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Determination of the Design Excess Reactivity for the TREAT Upgrade Reactor*

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Determination of the Design Excess Reactivity for the TREAT Upgrade Reactor

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The excess reactivity designed to be built into a reactor core is a primary determinant of the fissile loadings of the fuel rods in the core. For the TREAT Upgrade (TU)(1) reactor the considerations that enter into the determination of the excess reactivity are different from those of conventional power reactors. The reactor is designed to operate in an adiabatic transient mode for reactor safety in-pile test programs. The primary constituent of the excess reactivity is the calculated reactivity required to perform the most demanding transient experiments. Because of the unavailability of supporting critical experiments for the core design, the uncertainty terms that add on to this basic constituent are rather large. The burnup effects in TU are negligible and no refueling is planned. In this paper we discuss the determination of the design excess reactivity of the TREAT Upgrade reactor.

The TU reactor consists of a central modified core region located within the present TREAT reactor. The modified core region is further subdivided into insert, converter and buffer regions, the first being geometrically and neutronically optimized for the different test loops. The base excess reactivity values apply to each of these individual configurations.

The choice of the excess reactivity for TU is based upon the interplay of several factors. To ensure the performance of the planned transient experiment it is desirable to build in as large an excess reactivity as practical. The core performance (measured by the energy deposition in the centrally located test clusters) generally increases with decreasing core excess reactivity. The core safety parameters assume most benign values for low excess reactivities. The effects of reactivity management methods for static reactivity adjustments on the as-built core is an important consideration.

The most probable excess reactivity requirement was determined using analysis and all available supporting experimental data. The results of such an evaluation are shown in Table I. Each term shown in the table is a result of a series of detailed calculations. This reactivity needed to perform the most demanding transient was determined from kinetics calculations using a point kinetics model and suitable core-averaged kinetics parameters. The uncertainty in the kinetics parameters, especially the temperature coefficient of reactivity, requires that a large excess reactivity be designed in the core to cover contingencies. The evaluation also includes non-linear effects of reactivity management methods that lead to altered temperature feedback coefficients.

Uncertainties in the calculational methods and data were estimated by comparisons of calculations against Monte Carlo (VIM) analyses and against TREAT or critical experiment data where available. The treatment of unit cell heterogenerity and that of the in-core hodoscope slot yielded the largest corrections to the excess reactivity term. Effects of uncertainties in the fabrication of fuel rods and clad on dimensions and compositions were computed by using a random sampling procedure. The reactivity effect of deviations of these from assumed values was computed. Finally, because of the uniqueness of each fuel assembly in the modified portion of the TU core, the effect of spare fuel assemblies, if needed, implies a loss of reactivity. This was estimated by computing the reactivity change for a case which included six spare fuel assemblies in place of the regular assemblies.

The excess reactivity terms in the table are added algebraically while the uncerainties in each term are added in quadrature to yield a excess reactivity band within which the TU core cold unrodded excess reactivity is expected to lie. The reactivity band of interest is 3.41% to 6.95% with a most probable excess reactivity of 4.63% for the cold unrodded core.

Given the inevitable uncertainties in the estimated excess reactivity estimation, recovery methods have been devised for the case where the actual excess reactivity determined during the pre-operational tests is different from the reference value. To increase reactivity, the core outer boundary can be extended outwards yielding a reactivity increase of upto 2.1%. To decrease reactivity, unfuelled assemblies containing a small amount of boron (C/B atom ratio $\sim$ 4000/1) can be used to replace several driver fuel assemblies at the driver converter boundary. The small reactor performance decrements caused by these adjustments are acceptable given the low probability of the need to make large reactivity adjustments.

The approach described in the paper satisfies the necessary and desirable considerations for the selection of the excess reactivity for TU in an optimal fashion.

References:

1. D. C. Wade et.al., "Core Design of the Upgraded TREAT Reactor," Proc. Conference on Fast, Thermal and Fusion Reactor Experiments, Salt Lake City, April 1982.

2. S. K. Bhattacharyya et al., "Physics Design of the Upgraded TREAT Reactor," Proc. ANS Topical Meeting on 1980 Advances in Reactor Physics and Shielding, Sun Valley, Idaho, September 13-17, 1980.

3. N. A. Hanan and S. K. Bhattacharyya, "The Evaluation of the Temperature Feedback Coefficient of the TREAT Upgrade Reactor," Trans. Am. Nucl. Soc. 41, 616, 1982.

Table I. TREAT Upgrade Excess Reactivity Inventory*

I. EXCESS REACTIVITY COMPONENTS

		Excess Reactivity %	Uncertainty (%)
(a)	Reactivity Needed to Perform Most Demanding Transient		
	• Base Case	+4.53	
	• Limit of Buffer Poisoned Core	+5.17	±0.93
	• Expanded 21 x 21 Core	+4.99	
(b)	Effects of Unaccounted for Absorption and Uncertainties		
	• Variability in filters and axial shaping collars	-----	±0.40
	• Instrumented assemblies	+0.40	±0.10
	• Uncertainties in worths of parked control rods in axial reflector	-----	±0.5
	• Impurities in core materials (outside specs)	-----	±0.10
(c)	Effects of Data Processing, Modeling and Criticality Calculation Uncertainties		
	• Nuclear data uncertainties	-----	±0.12
	• Boron modeling in driver	-----	±0.95
	• Unit cell heterogeneity and axial Streaming effects	-1.00	±0.75
	• Eigenvalue calculation and cross-section processing uncertainties	-----	±0.68
	• Uncertainty in criticality calculation with hodoscope slot	+0.2	±0.10
	• Uncertainties in buckling calculations	-----	±0.35
(d)	Effect of Manufacturing Uncertainties	0.5	±0.12
(e)	Contingency for Replacement Assemblies	-----	±0.3

II. NET EFFECT

- Based Excess Reactivity (components added algebraically) = 4.63%
- Least Squares Combined Uncertainty = ± 1.86%
- Lower Limit with Buffer Poisons = 5.27 - 1.86 = 3.41%
- Upper Limit at Expanded Core = 5.09 + 1.86 = 6.95%

III. EXCESS REACTIVITY BAND = 3.41% - 6.95%

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*Applies to the following TU Core Configuration

- XY calculational model with slot explicitly represented
- At room temperature
- All control rods out