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UNITED STATES ATOMIC ENERGY COMMISSION

INDUCED ACTIVITIES IN A RECYCLING CONTROL SOLUTION

By
W. E. Drummond

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September 5, 1951

W. K. Alexander
 Pile Technology Unit

INDUCED ACTIVITIES IN A RECYCLING CONTROL SOLUTION

Reference: Your memo to R. L. Dickeman dated August 16, 1951 requesting an investigation of the radioactive buildup in a liquid control or "ink" solution recycling through the pile.

The induced activity in a solution which alternately spends a portion of its time in a neutron flux and a portion removed from the flux will depend upon the number of such cycles, isotopic composition of the solution, magnitude of the flux, and, of course, exposure time and decay time. The mathematical framework describing this is

$$A_n(t) = 1.5 \cdot 10^{-4} \sum_k (B_k E_k) \sigma \epsilon f a \frac{(1 - e^{-\lambda t_r})}{(1 - e^{-\lambda T})} (1 - e^{-(n+1)\lambda t}) e^{-\lambda t}$$

where: $A_n(t)$ denotes the dosage rate in mr/hr per cc from a single isotope of the solution t seconds after the particular cc in question has left the active region of the pile, having passed thru the active region of the pile $n + 1$ times, and thru the external circuit n times.

- t_r = time in the active region of the pile = 1 minute
 T = time of complete cycle = 31 minutes
 σ = capture cross section
 E_k = energy in Mev of gamma rays produced
 B_k = number of gamma rays per disintegration with energy E_k
 λ = $\frac{.693}{\text{half life}}$
 a = elemental concentration in atoms per cc
 c = isotopic abundance
 f = average thermal neutron flux

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The total dosage rate per cc of solution at 1 cm in air is the sum of all such dosage rates from the single isotopes. This total dosage rate builds up to a saturated value of approximately 5300 mr/hr/cc of solution at one cm in air ($t = 0$). The dosage rates or activities at one cm in air of the individual isotopes as well as the total activity per cc of the solution are plotted as a function of n , the number of cycles, in Figure 1. Figure 2 shows the decays of the saturated activities ($n > 100$) as a function of t , the time out of the pile. This decay is rapid for the first 30 seconds and after that decays with a half life of approximately 14.9 hours. All of the activities are based on an average thermal neutron flux of 10^{13} , and are in units of mr/hr/cc of solution at one cm in air.

The principle activities are due to 12.1 hr K and 14.9 hr Na. Since the sodium enters as an impurity, any error in the amount of impurities will have a proportional effect on the activities. If an attempt is made to minimize the activity of the solution it might be advisable to minimize the sodium impurity or to use a solution which does not contain an offending element such as potassium.

$$\text{Since } A_n(t) \propto \frac{1 - e^{-\lambda t_r}}{1 - e^{-\lambda T}} \approx \frac{t_r}{T} ; \lambda T \ll 1$$

$$n > 100$$

the saturated activities of the longer lived decays are proportional to the ratio of t_r/T . Thus reducing the time in the pile will reduce the activity proportionally.

The dosage rate at one foot from a .936 inch diameter pipe, assuming that the pipe had no shielding effect, was calculated and found to be 633 mr/hr.

The dosage rate was also calculated at a point separated by three feet of concrete from the bottom of a tank ten inches in diameter and two feet high, containing saturated solution which had been out of the pile one minute. This was found to be 3.28 mr/hr. Since this is of the order of the radiation limit at this point, it may be desirable to provide additional shielding by interposing a slab of lead between the tank and the concrete. Each half inch of lead so used will provide attenuation by a factor of two, or if some other material is used the number of inches needed will be simply the number of inches of lead which would be needed times the ratio of the density of lead to the density of the material used.

The composition of the solution is given in Table I. The method used to obtain the dosage rates is derived in Appendices 1 and 2.

TABLE I

Composition of the Solution

10% by weight solution of $K_2B_4O_7 \cdot 5H_2O$ in water

Impurities

Na	.35%
Cl	.05%
So ₄	.05%
Fe	.001%

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Appendix 1

In passing through the active region of the pile $G_0 = \frac{\epsilon \sigma f d}{\lambda} (1 - e^{-\lambda t_r})$ active nuclei of a particular isotope will be produced per cc of solution. In the next n cycles this will decay by $e^{-n\lambda T}$. Thus, after the solution has passed through the active region of the pile $n + 1$ times, there will be

$$G_0 \sum_{k=0}^n e^{-k\lambda T} = G_0 \frac{(1 - e^{-(n+1)\lambda T})}{(1 - e^{-\lambda T})}$$

exited nuclei.

After the particular cc in question has been out of the active region of the pile t seconds, the dosage rate in mr/hr at 1 cm in air will be

$$A_n(t) = 1.5 \cdot 10^{-4} \sum_k (B_k E_k) \epsilon \sigma f d \frac{(1 - e^{-\lambda t_r})}{(1 - e^{-\lambda T})} (1 - e^{-(n+1)\lambda T}) e^{-\lambda t}$$

Appendix 2

The activity at a point separated by x cm of concrete from the bottom of a cylinder y cm in diameter and z cm high, having an activity per unit volume of A_n (1 min.), assuming no self absorption, and making the conservative assumption that z is small compared to y , is

$$A = 2\pi A_n (1 \text{ min.}) B \int_0^{\theta \max} \int_{r=x \sec \theta}^{r=(x+z) \sec \theta} \frac{\sin \theta e^{-\mu x \sec \theta}}{r} dr d\theta \quad \sec \theta = \frac{y}{2x}$$

where B buildup factor $= 2$

$$A = 2\pi B A_n (1 \text{ min.}) z \left[-\text{Ei}(-\mu x) + \text{Ei}(-\mu x \sec \theta) \right]$$

where:

μ = absorption coefficient of concrete

$$-\text{Ei}(-\alpha) = \int_{\alpha}^{\infty} \frac{e^{-\alpha}}{\alpha} d\alpha$$

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FIG. 1

ACTIVITY PER UNIT VOLUME OF INK SOLUTION
AS A FUNCTION OF N, THE NUMBER OF CYCLES

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DECAY OF SATURATED INK SOLUTION AS A FUNCTION OF THE TIME OUT OF THE PILE

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