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CONVERSION RATIO INCENTIVE FOR USING BLACK
MINT IN AN E-N LOAD

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CONVERSION RATIO INCENTIVE FOR USING BLACK MINT IN AN E-N LOAD

R. Nilson

INTRODUCTION

The proposed E-N, tritium-plutonium producing reactor loading is made up of striped columns of lithium-aluminum (mint) target slugs and enriched uranium (.947 w/o U²³⁵) slugs. Both target and uranium slugs are of the I & E geometry. The ratio of mint (N) to uranium (E) is determined by the requirement of sufficient k-excess to sustain an operable reactor. The designer of the lattice loading has a choice between natural lithium (7.5 w/o Li⁶) or lithium enriched to ~ 38.5 w/o Li⁶ for the mint slugs, assuming enriched or "black" mint is available.

Conversion data are not available at this writing on enriched mint. Results from a production test⁽¹⁾ to determine in-pile conversion in a black mint E-N load will not be available in time to support a choice of black mint for the proposed E-N demonstration load⁽²⁾. However, simple analytical calculations coupled with reactivity-comparison data are adequate to distinguish between the conversion efficiencies of the two schemes.

SUMMARY AND CONCLUSIONS

It is possible to show at least 0.8% increase in total conversion ratio for an E-N load for enriched mint (38.5 w/o Li⁶) over natural mint. The basis of the calculations rests on measured E-N length ratios for equivalent neutron multiplicative properties for both types of mint (in a dry pile) plus analytical calculations. It is shown that both increased Pu and H³ production are obtained by using blacker mint. The basic phenomena are 1) increased resonance capture in U²³⁸ due to more uranium volume in the black mint E-N lattice and 2) more efficient utilization of neutrons in the mint pieces in the black mint E-N lattice.

The figure of 0.8% is to be considered a lower limit since further relative increases in utilization of neutrons in productive materials will be obtained when the water is factored into the calculations.

1. HW-60340, "Production Test IP-255-A-9-FP E-N Demonstration Test," R. E. Hall and W. S. Nechodom (Secret) May 8, 1959.
2. HW-60309, "Proposed E-N Demonstration Load," L. W. Lang (Secret) May 18, 1959.

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DISCUSSION

An 8 3/8" lattice reactor is chosen for the analysis, although the analysis would be very similar in the new K reactors. A striped E-N load is considered; the E-N length ratio is denoted by R. Both the natural lithium (7.5 w/o Li⁶) and the enriched (black) lithium (38.5 w/o Li⁶) aluminum alloys are considered. The weight percent of lithium in the alloy is 3.5 %.

The problem is to determine the relative conversion efficiency for both plutonium and tritium in the two types of E-N reactors. Basically, two phenomenon are associated with the enrichment level in the mint; 1) variation in resonance absorption in U²³⁸ due to different U²³⁸ content in the lattice and 2) variation in the efficiency of utilization of thermal neutrons in the mint.

For the purposes here, the neutron balance based on the simple four factor formula is quite adequate. Also, it is permissible to deal with room temperature, green reactor cross sections since any temperature or exposure-dependent effects are second order or higher in importance. One simplifying feature of reactor lattice theory however cannot be utilized. The one dimensional diffusion theory approximation cannot be relied on to calculate the relative thermal absorptions in the mint and uranium because of the extreme blackness of the enriched mint and the complicated axial flux variation due to the striped nature of the E-N column. However, this portion of the calculation can be bypassed by making simple assumptions and using available experimental data.

THE CRITICAL EQUATION

The conditions imposed on the E-N lattice that the local k_{∞} be equal to that for the natural uranium lattice. Thus,

$$[k_{\infty}]_{nat} = [\eta \epsilon p f]_{nat} = [\eta \epsilon p f]_{EN} \quad (1)$$

If we define the reproduction factor, η , as the number of fission neutrons from U²³⁵ produced per absorption in uranium, then η is changed by the presence of the mint only as far as it is dependent on enrichment level. The fast fission factor, ϵ , would be expected to be only slightly dependent on the presence of the mint due to a small increase in the escape probability of fast neutrons from the fuel rods. For all practical purposes one can assume ϵ a constant. Under the above assumptions:

$$[p f]_{EN} = \frac{[k_{\infty}]_{nat}}{\eta \epsilon} \quad (2)$$

The resonance escape probability, p , is dependent on the E-N ratio since p is a function of the volume of U²³⁸ in the lattice.

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$$P \approx \exp \left\{ - \frac{N_{28} V_u R I}{\sum_{sm} \xi_m V_m} \right\}$$

or

$$P \approx 1 - \frac{N_{28} V_u R I}{\sum_{sm} \xi_m V_m},$$

where

N_{28} = U^{238} nuclei per cm^3

V_u = volume of uranium per lattice cell

RI = effective resonance integral for U^{238}

$\overline{\sum_{sm} \xi_m}$ = average slowing down power of moderator

V_m = volume of moderator per lattice cell

Thus,

$$P_{EN} = 1 - [1 - P_{nat}] \frac{R}{1+R} \quad (3)$$

To be consistent with the definition of η previously given, the thermal utilization must be defined as the fraction of thermal neutrons absorbed in the uranium. Under this assumption

$$f_{EN} = \frac{1 - f_1}{1 + \varphi} \quad (4)$$

where

f_1 = thermal absorption of all parasitic absorbers in the lattice (clad graphite and aluminum).

φ = ratio of thermal utilization in the mint to the thermal utilization in the uranium

Using Equations 2, 3 and 4 one obtains for the critical equation

$$\left(1 - [1 - P_{nat}] \frac{R}{1+R} \right) \left(\frac{1 - f_1}{1 + \varphi} \right) = \frac{[k_{\infty}]_{nat}}{\eta_{EE}} = \text{const} \quad (5)$$

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APPLICATION OF EXPERIMENTAL DATA

The critical E-N length ratio for I & E geometry slugs has been measured in the HTP for both natural and black mint. The natural mint measurements date back to 1956⁽³⁾. The black mint measurements were completed very recently⁽⁴⁾. For 3.8" N slugs and 6" slugs (core dimensions quoted) the following ratios were found to give equivalent neutron multiplying properties to a natural uranium column of the same geometry. The measurements were made in a dry tube.

TABLE I E-N RATIO DETERMINATIONS

<u>Mint</u>	<u>R</u>
Natural (7.5 w/o Li ⁶)	10.5
Enriched (38.5 w/o Li ⁶)	15.1

For a dry cold lattice (the wet lattice is considered later), the following constants are applicable.

$$p_{\text{nat}} = .875$$

$$f_1 = .093 \text{ for natural mint, } .0918 \text{ for enriched mint}^*$$

$$k_{\infty \text{ nat}} = 1.060$$

$$\epsilon = 1.040$$

$$\eta_E = 1.447$$

Equation (5) now can be solved for $1 + \psi$ and the thermal utilizations of neutrons in uranium and mint for the two types of mint.

TABLE II THERMAL UTILIZATIONS IN E-N LOAD

<u>Mint Type</u>	<u>$1 + \psi$</u>	<u>f_u</u>	<u>f_m</u>	<u>f_1</u>
Natural	1.1397	.79582	.11118	.093
Enriched	1.1372	.79863	.10957	.0918

* It should be pointed out at this time that the parasitic absorptions in the graphite and aluminum are decreased considerably in the vicinity of the black mint pieces due to the large flux depression.

Thus, there is better productive utilization of thermal neutrons in the black mint case. The details of the calculation of the reduced parasitic absorption are presented in Appendix I.

3. HW-53360-RD, "Monthly Reports Reactor Physics Operation, September, 1956, to August, 1957 (Secret) J. H. Brown.

4. HW-59218-RD, "Monthly Reports Reactor Physics - 1959", (Secret) R. Nilson

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The U^{238} resonance capture probability can be obtained directly from Equation 3 for the two types of mint loadings.

TABLE III U^{238} RESONANCE CAPTURE PROBABILITIES

<u>Mint Type</u>	<u>P_{EN}</u>	<u>$1 - P_{EN}$</u>
Natural	.8859	.1141
Enriched	.8828	.1172

CALCULATION OF CONVERSION EFFICIENCIES

The initial atom-atom conversion ratios for plutonium and tritium can be given as follows in terms of U^{235} destruction.

$$P = \frac{\text{atoms Pu produced}}{\text{atoms } U^{235} \text{ destroyed}} = \frac{\nu_5}{\eta_E (1 + \alpha)} \left[1 + (1 - P_{EN}) \eta_E \right] - 1$$

$$T = \frac{\text{atoms } H^3 \text{ produced}}{\text{atoms } U^{235} \text{ destroyed}} = \frac{\nu_5}{\eta_E (1 + \alpha)} g \varphi$$

where

$$\nu_5 = \text{neutrons produced}/U^{235} \text{ fission} = 2.47$$

$$\alpha = \text{thermal capture to fission ratio for } U^{235} = 0.19$$

$$g = \text{ratio of } Li^6 \text{ captures to total captures in mint slug}$$

The g-factors for natural and enriched mint are 0.9768 and 0.9950, respectively.

For the two types of E-N loadings, the calculated conversion ratios are then as follows:

<u>Mint Type</u>	<u>P</u>	<u>T</u>	<u>P + T</u>	<u>% Increase</u>
Natural	0.68074	0.19574	0.87648	- -
Enriched	0.68743	0.19582	0.88325	.77

The ~ .8% increase in conversion resulting from the use of black mint efficiency in the striped E-N load is a lower-limit. The analysis has been restricted to the dry tube case for which E-N matching data are available. Further reductions in parasitic absorption is to be expected in the wet lattice again due to the markedly reduced thermal flux in the vicinity of the mint pieces. This factor is under study now as part of the physics calculations necessary to obtain the correct E-N ratio in the wet pile.

It is expected that the percentage increase in conversion ratio in the wet lattice would be at least 1%. A detailed neutron balance for the two types of E-N reactors is shown in Appendix II.

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APPENDIX I

CALCULATION OF REDUCED PARASITIC CAPTURE
WITH BLACK MINT

The absorptive properties of enriched mint are so great that in the vicinity of the mint slugs, almost all of the thermal neutrons are absorbed in the slug. Blackness theory calculation for mint slugs (solid rod geometry) of varying enrichment have been made.⁽⁵⁾ In addition the utilization of thermal neutrons in a simple two region lattice cell of mint and graphite were computed⁽⁵⁾. It is instructive to list the thermal blackness, the average graphite to average mint flux ratio, and the mint thermalization obtained from these calculations.

<u>% Enrichment of Lithium in Mint Rod</u>	<u>ρ_m (1.32" rod)</u>	<u>$\bar{\phi}_1 / \bar{\phi}_m$</u>	<u>f_m</u>
7.5 (natural)	0.745	2.524	.9307
10	0.813	2.887	.9400
20	0.944	5.032	.9466
30	0.976	7.231	.9485
40	0.985	9.374	.9499
50	0.990	11.49	.9508

The parasitic thermal utilization for the natural mint and a 38.5% Li^6 case are .0693 and $\sim$.050, respectively, yielding a difference of .0193. Only a part of this increase in productive neutrons can be credited in the E-N reactor, since the mint stripes make up only a small part of the column. A conservative reduction factor to use in scaling down the .0193 difference would be the ratio of mint length to total column length which is $1/16.1 = .062$ in the black mint case. Thus, we can credit at least $(.062) \cdot (.0193) = .0012$ additional productive thermal utilization in the black mint case. Thus, if $f_1 = .093$ in the natural mint case, $f_1 = .0918$ in the black mint case.

5. A. C. Sergi, private communication.

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APPENDIX II

Neutron Balance - E-N Reactor Natural Vs. Enriched Mint

Dry Lattice - Old Pile
(Upper Figures refer to Nat Mint E-N)
(Lower Figures refer to Enr. Mint E-N)

Definitions

- f_u = thermal utilization uranium
- f_m = thermal utilization mint
- f_l = thermal utilization parasitic
- q = thermal fission fraction in U
- Σ_c = macroscopic capture cross sec.
- p = resonance escape probability - U238
- η = thermal reproduction factor
- ϵ = fast fission factor
- ν = number neutrons per U235 fission
- g = Li⁶ fraction of mint absorption

* Represents all absorptions in graphite, process tubes

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