actors in various stages of design and development —SNAP 10a (35 kWth), SNAP 2 (55 kWth), SNAP 8 (600 kWth) and SNAP 50 (10 - 20 MWth)[1].

From information at present available, these are all to be reflected thermal reactors intended to satisfy orbital and deep-space requirements. There is a problem peculiar to the orbital operation of high-power thermal reactors that apparently has not been considered—the decay of thermal leakage neutrons will add relativistic electrons to the Van Allen belt.[2]

The magnitude of this contribution can be readily determined from a few approximate considerations. In making such a calculation, we can assume a 15 - MWth SNAP 50 reactor in equatorial orbit for one year at 1,000 kM above Earth. Weight limitations on shielding make it reasonable to expect a thermal-neutron leakage of about 7 per cent. This means that approximately 7.5×10^{16} neutrons per second would escape.

If only those neutrons decaying within the first kM were considered, the electron contribution would be 3×10^{13} particles per second. And since the trapped electron flux at present in the Van Allen belt has an angular spread of 72° in direction of motion[3], about 0.59 of the electron contribution would be emitted in directions that would allow trapping. We conclude therefore that at least 1.5×10^{13} electrons per second would be trapped.

These particles would tend to spread throughout a 2-kM-thick donut-shape volume of space about Earth. Thus, the change in the particle density per unit time (due to reactor contribution) would be 3×10^{-11} electrons / cm^3 / sec. This would be a change in flux per unit time of 9×10^{-1} particles/cm^2/sec^2.

The last detonation of a nuclear device in space showed that the decay time for electrons trapped in the Van Allen belt is quite long. This means that the reactor-produced electrons would effectively accumulate over the period of operation. Therefore, at the end of one year, the reactor-produced electron flux would be about 3×10^7 particles/cm^2/sec. from one SNAP device.

This value of 3×10^7 particles/cm^2/sec. for 0.26-MeV electrons is close to the high-solar-activity peak electron flux for Van Allen belt electrons of energy greater than 0.20 MeV.[4]

These electrons (or their Bremsstrahlung) could have significant effects on instrumentation, scientific experiments and organisms operating in that region.

In view of these considerations a thorough analysis of the problem should be performed in connection with any orbital operation of a nuclear reactor.

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Received September 17, 1963

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Doppler Coefficient Measurements for U^{238} in Fast-Reactor Spectra

The Doppler temperature coefficient of reactivity of U^{238}, of considerable importance to large fast power breeder reactors as a prompt shutdown mechanism, has been measured in two fast spectrum assemblies on the ZPR-III reactor. This letter summarizes the experimental results (which will appear in detail in the Proceedings of the Conference on Breeding, Economics and Safety in Large Fast Power Reactors, held at Argonne National Laboratory on October 7-10, 1963, and to be published as ANL-6792).

Zoned critical methods were used on ZPR-III to provide a central zone, in which the first measurements were made; this zone had the composition and therefore the soft neutron energy spectrum of a 5,000-liter uranium monocarbide fast power breeder reactor. Since enrichment changes little with size for reactors of this size range, this measurement is pertinent to the class of large ceramic reactors. The composition, in atoms/cm^3 $\times 10^{-24}$ of U^{235}, U^{238}, C, Na, and SS were, respectively, 0.00114, 0.00732, 0.00833, 0.01061 and 0.01657. A second experiment was arranged by replacing 40% of the sodium cans of the first central zone loading with graphite. This gave a significantly increased Doppler reactivity change and provided a second check point for theoretical analysis.

The procedure of the experiment was to repeatedly change the positions of a hot Doppler element and an essentially identical cold Doppler element at the center of the reactor until the reactivity difference of the exchange was established with a precision of approximately 5×10^{-8} $\Delta k/k$. The roles of hot (800 K) and cold (300 K) elements were exchanged, and relative cold-vs-cold worths were found. The autorod-oscillation

method[1] rather than the pile-oscillator technique used on a recent thorium Doppler study[2] was employed. Each Doppler element was rather large, containing 1.96 kg of U^{238} in the form of UO_2 sintered to 70% theoretical density as part of the design to minimize axial-expansion reactivity effects. The $U^{238}O_2$ had a diameter of approximately 3.5 cm and an active element length of 28 cm. Many precautions were taken in the design of the experiment to minimize the possibility of producing and observing reactivity changes which were of non-Doppler origin. Particular attention was given to the design of the Doppler element in order to remove or greatly reduce axial expansion effects of the $U^{238}O_2$ when heated.

A summary of the experimental results obtained when the $U^{238}O_2$ was oscillated in the 5,000-liter uranium monocarbide mockup of assembly 43 is given in Table I. Corresponding results for assembly 43A are given in Table II. As the tables indicate, each experiment was performed twice, except for the lower temperature run ($\overline{T}$ = 553 K) on 43A, to help establish the degree of confidence in the measurements. The second cold-vs-cold measurement of Table I was not used in the reactivity analysis, however, because this data was demonstrably poorer. The partially tentative theoretical comparisons were performed using a 1-D diffusion theory approximation and a recently developed ANL cross-section set.

An important test for the magnitude of possible expansion or other non-Doppler reactivity effects, discussed in more detail in the conference proceedings, consisted of placing B_4(nat) C around one of the two Doppler elements. This procedure removed most of the tail of the low-energy neutron flux, which produces almost all of the Doppler reactivity change while only mildly perturbing the remainder of the neutron flux. The residual, small, true Doppler perturbation was to be satisfactorily well accounted for by calculation, fairly large calculational uncertainties being relatively unimportant. Reactivity changes that do not depend on the low-energy tail should be largely unperturbed by this arrangement. The results of this study, which indicate that non-Doppler reactivity changes occurring in the assembly 43 experiment must be a small part of the true Doppler reactivity signal observed, are shown in Table III under the heading "Boron Test."

The test, "238 Expansion (43A)," was performed with standard ZPR-III plates of U^{238} replacing the Doppler element in very clean geometry. This test measured the importance of expansion of U^{238} in the flat axial flux distribution

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TABLE I

U^{238} Doppler Reactivity Coefficient in ZPR-III Assembly 43 - 5,000 ℓ U-C Spectrum

1 Hot vs 2 Cold ($\overline{T}$ = 800 K)		- .251 Inhours
1 Cold vs 2 Cold		+ .151 "
	Total	- .402 "
2 Hot vs 1 Cold ($\overline{T}$ = 800 K)		- .549 "
1 Cold vs 2 Cold		+ .151 "
	Total	- .398 "
1 Cold vs 2 Cold		(+ .138) "
Expt. = $- .90 \times 10^{-5} \Delta k/k$	=	$- .462 \times 10^{-5}$ $(\Delta k/k)/kg$ 28
Calc. = $- 1.00 \times 10^{-5} \Delta k/k$ (1-D Calculation)		

TABLE II

U^{238} Doppler Reactivity Coefficient in ZPR-III Assembly 43A - Very Soft Spectrum

1 Cold vs 2 Cold ($\overline{T}$ = 800 K)		+ .090 Inhours
1 Hot vs 2 Cold		- .593 "
	Total	- .683 "
1 Cold vs 2 Cold		+ .088 "
2 Hot vs 1 Cold ($\overline{T}$ = 800 K)		- .765 "
	Total	- .677 "
Calc. (1-D Calculations)		- .981 "
2 Hot vs 1 Cold ($\overline{T}$ = 553 K)		- .437 "
1 Cold vs 2 Cold		+ .089 "
	Total	- .348 "

TABLE III

Tests of Assembly 43 Results

Boron Test	
No-Boron Avg., (Table I), 1 Hot vs 2 Cold (Net)	- .400 Inhours
1 Hot vs 2 Cold (Net), B_4C	- .077 "
Calc. Residual Doppler	~ - .066 "
Probable Non-Doppler	~ - .01 "
238 Expansion (43A)	+ .0086 "/mm
Resonance Flux Dep. Test	
2 Hot vs 1 Cold (Net)	- .382 "
Prev. Result (Avg.)	- .400 "
Dummy at Center (43A)	+ .002 "/mm
Element at Center (43A)	+ .003 "/mm
Element at Out Position (43A)	- .005 "/mm

of the assembly and shows that the reactivity worth of axial U^{238} expansion is small.

The "Resonance Flux Depression Test" of Table III was designed to estimate the importance of resonance absorption by the U^{238} present in the central zone adjacent to the Doppler element on the reactivity change produced when the Doppler element was heated. In the basic experiments of Tables I and II, the material in the drawers immediately adjacent to the element was rearranged so that all of the sodium, in its stainless steel cans, (3.175 cm) was between the Doppler element and the fuel in the drawer. The "Flux Depression Test" consisted of repeating the assembly-43 measurements with this fuel arrangement exactly reversed, to give a "worst case" condition.

The last three results of Table III measure the significance of experimental uncertainties of position. Since positions could be reproduced to a fraction of a mm, positional errors must represent a small uncertainty.

The staff of the ZPR-III reactor, in particular Fred Thalgott, John Long, and Joe Gasidlo, are to be thanked for their very valuable support, which contributed importantly to the success of this experiment. Joe Handwerk and Dave White of the ANL ceramics group developed the low-density uranium dioxide pellets whose expansion characteristics were very important to control of non-Doppler reactivity effects. John Harmon was exceptionally valuable during the construction and testing of the Doppler elements.

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Received October 28, 1963
Revised December 16, 1963