguably the most important parameter and was therefore recorded for every configuration.

Σ_a

The measurement of the absorption cross section of the reactor graphite using PNS techniques. Although this parameter is not one of those required from the program, a knowledge of its magnitude is imperative for the accurate definition of the PROTEUS facility, see Sections 6.5. and 4.2.

Subcritical Core

The use of the PNS technique to measure a subcritical state. For instance in Core 1 a measurement of the subcriticality of the system was made with 16 layers loaded. Details of the PNS technique are given in Section 6.2.1.

Shutdown rods

The measurement of the integral worth of 1, 2, 3, 4 or 8 bulk absorber rods using either PNS (Section 6.2.1.) or IK (see Section 6.2.2). In Section 4 it was explained that there are eight bulk absorber rods and that four can be selected as safety and four as shutdown. Because the system interlocks only allow individual insertion of the shutdown rods, these rods were always selected as the ones to be measured. Various rod configurations were measured in order to investigate rod interaction effects.

Control rods
The measurement of the integral and differential worth of the individual control rods using the stable period technique (see Section 6.2.1.1.2.). Combinations of rods were not measured as interference effects have been seen to be small [5.1]. The accurate calibration of these rods in every core was very important as the rods are used to establish a critical balance and thus are needed to estimate the reactivity excess.

Upper reflector
The measurement of the worth of the upper reflector assembly by means of its removal and subsequent PNS measurement (see Section 6.2.1.)

β/Λ
Measurement of the kinetic parameter, β/Λ, at critical. This parameter is of particular interest to the Japanese who observe significant C/E discrepancies in VHTRC. Full details of this measurement are given in Section 6.4.

Measurement rod
Measurement of the reactivity worth of specially designed dummy control rods which can be placed in channels in the radial reflector. The rods consist of aluminum tubes containing pellets of boron-steel (see Section 4.2. for specifications). Used to investigate radial dependence of control rod worth. PNS technique used (see Section 6.2.1.)

Central control Rod
Similar to the above measurement. By means of a graphite sleeve in place of a column of pebbles, the worth of a dummy control rod in the core center is measured using the PNS technique (see 6.2.1.). This measurement can only be carried out in point-on-point cores.

Temperature Coefficient of Reactivity
The measurement of the temperature coefficient of reactivity around room temperature by means of controlling system temperature with the air conditioning system. It is only possible to produce temperature effects of around ±10°C. Effect is measured using calibrated control and auto rods

Component Worths
The measurement of the reactivity worth of the various components which represent perturbations to the clean system. Effect measured using calibrated control and autorods.

Reaction rate distributions
In core The measurement of core axial and radial reaction-rate distributions between the pebbles using activation foils and miniature fission chambers **or** the measurement of core axial and radial reaction-rate distributions using γ-scanning of irradiated fuel pebbles (see 6.3.1.)
In pebble The measurement of reaction rate distributions within the pebbles themselves using conventional foils or special fuel particle foils (see 6.3.1.)

Reaction rates and ratios
The measurement of core-center reaction-rates and ratios within the pebbles themselves using conventional activation foils and graphite foils containing fuel particles (see section 6.3.2.)

CORE	DATES	F:M	PACKING	COMMENTS
G1	3/92-5/92	-	-	ONLY PNS MEASUREMENTS , NO FUEL IN CAVITY, WITH AND WITHOUT MODERATOR PEBBLES. ZEBRA RODS IN-SITU
1	7/92-6/93	2:1	HCP	ONLY CORE WITH ZEBRA RODS
1A	6/93-8/93, 2/94-3/94	2:1	HCP	CORE 1 WITH ZEBRA RODS REPLACED BY CONVENTIONAL CONTROL RODS
2	8/93-10/93	2:1	HCP	CORE 1A WITH FIVE FUELED LAYERS REPLACED BY MODERATOR PEBBLES - "CAVITY EFFECT"
G2	10/93	-	-	PNS MEASUREMENTS WITHOUT FUEL IN CAVITY. ZEBRA RODS COMPLETELY REMOVED
3	10/93-2/94	2:1	HCP	CORE 1A WITH SIMULATED WATER INGRESS - EVERY AVAILABLE VERTICAL CHANNEL CONTAINED A 9mm CH_2 ROD
4(1,2,3)	3/94-6/94	1:1	RANDOM	THIS CONFIGURATION REPEATED THREE TIMES
5	7/94-4/95, 11/95-1/96	2:1	P-O-P	FIRST COLUMN HEX LOADING
6	4/95-5/95	2:1	P-O-P	CORE 5 WITH MAXIMUM CH_2 LOADING, COMPENSATED WITH COPPER WIRE
7	5/95-10/95	2:1	P-O-P	CORE 5 WITH MAXIMUM CH_2 LOADING, COMPENSATED BY REDUCING CORE HEIGHT
8	1/96-2/96	2:1	P-O-P	CORE 5 WITH EVERY VERTICAL CHANNEL CONTAINING A 15cm LONG TRIANGULAR CH_2 ROD
9	2/96-5/96	1:1	P-O-P	CORE 5 REPEATED WITH F:M OF 1:1
10	5/96-6/96	1:1	P-O-P	CORE 9 WITH MAXIMUM CH_2 LOADING, COMPENSATED BY REDUCING CORE HEIGHT

HCP = hexagonal close packed
P-O-P = point-on-point (column hexagonal),

F:M = fuel-to-moderator ratio
(yellow shading) indicates simulated water ingress in this core

Table 5.1. Summary of the Configurations Investigated (see also Section 7.2)

	CRITICAL LOADING	Σ_a	SUBCRIT CORE	SHUTDOWN RODS		CONTROL RODS		UPPER REFL.	β/Λ	MEAS. RODS	CENT. CONT. ROD	TEMP. COEFF	COM-PONENT WORTHS	MISC.	REACTION RATE DISTRIBUTIONS					REACTION RATE RATIOS		
															IN CORE			IN PEBBLE		AT CORE CENTRE		
METHOD / CORE	PEBBLE COUNT	PNS	PNS	PNS	IK	SP	PNS	PNS (SP)	PNS	PNS	PNS	COMP	COMP	-	FOILS	FISSION CHAMBER.	γ SCAN	FOILS	PARTICLE FOILS	FOILS	PARTICLE FOILS	WHOLE PEBBLE
G1		✓													F: 5 C: 8	F: 5, 8, 7, 9, 2, 1						
1	✓		✓	✓	✓	✓	✓		✓	✓			✓		F: 5, 8 C: 8	F: 5, 8, 7						
1A	✓				✓	✓										F: 5, 8, 7						
2	✓			✓	✓	✓	✓	✓	✓						F: 5, 8 C: 8	F: 5, 8, 7						
G2		✓														F: 5, 8						
3	✓		✓	✓	✓	✓	✓		✓													
1A	✓			✓		✓																
4(1)	✓					✓																
4(2)	✓			✓	✓	✓																
4(3)	✓			✓		✓																
5	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	water/ CH_2 CH_2 in lower axial reflector	F:5,8 C8	F:5,8,7	C8, Ftot	F:5,8,9 C8	Ftot C8	F:5,8,9 C8	C8/Ftot	C8/Ftot
6	✓					✓																
7	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		water/ CH_2 CH_2 in lower axial reflector	F:5,8 C8	F:5,8,7	C8, Ftot	F:5,8,9 C8	Ftot C8	F:5,8,9 C8	C8/Ftot	C8/Ftot
8	✓						✓															
9	✓				✓	✓	✓	✓	✓	✓					F:5	F:5,8,7,9	C8, Ftot	F:5,8,9 C:8				
10	✓		✓		✓	✓	✓	✓	✓	✓				subcriticality with CH_2 removed	F:5	F:5,8,7,9	C8, Ftot	F:5,8,9 C:8				

✓ F: 5 = PLANNED AND EXECUTED

F=fission, C=capture, 5=U-235, 8=U-238, 9=Pu-239, 7=Np-237, 2=Pu-242, G1,2=graphite (no fuel in core), COMP. = compensation with calibrated control rods

Table 5.2. Test Matrix for Cores 1-10

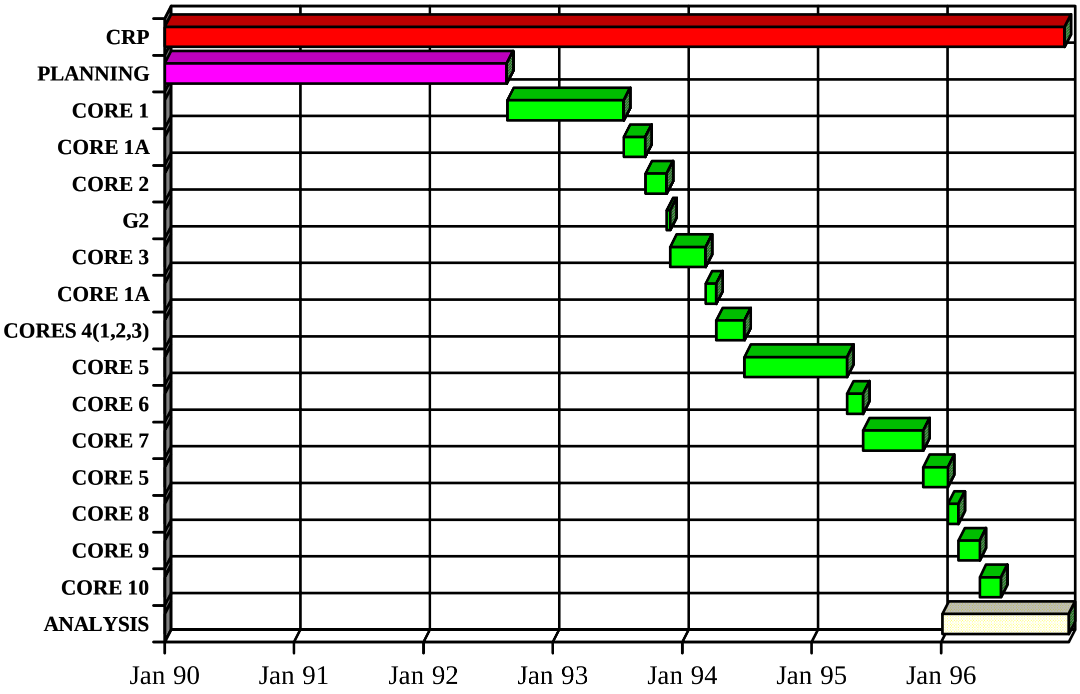

Figure 5.1 Time Allocation to Each of the HTR PROTEUS Configurations