

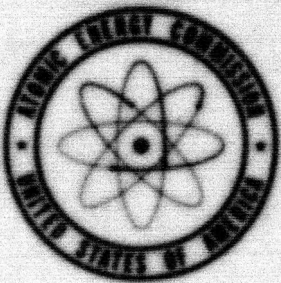
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UNITED STATES ATOMIC ENERGY COMMISSION

IV. PRODUCTION AND HEATING

By Harold Brown

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RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA - BERKELEY

ENGINEERING NOTES

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IV. PRODUCTION AND HEATING

BY Harold Brown

DATE Feb. 12, 1961

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We define $k_{\infty} = \eta \epsilon p f$ as the infinite reproduction factor where f is thermal utilization, p resonance capture escape probability, ϵ the fast effect coefficient, and η the number of neutrons emitted in thermal fission from the capture of a thermal in U. If ν is the number of neutrons per thermal fission of ^{235}U , we have

$$\eta = \frac{\sum \nu^{235} \text{ fission}}{\sum \sigma^{235} \text{ total}} \text{ where } \Sigma \text{ represents the macroscopic thermal cross section}$$

involved, $1 - x = \frac{\sum \sigma^{235} \text{ total}}{\sum \nu^{235} \text{ fission}}$ so $\eta = \frac{\sum \nu^{235} / (1 - x)}{\sum \sigma^{235} - \sum \nu^{235}}$ and $\frac{\sum \nu^{235}}{\sum \sigma^{235} + \sum \nu^{235}} = 1 - (1 + x) \frac{\eta}{\nu}$

Using a three-group model with resonance capture the diffusion equations are:

$$\frac{1}{\Lambda_1} \nabla^2 \phi_1 - \frac{1}{\Lambda_1} \phi_1 + \frac{\epsilon}{\nu \Lambda_3} \phi_3 = 0$$

$$\frac{1}{\Lambda_2} \nabla^2 \phi_2 - \frac{1}{p \Lambda_2} \phi_2 + \frac{1}{\Lambda_1} \phi_1 = 0$$

$$\frac{1}{\Lambda_3} \nabla^2 \phi_3 - \frac{1}{\Lambda_3} \phi_3 + \frac{1}{\Lambda_2} \phi_2 = 0$$

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In regions where the curvature of the thermal flux is small (everywhere except near the front face and then only if there is a large leakage there) $\nabla^2 \phi_3$ is small,

$\frac{1}{\Lambda_3} \nabla^2 \phi_3 \approx \frac{1}{\Lambda_2} \nabla^2 \phi_2$ is a very good approximation because the difference is

$\frac{1}{\Lambda_3} \left[\frac{\partial \phi_3}{\partial x} \Big|_0 - \frac{\partial \phi_2}{\partial x} \Big|_0 \right]$. If the leakages are small both $\frac{\partial \phi_3}{\partial x} \Big|_0$ and $\frac{\partial \phi_2}{\partial x} \Big|_0$ are near 0.

The total number of neutrons captured in the lattice per incident neutron is by definition $1 + k_{\infty} + k_{\infty}^2 + \dots = \frac{1}{1 - k_{\infty}}$. This number is also equal to the total

neutrons captured in group 2 plus those thermally absorbed in group 3. The total leaving the resonance group is $\int \frac{\phi_2}{p \Lambda_2} dx$ of which a fraction $1 - p$ is by

resonant capture. Thus:

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$\frac{1}{1 - k_{\infty}} = \int_0^{\infty} \left[\frac{\beta_2}{\lambda_2} \left(\frac{1 - p}{p} \right) + \frac{\beta_3}{\lambda_3} \right] dx$ in an infinite lattice with no leakage.

$$\frac{1}{1 - k_{\infty}} = \left[\int_0^{\infty} \frac{\beta_3}{\lambda_3} dx \right] \left[\frac{1 - p}{p} + 1 \right] = \frac{1}{p} \int_0^{\infty} \frac{\beta_3}{\lambda_3} dx$$

The total production of ^{235}U in the lattice is

$$\int \frac{\beta_2}{\lambda_2} \frac{1 - p}{p} dx \text{ in the resonance region}$$

$$+ \int \frac{\beta_3}{\lambda_3} \frac{\sum_{235}}{\sum_{\text{tot}}(\text{lattice})} dx. \text{ The second term is equal to}$$

$$\int \frac{\beta_3}{\lambda_3} \frac{\sum_{235}}{\sum_{235} + \sum_{238}} dx = \left[\int_0^{\infty} \frac{\beta_3}{\lambda_3} (f) (1 - [1 + \alpha] \frac{p}{\lambda}) \right]$$

$$P_{235} = \left[\int_0^{\infty} \frac{\beta_3}{\lambda_3} dx \right] \left(\frac{1 - p}{p} + f [1 - (1 + \alpha) \frac{p}{\lambda}] \right)$$

$$= \frac{p}{1 - k_{\infty}} \left(\frac{1 - p}{p} + f [1 - (1 + \alpha) \frac{p}{\lambda}] \right)$$

$$= \frac{1}{1 - k_{\infty}} (1 - p + fp [1 - (1 + \alpha) \frac{p}{\lambda}])$$

The number of fissions F in an infinite lattice with no leakage resulting from an incident neutron is

$$\int_0^{\infty} \frac{\beta_3}{\lambda_3} \frac{\sum_{235}}{\sum_{\text{tot}}(\text{lattice})} dx \text{ thermal fissions multiplied by } \frac{\nu/k - 1}{\nu - 1} \text{ to correct for fast fissions}$$

ν/k = number of neutrons from a thermal fission including following fast fissions

ν = number before fast fissions

$\nu/k - 1$ and $\nu - 1$ are respective excesses.

$$F = \frac{1}{1 - k_{\infty}} \left[pf \left(\frac{\nu/k - 1}{\nu - 1} \right) \right]$$

In a finite lattice with leakage at the front and back faces

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$$P = \left(\int_0^1 \frac{\phi_3}{\lambda_3} dx \right) \tau (1 - [\beta + \alpha] \frac{\tau}{\beta}) + \left(\int_0^1 \frac{\phi_2}{\lambda_2} dx \right) \frac{1 - \beta}{\beta}$$

$$\text{and } F = \left(\int_0^1 \frac{\phi_3}{\lambda_3} dx \right) \frac{\tau}{\beta} \tau \left(\frac{\beta \tau - 1}{\beta - 1} \right)$$

τ and F are in moles of product and fissions per mole of incident neutrons, respectively, if ϕ_2 and ϕ_3 are expressed in units of the incident fast flux Q_0 .

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