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**NPTR TERTIARY REACTIVITY
CONTROL SYSTEM**

S. L. Engstrom and H. C. F. Ripfel

April 1968

**AEC RESEARCH &
DEVELOPMENT REPORT**

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NPTR TERTIARY REACTIVITY-CONTROL SYSTEM

S. L. Engstrom and H. C. F. Ripfel

I. INTRODUCTION

A tertiary reactivity control system is contemplated for the NPTR to supplement the shim and primary safety system design it has in common with the FTR. Since the NPTR is an experimental physics facility, in which relatively large reactivity changes will be made, such a tertiary system is considered necessary to provide additional operational flexibility.

The NPTR is not a "split-half" machine; therefore, the large reactivity decreases usually associated with the separation of the assembly halves are not available, and other means of achieving large reactivity reductions should be furnished. Two major reasons for not considering a split-half construction are:

- . The presence of reactivity effects associated with opening and closing of the split-half machine (e.g., temperature redistribution and non-reproducibility at the closed position)
- . Mechanical difficulties connected with the opening and closing of the halves with full size FTR subassemblies in place.

Two types of shutdown rods were investigated. One possibility consisted of fuel-poison rods located in the driver fuel area. This type of control rod was considered at first, but was rejected because of mechanical design complications. At present, the preferred rod location is in the gap region of the split conical

core. The preferred configuration is a blade rod consisting of a canned sodium section followed by a poison section. The poison section will consist of B_4C (probably enriched), about 0.5 to 1 inch thick. The rods will move in rectangular guide tubes driven by electric motors and worm gears. Some structural material (preferably Al) will be necessary, and will replace an equal volume of sodium.

Water flooding was considered to be representative of a large reactivity addition and the tertiary control system was then sized to compensate for the effects of such an accident. Analyses of flooding accidents and achievable rod worths indicate that ample negative reactivities can be provided by this postulated blade rod system.

II. CALCULATION OF REACTIVITY INCREASES DUE TO WATER ADDITION

The accidental introduction of moderating material - specifically water - into the NPTR is considered to be unlikely. Since the reactor cell will be in a confinement or containment structure, water cannot enter from the outside, and furthermore, water lines will also not be installed inside the cell. Since some experiments may, however, employ liquid moderators, or a breakdown in administrative procedures could occur, the possibility of accidental moderator introduction cannot be completely ruled out.

For purposes of the present analysis, it is assumed that water can be introduced only into the central test loop, into a central test channel occupied by a "dry" (sodium free) FTR fuel bundle and into the NPTR cooling holes and gaps introduced by assembly tolerances. It is assumed that unoccupied fuel or test positions can generally be reduced to a single one by the use of Al or SSd dummies which are placed into these positions. It is further assumed that these dummies can be designed in such a way that they will not float.

To calculate the worths of water in these positions, a simplified, one-dimensional NPTR model was formulated. The zone dimensions for this model are shown in Table I. Volume fractions are given in Table II, and atom densities for the constituent materials are listed in Table III. The calculations were carried out by means of 1-D transport theory (DTF-IV) in cylindrical geometry, using an S-4 approximation and the 26-group fast reactor PNL cross section set. The results of the calculations are summarized in Table IV.

The reactivity worths of water in the NPTR cooling channels and void spaces were calculated, assuming a homogeneously mixed core-water medium. The water worth is a nearly linear function of the water density in the void spaces.

In the case of water flooding of the empty central test loop position, the water worth peaks for a water density of about one half. For "double density" water a negative reactivity worth was calculated.

Of the cases considered, the largest reactivity increase occurs for complete water flooding of a "dry" subassembly in the central loop position and simultaneous flooding of all core void spaces. For this case, the reactivity increase is calculated to be 3.6% $\Delta k/k$.

Table I

Zone Dimensions - Flooding Study

Zone	Description	Inner Radius-cm	Outer Radius -cm
1	Test Loop	0.0	7.14
2	Stainless Steel	7.14	7.46
3	Na	7.46	10.0
4	Core	10.0	22.5
5	Na	22.5	30.4
6	Core	30.4	63.3
7	Reflector	63.3	78.5

Table II

Material Volume Fractions - DTF Flooding Calculations

Material	Composition	Volume * Fraction
Core =		
.9038 Driver Zone	PuO ₂	.06715
+.09615 Control	UO ₂	.24285
Rod Follower	SS ²	.26531
	Na	.34780
	Void (or water)	.02170
Reflector	Inconel	.56000
	SS	.14000
	Na	.30000
Subassembly	PuO ₂	.07623
	UO ₂	.27568
	SS ²	.24587
	Void (or water)	.34000

* Remaining void, unlisted, occurs as the fuel is not 100% theoretical density

Table III

Material Atom Densities

Material	Isotope	Atom Density At/b -cm
PuO ₂	²³⁹ Pu	.022910
	²⁴⁰ Pu	.002546
	O	.050912
UO ₂	²³⁸ U	.024445
	O	.048889
Inconel	Fe	.009091
	Cr	.017572
	Ni	.062267
Stainless Steel	Fe	.063204
	Cr	.016509
	Ni	.006500
Sodium (300°K)	Na	.025235
Oxygen (Void)	O	.002701
Water	H	.067000
	O	.033500
Natural B ₄ C	¹⁰ B	.021892
	¹¹ B	.088784
	C	.027669
Enriched B ₄ C	¹⁰ B	.090743
	¹¹ B	.008937
	C	.033505

Table IV

Reactivity Worth of Water Insertion into the NPTR

Reactor Condition	Reactivity % $\Delta k/k$
1. Core voids (2.17 v/o) filled with half density water	1.432
2. Core voids filled with full density water	2.700
3. Central test loop filled with half density water (test loop, 7.14 cm radius)	2.361
4. Central test loop filled with full density water	1.268
5. Central test loop and core void filled with full density water	3.479
6. 34 v/o of FTR "dry" subassembly in central test loop filled with full density water	1.669
7. Subassembly and core void filled with full density water	3.603

III. CALCULATION OF REACTIVITY WORTHS OF THE TERTIARY REACTIVITY CONTROL SYSTEM

In order to carry out worth calculations for the tertiary shutdown rods, a fairly detailed (X-Y) model* of the NPTR core was utilized. (See Figure 1.) Rod worth calculations were made by means of two dimensional diffusion theory (2DB). In Table V the material volume fractions for these calculations are given.

The shutdown rods consist of two 8 x 0.5 inch blades placed between the C and B loops, and two 6 x 0.5 inch blades placed between the A and B loops. Normally, a 28 v/o B_4C composition was assumed (comparable to the FTR rods) for the blade rods, but calculations were also carried out for the case of 100 v/o B_4C enriched to 90w/o in B-10. For the highly enriched rods, worths were calculated with and without water in the central test loop. The results are shown in Table VI. The control worth of the rods increases from 5.2% $\Delta k/k$ for the water-free case to 5.7% $\Delta k/k$ for the flooded case.

In addition, to the worth calculations for the blade rods, calculations were also performed to determine the worth of FTR type rods (28 v/o B_4C) located in positions A-1, B-1, and C-1. This data could be of use if alternate secondary shutdown rod systems were to be considered. In general, fairly large safety margins appear to be achievable. (See Table VI.)

* From L. L. Mass, by private communication.

Zone	Material
1	Test Loop A-1
2	" B-1
3	" C-1
4- 9	Na-SS (C.R. Follower)
10	Na
11	Core
12	Reflector
13	Void

Figure 1. Calculational Model - Shutdown Control

Table V

Material Volume Fractions - 2DB Control Calculations

Material	Composition	Volume Fraction*
Core	PuO ₂	.07430
	UO ₂	.26870
	SS	.25100
	Na	.34250
	Cooling Channel	.00250
	Void	
Reflector	Inconel	.56000
	SS	.14000
	Na	.30000
FTR Type Control Rods	B ₄ C	.28600
	SS	.31000
	Na	.40000
Shutdown Rods Blade Type		
	B ₄ C	1.0000

*Remaining void, unlisted, occurs as the fuel is not 100% theoretical density

Table VI

NPTB Shutdown Rod Worth in Different
Locations in the Test Zone

Rod Position	Cross Section Area cm ²	28 v/o Natural B ₁ C Rod		100 v/o Enriched* B ₁ C Rod	
		% $\Delta k/k$	% $\Delta k/k/cm^2$	% $\Delta k/k$	% $\Delta k/k/cm^2$
Central Loop A-1	182.25	2.007	0.0106		
Central Loop A-1	120.0	1.451	0.01165		
Loop B-1	164.8	1.259	0.00737		
Loop C-1	126.5	0.218	0.00166		
4 Blade Rods	90.32	0.893	0.00953	5.211	0.05769
4 Blade Rods with water in A-1	90.32			5.725	0.06338

* B₁C arbitrarily enriched to 90% B₁₀

IV. CONCLUSIONS

The results of this investigation indicate that a B₄C-blade type tertiary control system for the NPTB could provide the operational flexibility desired for a critical facility. The system is large enough to supply adequate negative safety margins to compensate for the effects of certain flooding accidents. Rod worths of about 5.7% $\Delta k/k$ could be provided to overcome a possible water insertion accident resulting in a reactivity increase of $\sim 3.6\%$ $\Delta k/k$. The primary and secondary safety systems would, of course, provide additional safety margins.

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