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MOUND LABORATORY-MONSANTO
Central File No. 52-10-65

OAK RIDGE NATIONAL LABORATORY ALMD52106501093

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CARBIDE AND CARBON CHEMICALS COMPANY

A DIVISION OF UNION CARBIDE AND CARBON CORPORATION

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NOTEBOOK NO. 1792

Assigned to: J. R. Parks

Department: Res. Dir. Div

Location: 9204-1 4-12

Date: 11-30-51

CF, INV. 5/16/53

This notebook is assigned to personnel performing research and development work and must be used for all original calculations, notes and abstracts from reports.

Assignee is responsible for the safe-guarding of this notebook in accordance with security regulations.

Do not use scrap paper. INV. 5-54 MSW

Be sure to record all personal conferences.

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Subject	Page

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VERNON ROYAL LINE
U. S. A.

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Date

$\cdot 0[\frac{\delta+\beta}{\tau}]$ = excess react.

Machine cal. ~~[illegible]~~

simple formula $\mu=0$

inertia 5.61

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HFE $\tau = 10$ s.

	α_1	α_2	$\frac{\delta-\beta}{\tau}$	$\frac{P}{P_0}$ (S)	$\frac{P}{P_0}$ I	$\frac{P}{P_0}$ (F)	$\bar{P}(s)$	$\bar{P}_i$ I	$\bar{P}_i$	$\bar{P}_f$	$\bar{P}$
1	0	0	375	7470		9326	$\frac{1700}{2500}$		2686	0	2688
2	0.3	0	300	3360		4152	$\frac{750}{1275}$		956	2.5	958.5
3	0	0.01	300	4560		4152	1860		956	(3.6) 17230	18186
4	0.3	0.01	300	4560	4250	4152	1860	1870	956	17230	18186
5	0	0	100	129		146	~~30~~ 14		11.2	(.4) 30 0	11.2
6	0.1	0	25	14.9		14.5	0.64		0.28	.0027	0.283
7	0.3	0	25	14.9		14.5	0.64		0.28	.0081	0.288
8	0	0.01	25	14.9		14.5	0.73		0.28	0.18	0.46
	0.3	0.01	25	14.9		14.5	0.73		0.28	0.19	0.47
10		"	-25	2.53	2.43	3	0.156	0.160	0.10	0.005	0.105
		"	-5	4.71	4.43	15	0.25	0.24		0.20	0.34
12		"	50	36.2	36.8	36.9	2.8	2.5			
13		"	100	145.4		149.5	28.0				
14		"	-50		1.44						
15		"	75		78.5						
16		"	125								
17											

$\mu = \alpha_1 + \alpha_2 |\dot{\rho}|$

delayed neutrons accounted for

[redacted]

an unauthorized person is prohibited.

GROUP 1

Excluded from automatic downgrading and declassification

Const-press. const power model

$$\dot{P} = \frac{1}{\tau}\left(\delta + \frac{dk}{d\rho}\rho\right)P - \frac{1}{\tau}P\beta + \frac{\beta}{\tau}\bar{P}$$

$\bar{P} = P_0$

$\dot{S} = \epsilon(P - P_0)$ assume $\rho = \left(\frac{\partial\rho}{\partial S}\right)_P S$

" reciprocal wt. cap.

initial cond. $t=0,\ \delta=0,\ P=P_0,\ S=0$

$t>0,\ \delta=\delta$

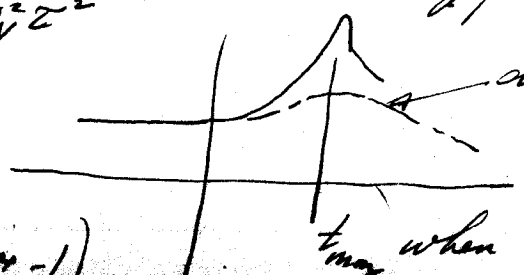
if $\frac{dk}{d\rho}$ is small $P = P_0 e^{\frac{\delta}{\tau}t}$

until $\frac{dk}{d\rho}$ is sig.

sol.

$$\frac{P}{P_0} = 1 + \ln\frac{P}{P_0} + \frac{\delta^2}{2\omega_N^2\tau^2}$$

$$S = \epsilon P_0\left(\frac{e^{\frac{\delta}{\tau}t} - 1}{\frac{\delta}{\tau}} - t\right)$$



$$\delta = \frac{dk}{d\rho}\left(\frac{\partial\rho}{\partial S}\right)_P \frac{\epsilon P_0 \tau}{\delta}\left(e^{\frac{\delta}{\tau}t_{max}} - \frac{\delta t_{max}}{\tau} - 1\right)$$

t_{max} when the temp(s) effect just opposes the power increase

$$\frac{\delta^2}{\omega_N^2\tau^2} = \frac{P}{P_0} - 1 - \ln\frac{P}{P_0}$$

must [illegible]

SECRET

[redacted]

with delayed neutrons

$$P = \frac{P_0}{\delta-\beta}\left[\delta e^{\frac{\delta-\beta}{\tau}t} - \beta\right]$$ or through approx solution on page 5.

The requirement is that $\dot{P} = 0$ when $\dot{S} = 0$ + algebra

$$\frac{P}{P_0} = 1 + \frac{\delta}{\delta-\beta}\ln\left(\frac{\delta-\beta}{\delta}\frac{P}{P_0} + \frac{\beta}{\delta}\right) + \frac{(\delta-\beta)^2}{2\omega_H^2\tau^2} + \frac{\beta(\delta-\beta)}{2\omega_H^2\tau^2}\frac{P_0}{P}$$ (Solution to)

---

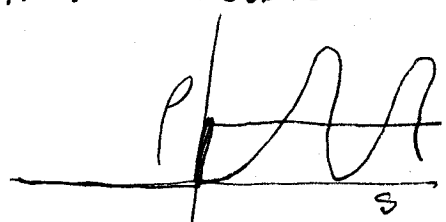
friction in pressurizer

$$\frac{1}{\omega_H^2}\ddot{\rho} + \frac{\mu}{\omega_H^2}|\dot{\rho}|\dot{\rho} + \rho = \left(\frac{\partial\rho}{\partial S}\right)_P S$$

for HRE μ is taken to be constant & the friction terms is unimportant & negligible.

ω_H = mech frequency.

we can take S as source term



critical region when time for power surge is comparable to ω_H

solve for $\rho = -\frac{\epsilon P_0}{\tau}\left|\frac{\partial\rho}{\partial S}\right|_P \tau^2 \frac{\delta}{\delta-\beta}\left[\frac{e^{\frac{\delta-\beta}{\tau}t}}{1+\omega_H^2\tau^2} - 1 - \frac{\delta-\beta}{\tau}t\right]$ This does not satisfy initial cond.

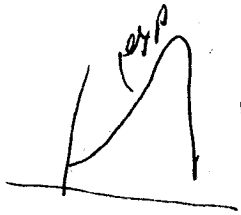
$1 + \frac{(\delta-\beta)^2}{\omega_H^2\tau}$

if $\frac{1}{\omega_H} \ll \frac{\tau}{\delta-\beta}$ then $\approx$

therefore we may put in the inertial correction in $\frac{P}{P_0}$ above.

$$E = \frac{2\delta_{prompt}}{\epsilon\left(\frac{\partial k}{\partial S}\right)_P}\left[1 + \frac{\delta^2}{\omega_H^2\tau^2}\right]$$ - energy release

bomb formula leave out 1; $E \propto \frac{\delta^3}{\omega_H^2\tau^2}$



$\dot{P}_{max} = 0.4\frac{\delta-\beta}{\tau}F$

for pressure

$P_{ren} = P$

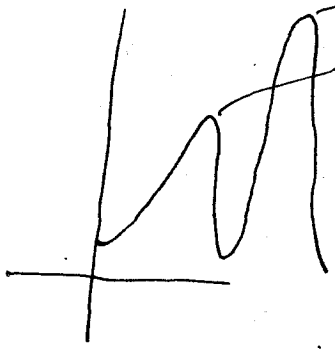
$$P = P_i + P_f = \frac{e^2}{\omega_H^2}\left|\frac{\partial\rho}{\partial S}\right|_P \epsilon\dot{P} + \frac{e^2}{\omega_H^2}\mu\left(\epsilon\left|\frac{\partial\rho}{\partial S}\right|_P(P-P_0)\right)\epsilon\left|\frac{\partial\rho}{\partial S}\right|_P(P-P_0)$$

inertial, frictional

P

Signed

The max of P_i & P_f will not occur at same time hence ρ will have 2 max
$2^{nd} > 1^{st}$

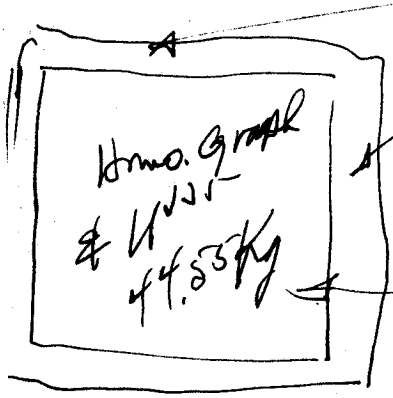


see column in table $\bar{P}(CS)$
for stem model $\bar{P}_f$

Date

Critical Experiments

Be	C
21×21×23.22"	51×51×44.11"
Mass 25 = 19.36 kg.	Mass 25 = 57.092 kg (bare reactor)
keff = 0.98	keff = 0.9912
Mef = 1.1 ev.	M.C.F. = 0.15
% thermal = 10.7	% thermal = 27.4
Age to th. = 56 cm²	age to th. = 391 cm²



graph

keffc o p scat. 1.02, no. self shield = 1.05

self shield = $\sigma_{f\,eff}/\sigma_f$

coveyu.

$$-D\nabla^2\phi + \Sigma_a\phi = -\frac{\partial q}{\partial u} + S \qquad (A)$$

$$q = \xi\Sigma_t\phi$$

Coveyo model → neutron diffusing or slowing down not both.

$$-D\nabla^2\phi + \Sigma_t\phi = \frac{q}{\xi} + S \qquad (B)$$

$$\frac{\partial q}{\partial u} + \frac{q}{\xi} = \Sigma_s\phi$$

A

$$\frac{\partial q}{\partial u} + \left(\frac{DB^2+\Sigma_a}{\Sigma_t}\right)\frac{q}{\xi} = S$$

keff = 0.9912

B

$$\frac{\partial q}{\partial u} + \left(\frac{DB^2+\Sigma_a}{DB^2+\Sigma_t}\right)\frac{q}{\xi} = \left(\frac{\Sigma_s}{DB^2+\Sigma_t}\right)S$$

resonance escape & leakage proba. decreased.

reduces source neutrons

$$\phi(u) = \frac{q(u)}{\xi\Sigma_t} \qquad (A)$$

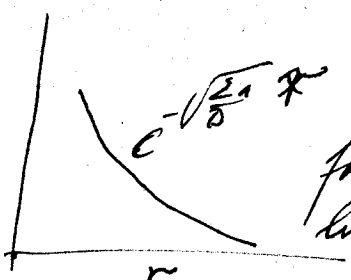
keff = 0.97

$$\phi(u) = \frac{q(u)}{\xi\Sigma_s + \gamma(\Sigma_a + DB^2)}$$

[illegible] 1.27%

Date

4/5 correction



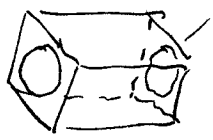
for away the source looks like a reduced strength S.

$\left(1-\frac{4}{5}\frac{\Sigma_a}{D_t}\right)S$

$-D\nabla^2\phi + \Sigma_a\phi = S$ is an approx to Boltzman Eq.

the correction term can be important at a resonance ($\frac{\Sigma_a}{\Sigma_t}$ large)

regions in react assem



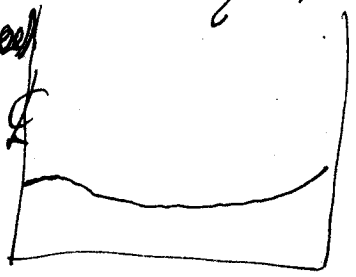
N = Ctg rate of foil

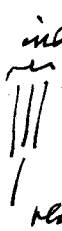
$\frac{Im}{Au}\left\{\frac{N_{Bar} - N_{cd\,cov}}{N_{cd\,cov}}\right. = \alpha\phi_{th}$ ($\alpha = R$) (experiment some bnd scatter)

	exp.	Rcalc.
ind.	R = 0.20	0.17 ε
Au	R = 0.26	0.17
$\frac{Ind}{Au}$ =	0.8	1.00

ε due to using σ = 17,000 b instead of 20,000 b.

New Val. R_{av} = 0.12 (worse) in taking into consideration self absorption the added σ was not enough to bring it back up.





Thick
$\left\{\begin{array}{l} In = 0.4 \text{ mil} \\ Au = \end{array}\right.$

These could be in serious error due to self absorption

no correction for depression due to foils in react.

How sig is $\frac{In}{Au}$ to spectrum of neutrons in react.

fuel discs with Al. foil and covered with Cd cov. Cov with ind

Cd ratio = $\frac{N_{Bare}}{N_{cd\,cov.}}$; Cd-Ind ratio = $\frac{N_{Bare}}{N_{cd\text{-}ind\,cov.}}$

	r_1		r_2
r_1	2.11 center	2.60 edge	cal. 2.72
r_2	3.40	3.90	2.96

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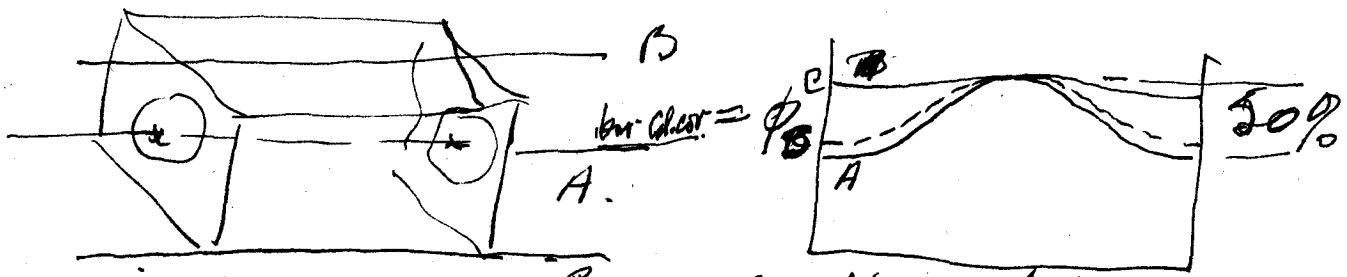
3×3×1 ; k_{eff} ; spread over entire reactor, $(\frac{\pi}{2})^3$ correction.
self shielding ; not quite center. essentially so.

danger coef. $\frac{\Delta k}{k}$ —		exp.	calc
	Na	−1" −.000068	−.000002
	Fe	1" −.00146	−.00142
	Fe	$\frac{1}{4}$" −.000162	−.000368
	Ni	$\frac{1}{4}$" −.000675	−.00070
	Mo	$\frac{1}{2}$" +.000030	+.000127

+ why? Mo. heavy absorbed of neutrons

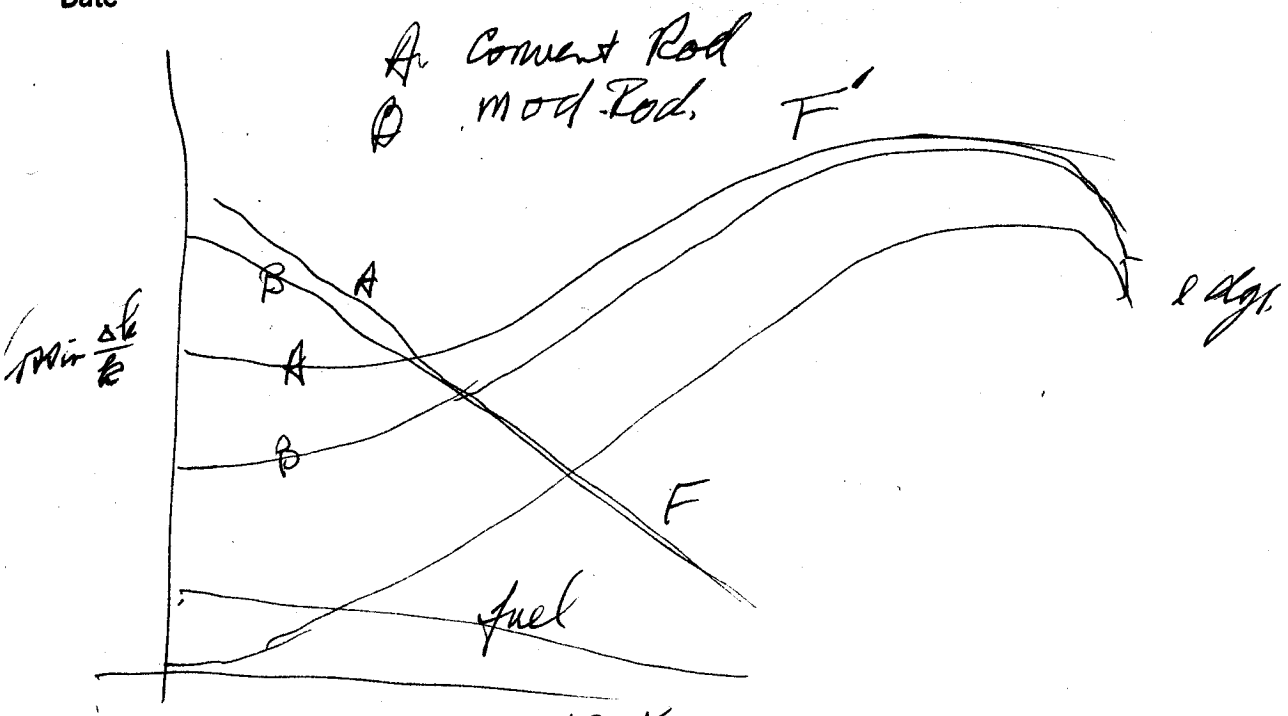
Materials in blocks 2.875" sq.
Averaging should be specified since it is thought that the averages can be made
Take 3 min to discuss calc. of $\frac{\Delta k}{k}$; Mo is to be remeasured again.

power vs position in react checks with Cosine law using 0.71 λ_t as extrapolation distance.
other curves check well. λ_t was taken as the usual thermal neutron transport mean free path.
should be some judicious choice like migration length
$\sqrt{L^2+\tau}$
Traverses through graph block



$\frac{\Delta k}{k}$	Exp	calc contains Σ_a & Σ_s	Perturbation Σ_a only
Na	−0.000066	−0.000002	
Fe 1"	−.00144	−0.00142	−0.00223
$\frac{1}{4}$"	−.000458	−0.000368	−0.00056
Ni $\frac{1}{4}$"	−.000657	−0.00070	
Mo $\frac{1}{2}$	−.00131	−0.00060	−0.00096

reactor 27% thermal



$$F(x) = \frac{d}{dx}\int_0^x\int_0^x \Delta I(x',x'')\,P(x',x'')\,dx'\,dx''$$

I = importance function

$I = \text{Const}\,x$

Y-F10-78, C.B. Mills water sol. of 2v
τ corrected by one term.

Date

Xenon poisoning

$$_{52}Te^{135} \xrightarrow[<2m]{\beta} {}_{53}I^{135} \xrightarrow[6.7h]{\beta} \begin{cases} 10\%\ {}_{54}Xe^{135} \xrightarrow[15.6\pm2m]{\gamma} \\ 90\%\ {}_{54}Xe^{135} \xrightarrow[9.2h]{\beta} {}_{55}Cs^{135} \quad (T_{\frac{1}{2}} = 2.1\times10^{4}y) \end{cases}$$

$$N_{Xe} = R\left[\frac{1-s}{\lambda_{Xe}}(1-e^{-\lambda_{Xe}T})e^{-\lambda_{Xe}t} + \frac{1-s}{(\lambda_I-\lambda_{Xe})}(e^{-\lambda_I T}-e^{-\lambda_{Xe}T})e^{-\lambda_{Xe}t} + \frac{1-s}{\lambda_I-\lambda_{Xe}}(1-e^{-\lambda_I T})(e^{-\lambda_{Xe}t}-e^{-\lambda_I t})\right]$$

R = rate of formation of chain, (fis. sec^{-1})(yield)

$\lambda_{Xe} = \phi\sigma + \lambda$, sec^{-1}

T = OP. time of react., sec

t = time after shutdown, sec.

s = % fis. that give Xe^{135} direct = Xe_{Dir} = 5% of Xe from I^{135}

Mass No

131 23m Sb $\xrightarrow{15\%}$ 30h Te ; 23m Sb $\rightarrow$ 25m Te $\rightarrow$ 8.0d I $\xrightarrow{1\%}$ 12d Xe ; 8.0d I $\rightarrow$ ∞ Xe

132 2m Sb $\rightarrow$ 77h Te $\rightarrow$ 2.4h I $\rightarrow$ ∞ Xe

133 44m Sb $\xrightarrow{82\%}$ 63m Te ; 44m Sb $\rightarrow$ 2m Te $\rightarrow$ 22.4h I $\rightarrow$ 2.3d Xe ; 22.4h I $\rightarrow$ 5.27d Xe $\rightarrow$ ∞ Cs

134 0.8m Sb $\rightarrow$ 44.5m Te $\rightarrow$ 52.5m I $\rightarrow$ ∞ Xe

135 48s Sb $\rightarrow$ [2m Te] $\rightarrow$ 6.68 I $\xrightarrow{30\%}$ 15.3m Xe ; 6.68 I $\rightarrow$ 9.2h Xe $\rightarrow$ 2.1×10^{4}y Cs.

136 86s I $\rightarrow$ ∞ Xe

137 22.0s I $\rightarrow$ 3.9m Xe $\rightarrow$ 33y Cs

if D_s & T are assumed stationary

Xe affects the thermal utilization $\frac{\delta h}{h} = \frac{f\phi\sigma y}{\phi\sigma+\lambda}$; y = yield

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consumption of Xe by absorption

$$\frac{dN_{Xe}}{dt} = S + \lambda N_{Xe} - \phi\sigma N_{Xe}$$

$$(\lambda + \phi\sigma) = \lambda_{Xe}$$

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time λ_e to Max

$$t_{max} = \frac{1}{\lambda'_{xe} - \lambda_I} \ln\left[\frac{\lambda'_{xe}(\lambda_{xe} + \lambda_I - \lambda'_{xe})}{(1-r)\lambda_{xe}\lambda_I} - \frac{r}{1-r}\right]$$

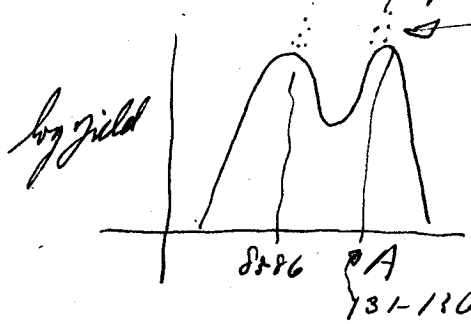
$\lambda_{xe} = \phi\sigma + \lambda$

$\lambda'_{xe} = \phi'\sigma + \lambda$

$r = \frac{\phi'}{\phi} = \frac{R'}{R}$

ϕ' = flux after shut down due to secondary processes

← up to now little known of σ & y_f



a. radio chem.

i. activity + mass spect.

diff. chemistry

~~133~~, 132, 134 136 → related to 131 → to Ba

135, 137, 133 related to 131 through Cs.

I-131 2.8 %

3.0 %

3.18 %

taken as true

errors are due to this determination

	Thode	Poppas	Parker → to tally decayed slugs	
131	3.0	3.0	3.0	
132	4.47	4.5	4.6	Jaffe
133	6.74	6.1		
134	7.94	7.9	8.0	
5	~~6.30~~ (6.50)	6.4	~~6.6~~	6.9
6			6.6	
7	6.15			

best value

$(6.7 \pm 0.2\ \%)$

based on 2.8% I

Pile experiments

1. shut pile down & observed $\frac{\Delta k}{k}$

fitted data to $\frac{\Delta k}{k} = \frac{f\eta}{\nu}\left(\frac{\sigma_{xe}}{\sigma_f}\right)\frac{N_{xe}}{N_{2v}} = ae^{-\lambda_I t} - be^{-\lambda_e t}$

fit const = $a = \frac{f\eta}{\nu}\frac{\sigma_x}{\sigma_f}\frac{y\,P(1-s)}{N_{2v}(\lambda_I - \lambda_{xe})}$; P = fiss./sec.

202 MeV/fission

$\frac{\sigma_{xe}}{\sigma_f} = F(T)$

$\frac{\sigma_{xe}}{\sigma_f} y = 3.19 \times 10^2$

T = temp reactor

$\eta = 5.1\%$

T = 0.01 eV y = correct

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Date

Borst $\sigma_{xe} y = 18.5 \times 10^4$ b

Canada $= 18 \times 10^4$ b

BNL $= 16 \times 10^4$ b

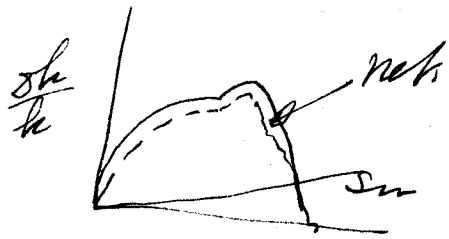
corresp. $y = 5.5 - 6.4$

Ktr — 0.750 Ma.

shut to $\frac{1}{40}$ & followed $\frac{\Delta k}{k}$ with Cal. control rod. with unif. poison

$t_{max} = 323$ min

$\frac{\Delta k}{k}$ equil $= 2.44\%$



$\frac{\Delta k}{k}$ $m_{ax} = 2.87\%$

$(f = 0.697)$?

t_{max} used to calc. $\phi\sigma$ & $\frac{\Delta k}{k}$ to get $y = 6.7\%$

$\bar{\phi} = 7.85 \times 10^{12}$; $\sigma = 2.90 \times 10^6$ b

$y\sigma = 19.4 \times 10^4$ corresponds to 130°F, Temp Re.

distribution of poison taken as $\cos^2 r$; MTR to start in 3 wks.

Signed

Date March 12, 52

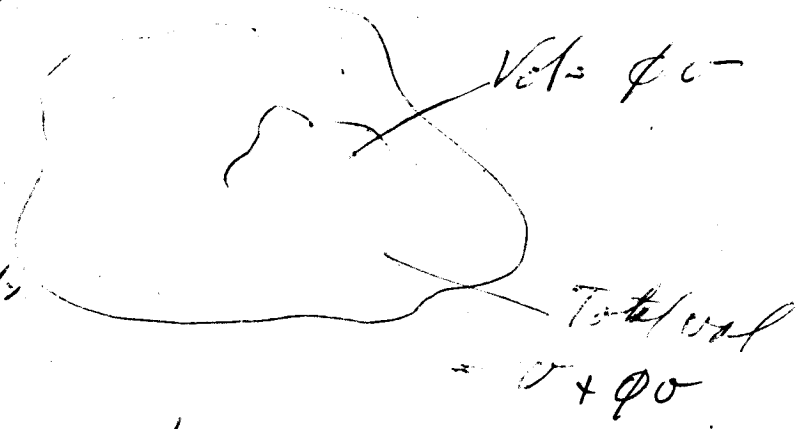
Larry Moderer —

Some New Ideas on Diffusion Theory Effects of Voids

Small holes have a density effect on M, L, τ.

$$\int_0^\infty \frac{1}{\lambda} e^{-\frac{z}{\lambda}} dz = 1, \quad \bar{z} = \lambda, \quad \overline{z^2} = 2\lambda^2$$

$$M^2 \simeq 2N\overline{z^2}.$$



$\psi(x, \Omega)dx$ = probability of a chord x between x & x+dx for any Ω

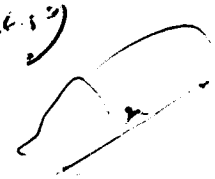
$$\therefore \int x\psi(x, \Omega)dx = \phi v \quad \text{for a given } \Omega$$

Now

$$\int \psi(x, \Omega)dx = \frac{1}{2}\int |\Omega \cdot ds|$$

$$\int\int \psi(x, \Omega)dx \frac{d\Omega}{4\pi} = \int\int \frac{1}{2}|\Omega \cdot ds| \frac{d\Omega}{4\pi} = \frac{s}{4}$$

Cauchy — $\bar{s} = \int dA \cos\alpha = \frac{1}{4}\bar{s}$ (Weinberg)



$$V = \int dA \cos\alpha \, r$$

$\therefore \bar{r} = \frac{4V}{s}$. Calculate nuclear processes in the hole. $\frac{n\sigma}{4} \cdot s \cdot \Sigma \cdot \bar{r} = n\sigma V \Sigma$

Chord distribution function

$$\int \psi \, d\Omega$$

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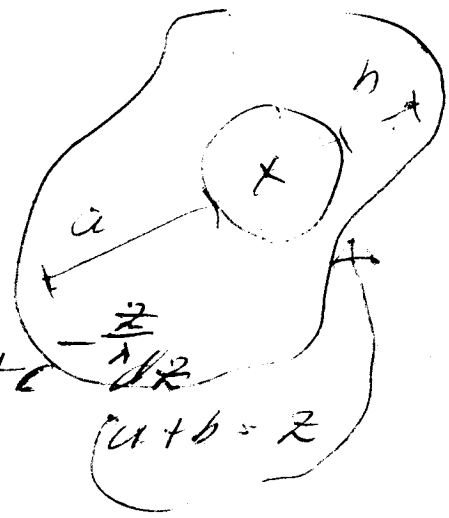
Date

Assume $v \gg s\lambda$, neutron hits only one hole.

$p(x, \Omega, z)\,dx$ = (probability that n will hit a hole and add x to z) $= \dfrac{z\,\psi(x,\Omega)\,dx}{v}$



$$\int p\,dx = \frac{sz}{4v\phi}$$

$$y^2 = \int_{\Omega}\int_0^{\infty}\left[\int_0^{\infty}(z+x)^2 p\,dx + z^2\left\{1-\int_0^{\infty} p\,dx\right\}\right]\frac{d\Omega}{4\pi}\frac{1}{\lambda}e^{-\frac{z}{\lambda}}dz$$

$$= 2\lambda^2 + 4\lambda^2\phi + \overbrace{\frac{\lambda}{v}\iint x^2\psi\,dx\,\frac{d\Omega}{4\pi}}^{\frac{\lambda}{v}\,\sigma r\phi v}$$

now let $q = \dfrac{\overline{x^2}}{(\bar{x})^2} = \dfrac{\iint x^2\psi\,dx\,\frac{d\Omega}{4\pi}}{\dfrac{\left[\iint x\psi\,dx\,\frac{d\Omega}{4\pi}\right]^2}{\iint \psi\,dx\,\frac{d\Omega}{4\pi}}} = \dfrac{\iint x^2\psi\,dx\,\frac{d\Omega}{4\pi}}{\dfrac{\phi^2 v^2}{\frac{s}{\psi}}}$

hydraulic rad $= r = \dfrac{2\phi v}{s}$

prob. of not hitting hole $= e^{-\int p\,dx}$

" " hitting hole $= p\,dx\,e^{-\int p\,dx}$

" " " n holes $= \dfrac{e^{-\int p\,dx}}{n!}\prod p(z,\Omega,x_i)\,dx_i$

$$y^2 = \left(z + \sum x_i\right)^2$$
$$= z^2 + 2z\bar{x}_i n + n(n-1)\bar{x}^2$$

$$\bar{x} = \frac{\int x\,p\,dx}{p - \int p\,dx} = \frac{\phi v z}{pv}$$

$$\bar{x}^2 = \frac{\int x^2 p\,dx}{\int p\,dx}$$

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$$\frac{\overline{y^2}}{2\lambda^2} = 1 + 2\phi + Q\frac{r\phi}{\lambda} \qquad v \gg s\lambda$$

$$\overline{y^2} = 1 + 2\phi + \phi^2 + Q\frac{r\phi}{\lambda} \qquad v \ll s\lambda$$

$$= 1 + 2\phi + \frac{\phi^2 \frac{2r}{\phi\lambda}}{\left(e^{\frac{2r}{\phi\lambda}} - 1\right)} + Q\frac{r\phi}{\lambda} = E \qquad v \sim s\lambda$$

all of this analysis depends on isotropy but Q is an average over ~~[illegible]~~

assuming Maxwellian distribution

$$L_0^2 = \int \lambda_a v M(v)\,dv \int \lambda_s v M(v)\,dv$$

Show that $\frac{L^2}{L_0^2}$ follows the formulas given here.

$\frac{r}{\lambda}$	$\frac{\overline{L^2}}{\overline{L_0^2}}$
0	1.44
1	1.53
2	1.67
6	2.20
10	3.00

fast leakage $= B^\alpha \tau$

slow " $= B^2 L^2$

τ & L^2 increase & B^α is decreased since

$R_c = R_0 + 0.71\lambda_t$ is increased

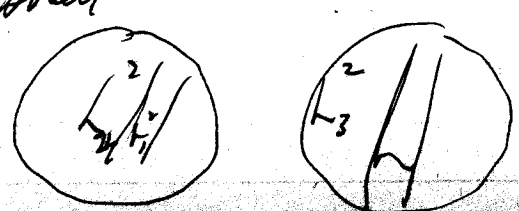
plane gas leads to ∞ in L^2 & τ does not fit exp.

material in hole

$L_0^2 \sim C_0 \frac{1}{\Sigma_0^2}$ in v, L_1^2 in ϕv

Two systems

superposed



$$L_2^2 = L_1^2 = \frac{L_0^2}{\alpha^2}$$

$$L_3^2 = \frac{L_0^2}{1-\alpha^2} \qquad \Sigma_3 = (1-\alpha)\Sigma_0$$

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$$L_4^2 = F(\lambda_0)\, L_3^2 / (1-\alpha)^2$$

$$\Sigma_4 = \frac{1-\alpha}{F^{\frac{1}{2}}}\, \Sigma_3$$

$$\Sigma = \Sigma_4 + \Sigma_2$$

$$\frac{L^2}{L_0^2} = \frac{1}{\left(\frac{1-\alpha}{F^{\frac{1}{2}}} + \alpha\right)^2}$$

in limit correct

A.W. suggested close extrapolation

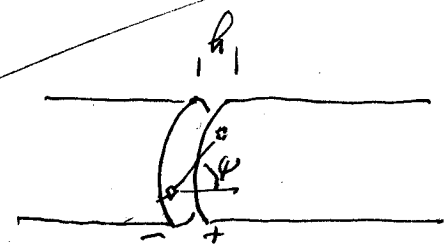
more exact solution using Behrens method.

$$\frac{L^2}{L_0^2} = \frac{1}{\left[\alpha + \frac{1-\alpha}{1+\phi}\right]\left[\alpha + \frac{(1+\phi)(1-\alpha)}{F}\right]}$$

another

Ted Welton suggested using perturbation method on introducing holes with material and cal. effect on flux

Tamor - on gash in reactor



$$\frac{\phi_0}{4} + \frac{\lambda}{6}\frac{\partial \phi}{\partial z} = \frac{1}{4\pi}\int \left[\phi_+(\rho') + \lambda\, \nabla \phi_+(\rho')\cdot \vec{r}\right] \cos\theta\, d\theta$$

If edge flow is neglected

$$\frac{\phi'}{\phi} = \frac{3}{2\lambda}\,\frac{1-(\gamma h)K_1(\gamma h)}{1+(1+\gamma h)e^{-\gamma h}} + \frac{3}{3}(\gamma\lambda)(\gamma h)e^{-\gamma h}$$

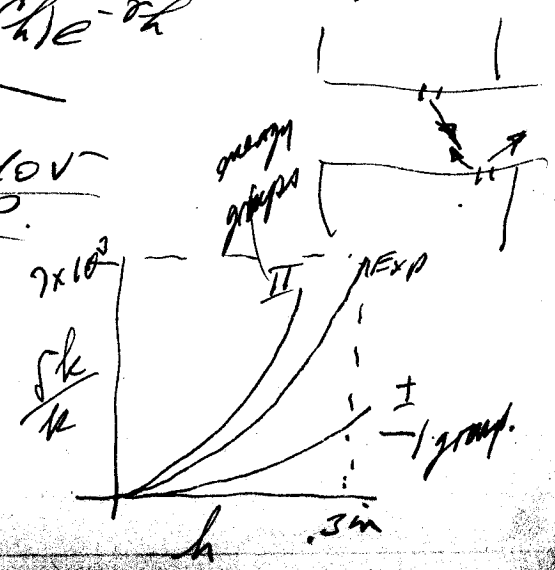
radial flow

This is exchange along $\vec{r}$ + loss to edge. (radial deriv.)

valid for h large.

$$\gamma = \frac{2.40\,v}{R}$$

k calculated with this equat by introducing as fictitious absorption in gap to get right loss of neutrons



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Date

Paul Kasten — Stability Boiling R.

1. Bubble hold up can limit power of R.
Bubbler formation decay function.

1) $\frac{dP}{dt} = \lambda_0[k(1-\beta)+k_c]P + \Sigma_i \lambda_i c_i$ $\quad \lambda_0 = \frac{1}{\tau_p k_c} \sim \frac{1}{\tau k_{c0}}$

2) $\frac{dc_i}{dt} + \lambda_i c_i = \lambda_0 \beta k P$

$k_c = 1 + B^2 M^2 = 1 + \left[\left(\frac{\pi}{h}\right)^2 + \left(\frac{2.405}{R}\right)^2\right]\left(\frac{M_0 \rho_0}{\rho}\right)^2$; $\quad M^2 = \cancel{1+B}^2 h^2 + \tau = M_0^2\left(\frac{\rho_0}{\rho}\right)^2$

Cylindrical reactor.

Weinberg — pointed out that the reactor will not be rt cyl during operation. Wigner & Wilkins showed that the surf is a convex surface at top.

$h = a\frac{1}{\rho}$; let $A = \left(\frac{\pi R}{2.405 h_0}\right)^2$

$k_c = 1 + \frac{k_{c0}-1}{1+A}\left(\left(\frac{\rho_0}{\rho}\right)^2 + A\right)$; suppose $k = k_0 + cT$ 3)

Now we can say that $\rho \sim P$; $V_0 = V_\ell + V_{stem}$

$M_0 = V_\ell \rho_\ell + V_{ST}\rho_{ST}$

$\rho = \rho_\ell - f_v(\rho_\ell - \rho_v)$ 5)

$V_{ST} = F_1(P)$

$f_v = \frac{V_{Bub.}}{V_\ell + V_{Bub.}} = \frac{H}{H + F_2(P)} =$ 4) $\quad H$ = Heat content of bubble

6) $\alpha\frac{dT}{dt} = P(t) - K(T - T_{st})$ { super heat temp. of sat liquid

heat drawn from reactor. thru bubbles

$\frac{dH}{dt} = K(T - T_{st}) - Q_v$

$\quad \parallel$

λH $\quad \lambda = sec^{-1}$ time of leaving of bubbles —

$T - T_s = \frac{1}{\alpha}\int_0^\infty e^{-\frac{K}{\alpha}x}[P(t-x) + K(T_s - x)]dx$

$= \frac{1}{\alpha}[g + Kg]$

$\dot{g} + \frac{K}{\alpha}g = P(t)$

$\dot{g} + \frac{K}{\alpha}g = T_s$

$\frac{dH}{dt} = \frac{K}{\alpha}[g + Kg - \alpha T_s] - \lambda H$

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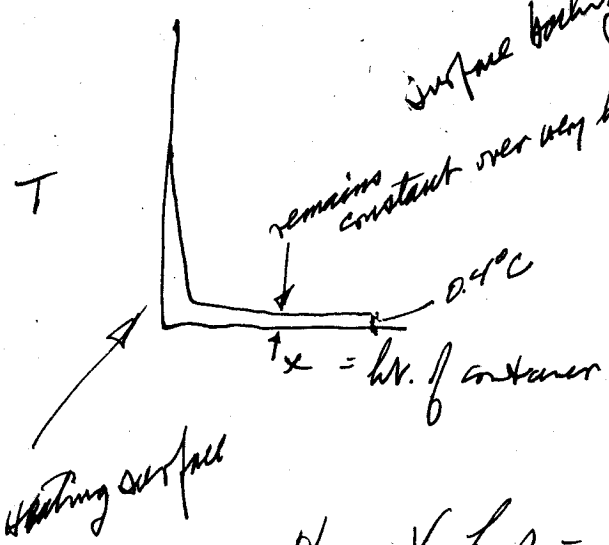


surface
Pigford $(T-T_s)$ may be small in which case K is very large
Vol. Boiling seems to be

$$H_{ST} = V_{ST}\, h_f \rho_v = F_f(P)$$

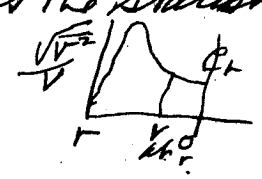
$$\left(\frac{dH_{ST}}{dP}\right)\frac{dP}{dt} = K(T-T_s) - P_c$$

and $P_c = C_c G[t_{out} - t_{in}] = F_s(P)$

Assumed given by $A + \frac{B}{P-C}$

Poppendiek — Turbulence & Heat Transfer

Mean velocity profile generalized - curve
fluctuating " " $\frac{\sqrt{\overline{v^2}}}{u} = f(r)$ - charateriges the statistical character of the curve.



Mixing Lengths. — $l\sqrt{\overline{v^2}}$ is a diffusivity like quantity
Analogies eddy diffusivity Heat = α eddy diffusivity of momentum.

$\tau = \rho \varepsilon_{zH} \frac{\partial \overline{v}}{\partial z}$; $\tau_0 = \frac{1}{2}\rho C_D \overline{v}_r^2$ reference velocity (lift force)

$\left(\frac{q}{A}\right)_{conv.} = -\gamma C_p \varepsilon_{zH}\left(\frac{\partial t}{\partial z} + \Gamma\right)$ adiabatic rate. , $\left(\frac{q}{A}\right)_{conv_0} = h_c(t_s - t_r)$ reference plane

Cross correlation & autocorrelation of fluctuating components u, v, w
$\overline{u^2}$, ,, $\overline{uv}$, ... can characterize a turbulent situation.
These are modes of approach
California is working on the Hydrosphere of the earth.
Mojave desert ∞ plane experiments

Signed

Date

Total in

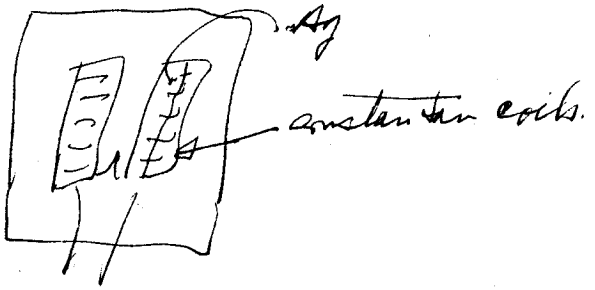
heat balance at earth's surf evaporative in desert = 0. ~~radiant~~ Abs.

$$\left(\frac{q}{A}\right)_{th_0} = \left(\frac{q}{A}\right)_{conv_0} + \left(\frac{q}{A}\right)_{e_0} + \left(\frac{q}{A}\right)_{g.r.} + \left(\frac{q}{A}\right)_{g_0}$$

conv. reflection leakage in.

found

difference thermopile, constantan half plated with silver.

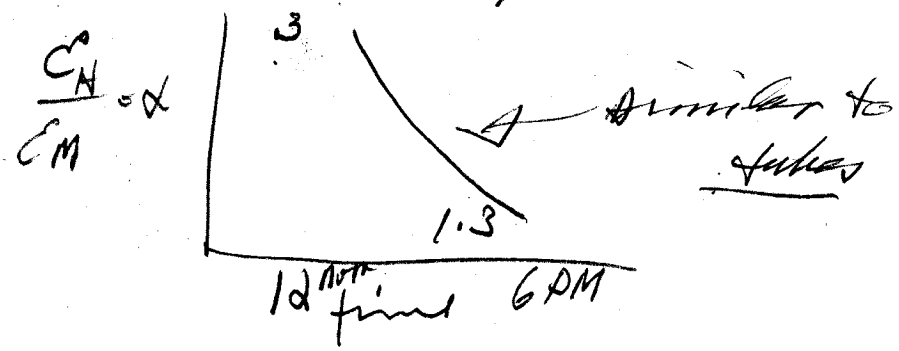


can be buried to get $\left(\frac{q}{A}\right)_{g_0}$, above ground at gets.

$$\left(\frac{q}{A}\right)_{th_0} - \left(\frac{q}{A}\right)_{g.r.}$$

to get temperatures near surf of earth, Thermopile junctions .001 to .003"

set to earth to 0.001" by microscope.



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Date

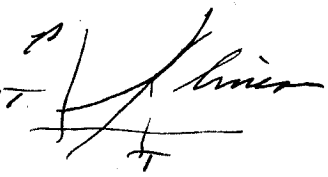
P. Kasten.

discussion of $K(T-T_s)$ this is a flow of power in to bubbles

$Q_x = \underline{h}A(T-T_s) + \frac{k_\ell A}{k_{\ell g}}(P-P_g)$ mass transfer

surface of Bubbles lat. transf. cross "heat of vaporization"

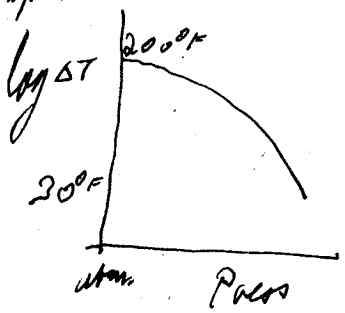
$P = aT$



or $Q_x = K(T-T_s)$

vol. boiling experiments with high K.F.
resistance of liquid as a function of vol. dissipation of power.
MIT — 4 ms delay time on pulse } must develope
UCLA — .3 s } superheat.

superheat

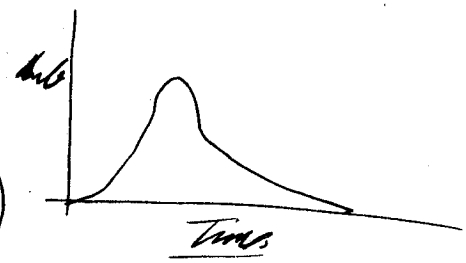


This gives

$$\frac{dH}{dt} + \lambda H = \mu G$$

$$\frac{dG}{dt} + \mu G = K(T-T_s)$$

$$\frac{dT}{dt} + K(T-T_s) = P(t)$$

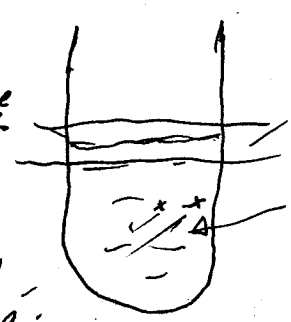


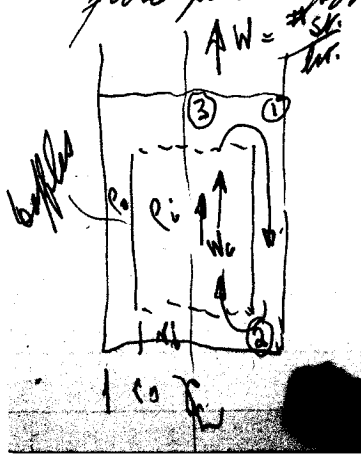
in this stability depends on μ, stable if $\mu \geq 10\ s^{-1}$
unstable $\mu < 7\ s^{-1}$

μ may depend on power; question on level of power - if lo stable if $\mu > 0$.

Pzmola. - Power removal

I control of mean density
I steam separation
I(a) circulation $v_H > v_{bubble\ rise}$
flow pattern postulate





$v_H \{ \rho_1, \rho_2$

assume (1) unif. power density
(2) bubbles small ~ liq. compressible
(3) $A_{r_i} = A_{r_o}$, $\left(\frac{r_i}{r_o}\right) = \frac{1}{2}$
(4) mean $\vec{\rho}_i$, $\vec{\rho}_o$

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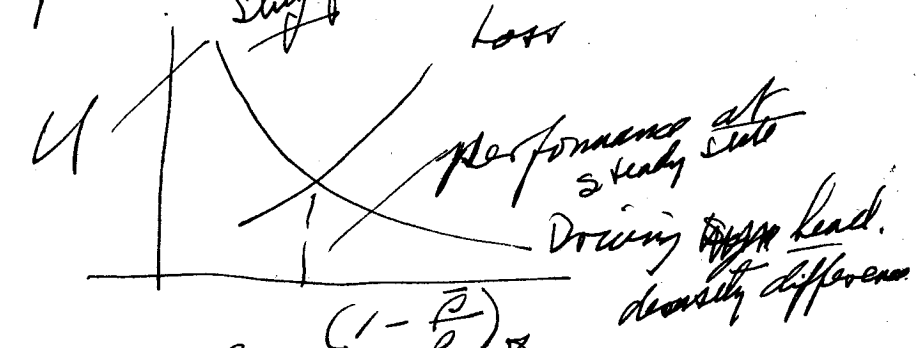
η = circ. ratio $= \frac{W_c}{W}$

Define η = fraction of bubbles that enter the down region.

$V_x = V_f + x(V_g - V_f)$ ← quality / steam vol. fractions

performance probable

$U_{(3)}$ vs $F_1\left(\frac{\rho_i}{\rho_0}\right)$ $F_2\left(\frac{\rho_f}{\rho_0}\right)$



$\alpha = \frac{\bar{\rho}}{\rho_f}$

Nuclear properties not calculated for this system

$W = W_c \alpha_3 (1-\eta) = \frac{W_c}{\eta}$; $\therefore \eta = \frac{1}{(1-\eta)\alpha_3}$

$P_{power} = \dot{q}'' V_{liquid(dry)} = W \eta_{fg}$

↳ mean power density

question of flow pattern — small bubbles imply turbulent flow.

$V_j = V_f + \omega_j V_{fg}$
$v_1 = V_f + \omega_j \eta (V_{fg})$

$V_{av} = \frac{V_1 + V_2}{2} = V_f + \omega_j V_{fg}\left(\frac{1+\eta}{2}\right) = V_2$

$P_0 = \frac{2}{V_1 + V_2}$, $\rho_i = \frac{2}{V_2 + V_j}\left(1 - \frac{\rho_i}{\rho_0}\right) = \pi_3 = \frac{4V_f + \omega_j V_{fg}(1+3\eta)}{4V_f + \omega_j V_{fg}(3+\eta)}$

$U_j = \frac{\eta W V_j}{A_i}$

$\omega_j = 4\frac{V_f}{V_{fg}}\left[\frac{1}{\frac{2(1-\eta)}{\sigma} + (3+\eta)}\right]$

$= \frac{P}{\eta_{fg} A_i} \frac{V_{fg}}{(1-\eta)}\left[\frac{\frac{2(1-\eta)}{\sigma} - (3+\eta)}{4} - 1\right]$; σ = measure of bunching in inner region — driving force

Head loss $= \frac{C U_j^2}{2g} = \frac{\Delta \text{pressure loss}}{\rho}$; ΔP = driving force $\times (1 - \frac{\rho_i}{\rho_0}) \rho_0 h$

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$V_s = \sqrt{\frac{2gh\eta}{C}}$; Curves based on 20'Ø × 20'h.

$q_0 = \frac{2.6\ kw}{liter}$ fixed by boiler practice.

Dr. Weinberg MTR

Load — 3.66 kg 25 — 12.5 (30 MWD)

ran 375 MWD — last 3 days at 30 MW.

at 30 MW — Shim rod removed more quickly

burn up 485 g — Hopped for 2.5 days op. at 30 mw.

(18.9%) $\frac{\Delta h}{h}$ — design, 12-13% in now. (meas. with wires)

→ due to 0.73% Val/H_2O

→ H_2O% in Be > 2%

→ large Hole next to lab

Xe([illegible] + Sm([illegible]

Tot [illegible]

burnup → 7.0% (est. [illegible] 5.6%)

[illegible]

η 0.65 Val/H_2O

Now load 3×9

in high burnup reactors

(flux) importance functions are important

Non uniform dist. → 1.5% of 7%.

Burnup calculated 1.29 gm 25/MWD } [illegible]

193 Mev/fission } this.

Moral — (check everything) will they do it

Scientific — no second order processes that poison the [illegible]

Can a high reactivity reactor like the MTR be shimmed in the reflector rather than in the core.? June 15, 52.

How about tubes of circulated controlled concentration [illegible] [illegible] borated water; poisoning [illegible]

Date

Wigner – Diffusion & Multiple scattering

Boltzmann equat gives a $f(\underline{r}, \underline{\Omega})$
replace with $\phi_i(\underline{r})$ $i = 1 - 4$.
let $g(\Omega)$ = distribution
after scattering $g'(\Omega) = \int g(\Omega)\, \sigma(\Omega, \Omega')\, d\Omega$

$g(\Omega) \to g(R)$ R = Rotation

$\sigma(\Omega, \Omega') \to \sigma(R^{-1}S)$

$g'(S) = \int g(R)\, \sigma(R^{-1}S)\, dR$ ← convolution (general)

$\mathcal{L}[\text{conv}] = \mathcal{L}[F]\,\mathcal{L}[G]$

$$\int \mathcal{D}^{l}(R)_{\alpha\beta}\, \mathcal{D}^{l'}(R^{-1}S)_{\alpha'\beta'}\, dR = \sum_{\gamma} \int \mathcal{D}^{l}(R)_{\alpha\beta}\, \mathcal{D}^{l'}(R^{-1})_{\alpha'\gamma}\, \mathcal{D}^{l'}(S)_{\gamma\beta'}\, dR$$

$$= \sum_{\gamma} \frac{h}{l}\, \delta_{ll'}\, \delta_{\alpha\gamma}\, \delta_{\beta\alpha'}\, \mathcal{D}^{(l')}(S)_{\alpha\beta'}$$

$$= \frac{h}{l}\, \delta_{ll'}\, \delta_{\beta\alpha'}\, \mathcal{D}^{l'}(S)_{\alpha\beta'}$$

$g(R) = \sum_{l\alpha\beta} g^{l}_{\alpha\beta}\, \mathcal{D}^{l}(R)_{\alpha\beta}$ now if $\sigma = a + b\mu$
$= a\mathcal{D}^{0} + b\mathcal{D}^{1}_{00}$

$\sigma(R) = \sum_{l\alpha\beta} \sigma^{l}_{\alpha\beta}\, \mathcal{D}^{(l)}_{\alpha\beta}(R)$ $\sigma^{0}_{00} = a$, $\sigma^{1}_{00} = b$

$g'(R) = \sum_{l\alpha\beta} g'^{l}_{\alpha\beta}\, \mathcal{D}^{l}_{\alpha\beta}(R)$ Integration replaced by Matrix Multiplication.

collision is a transformation
of $(\underline{V}, \underline{\Omega}) \to (V', \underline{\Omega}')$ 3 dimensional inhomogeneous transf.
a 3×4 Matrix in Rotation $\begin{pmatrix} R_{ij} \\ b_i \end{pmatrix}$ $i = 1 \ldots 3$, $j = 1 \ldots 3$, $i = 1 \ldots 3$

Signed

Date

Weinberg in 506 Wheeler, K. Way, nobody seems to know.

$$\bar{\sigma} = \frac{\delta x \sigma_x}{\delta x} \text{ function of time.}$$

Information Meeting Sept. 10, 11, 12, '52

Weds. ~~AM~~ AM in ~~[illegible]~~ AM.

1. MTR - 10:00
2. EBR - 10:40
(3.) PM to #6 - 4:15 PM.
3. Room 206

Thurs. Aud. all day

Fri. Aud. all day.

$\frac{6000}{200} \sim 30 = 28$

$$N\sigma_f = \frac{0.6 \times 20 \times 545}{225}$$

Signed

Date

CRGP 500 D. G. Hurst - Oct 57.

Estimate of Total cross-section of accumulated Fission Prod.

DR - 21 Feb. 52

W. B. Lewis - Reactivity chags. Predicted & observed in long irred. of nat. uranium in NRX.

Hurst assumes that the end product of the chains are of imp. and 2nd ord captures an important

$$\frac{dx(A)}{dt} = b_x(N\sigma_f)\phi - \sigma_x\phi x$$

yield

$0.1 \le T \le 1$

$$x = \frac{b(N\sigma)_f}{\sigma_x}\left[1 - e^{-\phi\sigma_x t}\right]$$

$\phi\sigma_a(2\nu)T = t$

$T = 1 \sim 5600$ MWD/ton

$\frac{T}{t} = 1 = \frac{1}{\phi\sigma_a(2\nu)}$ equiv to sys at 10^{13} n cm^{-2} sec^{-1}

case 1) $\sigma_x < 4\sigma_a \le 250$ b

$$x\sigma_x = b(N\sigma)_f \frac{\sigma_x}{\sigma_a(2\nu)} T$$

20% error

case 2) $\sigma_x > 10\sigma_a$ (Xenon not included)

$x\sigma_x = b(N\sigma)_f$ 37% error

$$\sigma_p = \sum_{\text{case 1}} x\sigma_x + \sum_{\text{case 2}} x\sigma_x = (N\sigma)_f\left\{\frac{T}{\sigma_a(2\nu)}\sum_{(1)} b\sigma_x + \sum_{2} b\right\}$$

Sm.

$$= \{0.055\,T + 0.0155\}(N\sigma)_f$$

- data taken from the usual charts of NBS circular

Zr 93	6%
Tc 99	6.2
Sm 157	0.55
Sm 147	
Pd 107	0.2
Cd 111	0.018
Cd 112	0.011
Gd 156	0.013

50 b/fission

80 b/fission Hanford

100 b/fission MTR

Signed

Date Sept 10, 52

MTR CM-1670, 1650 gms.

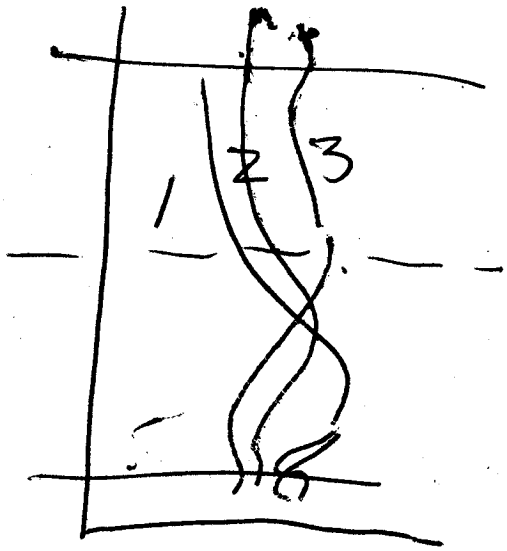
Final assem 3x9, 140 gm 25 each

vertical flux dist., wire co.

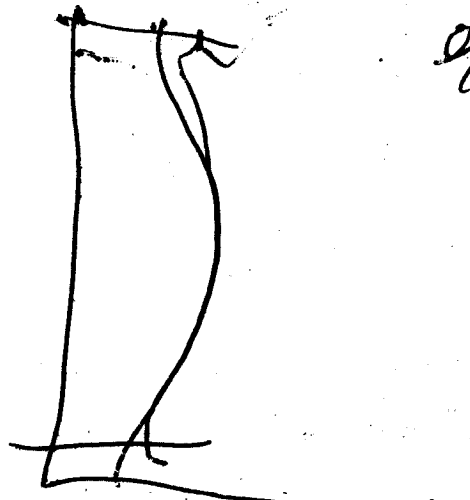
Shim rods $\frac{2}{3}$ way down.

$\frac{1}{2}$ way out on 3x9

C-25



Center rod



extreme corner

out in Be a cosine is found.

3x9 Σ pile = 7800 cm²

Gross temp coef.

$1.1 \times 10^{-4} \frac{\Delta k}{k}$ °F^{-1}

$0.8 \times 10^{-4} \frac{\Delta \rho}{\rho}$ °F^{-1}

Calibration

Complete Burn up.

376 MWD 13% Δk

Be fast reaction

Can give in 10 yrs

1%

Signed

Date

Burn up + geometry gave 7% instead of 4% in 3x9

5x5 excess k. — 15%
Burn-out ~ ~~400~~ 475 MWD.

HB plugs removed 2.5.

168 gms 25 instead of 140 gm 3x9 $\frac{\Delta k}{k}$% = 18%

flux used in fuel elements gives 2 gms of Li / fuel element
units for 3%
Al/H_2O ~ 0.65 ideal

~ 0.71 as built ~ 1.5%

H_2O/Be ~ 3%

Calculated wts are on shy side calc. wt. F = 1.4
meas ~ 1.2
apparently for the 3x9 lattice the wt factors approx ϕ^2
Also apparent from this, the assymmetry of the flux affected the burn up more than it does the flux in the outer regions of the reflector.

Nat & D_2O lattices
Cohen et al. North Ann.

$\bar{\lambda}$ flux averages (meas)

$\frac{\nu^2}{\ell} > \frac{\lambda}{2\Sigma_a} \frac{V_m}{V_u} F F_m$ $F F_m = \frac{\bar{\phi}_m}{\phi_u}$; $\lambda = 2.55$ cm gives a spread in N for rod sizes

disad. factors

τ to ind 100 cm
ind to ther $\frac{20}{120 \text{ cm}^2}$ must be corrected for N effect
(112 to 115 cm²)

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Date

$\lambda = 2.7$ increase spread

$= 3.0$ spread greater in $> \frac{V_m}{V_u}$

$= 2.4$ " " " $<$ "

$\pm .08$

$\lambda = 2.58$ gave min spread of N (dia)

$N = 1.714 \pm .008$

$$F = \frac{\bar{\Phi}_m}{\Phi_{su}}$$

λ spreads because ϕ is peaked much higher in mod than by diffusion theory.

The simple k_∞ formula applies well to finite reactors.

Normal water slightly enriched lattices.
BNL.

$$B^2 = \left[\frac{2.405}{R+\lambda}\right] - \frac{1}{L^2}$$

L = relaxation length of lattice

$\tau = 33$ is asymptote

σ_{in}	28 detector	Al det.
Al	0.44	
Fe	0.82	← shows that reduce by 10%.
Cu	1.05	
Ag	1.71	
Sn	1.26	
Au	2.1	← sum of cross section for high E neuts
Pb	0.89	and " " for low E "
U	2.5	

Signed

Date

$\sigma_{in} = \pi(R^{\prime\prime} + \lambda\!\!\!^{-})^2(1 - \frac{1}{N})$ N = no. of levels below E of neut. that can be excited on the gsel Nucleus.

Slowing down with Σ_a Sept 17, 52

$\frac{\Sigma_a}{\Sigma_s}$ has small variation in ΔE for a collision

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