



0

REPORT NO. CP-499

RADIOACTIVITY OF THE COOLING WATER

E. P. Wigner

March 1, 1943

ABSTRACT

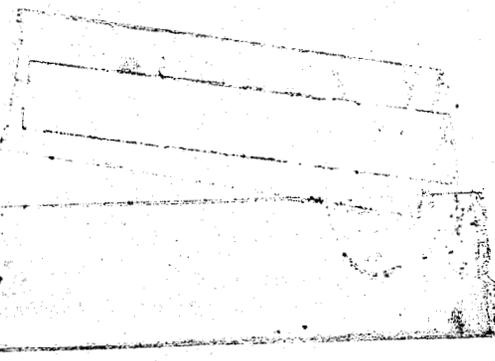
The most important source of radioactivity at the exit manifold of the pile will be due to  $O^{19}$ , formed by neutron absorption of  $O^{18}$ . A recent measurement of Fermi and Weil permits to estimate that it will be safe to stay about 80 minutes daily close to the exit manifolds without any shield. Estimates are given for the radioactivities from other sources both in the neighborhood and farther away from the pile.

Photostat Price \$	<u>1.80</u>
Microfilm Price \$	<u>1.80</u>

Available from the  
Office of Technical Services  
Department of Commerce  
Washington 25, D. C.



This document is  
**PUBLICLY RELEASABLE**  
*Lester E. Williams*  
Authorizing Official  
Date: 07/14/2005



709-1

## **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

RADIOACTIVITY OF THE COOLING WATER

E. P. Wigner

1. If the water contains  $p$  parts per million of an element with an atomic weight  $m$  and slow neutron cross section  $\sigma$ , this substance will absorb about the fraction

$$f = \frac{pV\sigma L \times 10^{-6}}{m\Sigma} = \frac{10^{24} \sigma p}{m} \times .425 \times 10^{-6} \quad (1)$$

of all neutrons. In the above,  $L = 6 \times 10^{23}$  is Loschmidt's number,  $V = 3 \times 10^6 \text{ cm}^3$  is the total volume of the water in the pile and  $\Sigma$  is the total cross section of all materials (U, C, etc) in the pile. For a 200 ton U pile  $\Sigma \approx 4.25 \times 10^6 \text{ cm}^2$ . Since, in a 500,000 kw pile,  $3.5 \times 10^{19}$  neutrons are absorbed per second, the number of new nuclei formed by neutron absorption of the element in question becomes

$$N = 35 \times 10^{19} f = \frac{10^{24} \sigma p}{m} \times 1.5 \times 10^{13} \text{ sec}^{-1} \quad (1a)$$

The nuclei thus formed by neutron absorption may or may not be radioactive. If, in the former case, the radioactivity is connected with the emission of  $\gamma$ -rays, it may present a hazard to the personnel at the water exit end of the pile. This hazard is, of course, removed if the pile is shut down as soon as the water which has been in the pile during operation has left the system but is present as far as the personnel inspecting the water outlet system during operation is concerned. In addition, the radioactivity of the cooling water--from the above and other sources to be discussed below--may make it necessary to shield the outlet pipes etc., for some distance.

The  $\beta$  radiation will present little actual danger. More probably, it may render it difficult to detect failures in the U sheathing or coating.



It is assumed that 1 r unit corresponds to  $5 \times 10^8 \gamma$  rays per  $\text{cm}^2$ .

The following will give an enumeration of possible sources of radioactivity in the cooling water, either from the above or other reasons, as far as we can foresee them at present.

Hydrogen

$p = 1.11 \times 10^5$ ,  $10^{24} \sigma = .39$  for  $\text{H}^1$  so that  $f \approx 1.8 \times 10^{-2}$ . The product from this reaction  $\text{H}^2$ , is stable so that no radioactivity results from this source. For  $\text{H}^2$  itself,  $p = 4 \times 10^{-4} \times 1.11 \times 10^5$ ,  $10^{24} \sigma = 1.8 \times 10^{-3}$  so that the activity would represent ( $\tau = 10^9$  sec)

$$A = \frac{.064 \times 1.8 \times 10^{-3} \times 44.4}{2 \times 10^7} = 2.5 \times 10^{-12} \frac{\text{r}}{\text{sec}}$$

which is a negligible activity quite apart from the fact that the  $\text{H}^3$  formed emits no  $\gamma$  rays and even its  $\beta$ -ray is extremely soft.

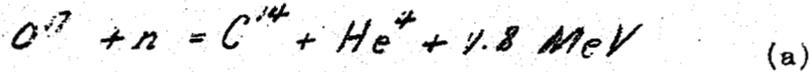
Oxygen

The nuclei formed from  $\text{O}^{16}$  and  $\text{O}^{17}$ , viz  $\text{O}^{17}$  and  $\text{O}^{18}$  are again stable.  $\text{O}^{18}$  itself has  $p = .89 \times 2 \times 10^3$  and, according to Fermi and Neil's recent measurement,  $10^{24} \sigma \approx 3 \times 10^{-4}$ ,  $\tau = 31$  sec. Hence

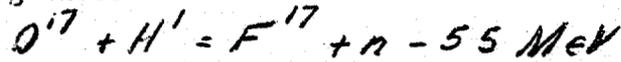
$$A \approx \frac{.064 \times 3 \times 10^{-4} \times 18 \times 10^3}{18 \times 31} = 6 \times 10^{-5} \frac{\text{r}}{\text{sec}}$$

It was mentioned before that this is the most serious source of radioactivity to be expected in the cooling water at the exit pipings. If it is connected with a penetrating  $\gamma$ -ray, which is very likely, it will make it unadvisable to stay very near to the exit manifolds of the pile for more than about 80 minutes daily. On the other hand, since the radioactivity of  $\text{O}^{19}$  decreases by a factor of  $10^6$  in 10 minutes, this radioactivity will become insignificant rather near to the entrance of the water into the river.

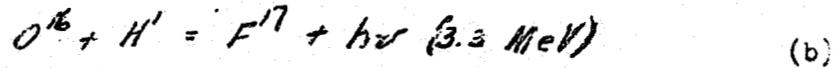
There are a few other nuclear reactions which may cause radioactivity in the water. Only one of these



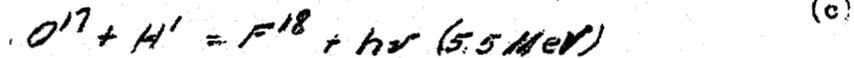
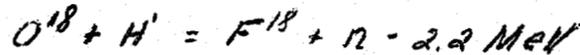
is caused by the neutrons directly (this reaction may be responsible for a non-negligible fraction of the absorption of oxygen). Most of the others are induced by the fast recoil protons produced by the fission neutrons in water. Among these



may be safely disregarded because  $F^{17}$  is produced more abundantly by the



reaction. Both



produce  $F^{18}$  but the first one is probably the more abundant source.

Reaction (a) probably has a reasonably high cross section. However, the abundance of  $O^{17}$  is even lower ( $4 \times 10^{-4}$ ) than that of  $O^{18}$  and the half life of  $C^{14}$  very long ( $\tau = 5 \times 10^7$  sec). Hence, (a) will cause no serious radioactivity.

Both (b) and (c) require reasonably fast protons. The number of these can be estimated as follows: The number of fission neutrons crossing the water jacket is  $3.5 \times 10^{19}$  per sec. They cross, on the average, .3 cm of water which contains  $2 \times 6 \times 10^{23}/18$  H atoms per  $cm^3$ . Assuming a cross section of  $2 \times 10^{-24} cm^2$  for this, the number of recoil protons per second becomes

$$3.5 \times 10^{19} \times .3 \times .67 \times 10^{23} \times 2 \times 10^{-24} = 14 \times 10^{18} \frac{\text{protons}}{\text{sec}}$$

Only a small fraction of these protons will be able to participate in reactions (b) and (c) to any considerable extent because of the potential barrier that they have to penetrate. Let us assume that this fraction is .1, representing the protons of 3 MeV and more. Actually, this number cannot be calculated at present because the fission spectrum is not well known. The above appears to be a safe estimate. The proton will remain effective for reactions (b) and (c) only until it loses about 1 MeV energy by collisions. This gives them an effective range of less than 10 cm in air or about  $1.3 \times 10^{-2}$  cm in water. If the cross section of reaction (b) or (c) is  $\sigma$ , the number of reactions will be

$$N = 1.4 \times 10^{17} \times 1.3 \times 10^{-2} \times .33 \times 10^{23} \sigma = 6 \times 10^{38} \sigma$$

in case (b), the number of  $O^{16}$  atoms per  $cm^3$  being  $.3 \times 10^{23}$ . For  $\sigma$  we can assume about  $10^{-28} cm^2$  in this case which gives  $N = 6 \times 10^9 F^{17}$  / sec. This is a strong positron activity which has to be reckoned with when the leak detecting apparatus is designed. However, it is very much smaller than the activity due to  $O^{19}$  of which about  $N = 5 \times 10^{11}$  are formed in a second.

The situation is similar with respect to reaction (c). The number of the  $O^{18}$  nuclei which participate in (c) is 500 times smaller than that of the  $O^{16}$  nuclei participating in (b). On the other hand, the cross section for (c) may be  $10^{-25} cm^2$  (this is about the highest cross section known for a nuclear reaction of this type) so that, conceivably,  $N = 10^{10} F^{18}$  nuclei may be formed per second. This, again, is more important for the design of leak detecting counters than for the total radioactivity in front of the pile. Only if  $O^{19}$  should not emit  $\gamma$  rays would (b) become the largest source of radioactivity in pure water. The half life of  $F^{17}$  is 64 sec and thus has a larger probability of disinte-

grating in the front pipings than the  $F^{18}$  the half life of which is 6700 sec. Actually, the total radiation is very small, both from (b) and (c) so that, if  $O^{19}$  is really free from  $\gamma$  rays, the impurities in the water may contribute fully as much radiation as  $F^{17}$  or  $F^{18}$  do.

It is, probably unnecessary to mention that, while the radioactivity due to  $O^{19}$  can be estimated reasonably accurately, the amount of  $F^{17}$  and  $F^{18}$  may be twice greater or more than ten times smaller than given above.

#### Impurities.

The most important impurities in water are, apparently, Fe,  $SiO_2$ , Ca, Mg, Na, K,  $SO_4$ ,  $NO_3$ , Cl, Br,  $CO_3$ . To these  $PO_4$ , may be added which is used as an inhibitor. In a good water source these are present only to the extent of a few parts per million. The radioactive nuclei which may be formed from these elements are  $Fe^{56}$  (harmless),  $Fe^{59}$ ,  $Si^{31}$  (no  $\gamma$ , harmless),  $Ca^{41}$ ,  $Ca^{45}$ ,  $Ca^{49}$ ,  $Mg^{27}$ ,  $Na^{24}$ ,  $K^{42}$  (probably no  $\gamma$ ),  $S^{35}$  (probably no  $\gamma$ ),  $S^{37}$  (hardly to be expected to amount to anything),  $N^{16}$ ,  $Cl^{36}$ ,  $Cl^{38}$ ,  $Br^{80}$ ,  $Br^{82}$ ,  $Cl^{14}$  (harmless),  $P^{32}$  (no  $\gamma$ , harmless). The following table gives N and A for the case that the element in question is present to 1 ppm (i.e., the p assumed in the table is the abundance of the relevant isotope). The table gives, therefore, a sort of "danger coefficients" for outside the pile (N) and for the exit manifold (A). However, in the former case, allowance should be made for the life time of the radioactive nucleus. This will decrease the danger both if it is very long and also if it is very short. In the former case, most of the disintegration will occur after the water is well mixed with river and perhaps sea water. In the latter case, most of the disintegration will occur in the neighborhood of the plant, partly already in the conduit to the river where proper precautions can be taken against the effects of it.

Nucleus	$10^{-11} N$ sec	$t$	$\gamma$ energy	A sec/r	ppm in Site X water
Fe <sup>59</sup>	$\ll 8, \sim .02$	47 days	1 MeV	$\ll 7.8 \times 10^{-10}$	5
Ca <sup>41</sup>	1.6	8.5 "	1.1 "	$10^{-9}$	) 26
Ca <sup>45</sup>	$\ll 1.6, \sim .03$	180 "	.7 "	$\ll 4.4 \times 10^{-11}$	
Ca <sup>49</sup>	$< .03$	2.5 hrs.?	.8 "	$< 1.4 \times 10^{-9}$	
Mg <sup>27</sup>	$< .17$	10.2 min	.9 "	$< 1.1 \times 10^{-7}$	$10^{-3}$ ?
Na <sup>24</sup>	2.5	14.8 hrs.	1,2,3 "	$2 \times 10^{-8}$	5 - x
K <sup>42</sup>	.18	12.4 "	) probably none	$1.7 \times 10^{-9}$	X
S <sup>35</sup>	$\ll 2, \sim .08$	88 days		$\ll 10^{-10}$	2 1/3
N <sup>16</sup>	$< 4.3, \times 10^{-4}$	8 sec	probably present	$2.3 \times 10^{-8}$	1/2
Cl <sup>36</sup>	110	$\sim 300$ years	positron active	$4.8 \times 10^{-12}$	) 3
Cl <sup>38</sup>	.35	37 min	2,2.5 MeV	$6.6 \times 10^{-8}$	
Br <sup>80</sup>	6	( 4.4 hrs)	Soft	$1.8 \times 10^{-7}$	) ?
Br <sup>82</sup>	6	( 18 min )		$2.6 \times 10^{-6}$	
	1.5	34 hrs.		.65	
O <sup>19</sup>	5	31 sec.	?	$6 \times 10^{-5}$	

The last column gives the analysis of site X water. It is added only as an illustration of a possible water analysis. The last row gives, for sake of comparison, the actual (not for 1 ppm) radioactivity of O<sup>19</sup>. The  $\ll$  sign means that the corresponding figure has been arrived at by attributing all the neutron absorption of the element to the isotope in question. The  $\sim$  means an approximate figure obtained by assuming the same absorption cross section for all the isotopes of the element. The rest of the figures was obtained on the basis of a cross section measurement of one isotope.\*

Water saturated with air contains about 20 ppm N<sub>2</sub>. The radioactivity, of this (if it emits  $\gamma$  rays) is still considerably below the radioactivity of the O<sup>19</sup>.

\*F. Rasetti, Phys. Rev. 58, 869, 1940. Goldhaber and O'Neal, Phys. Rev. 59, 102, 109, 1941. Manley, Haworth and Luebke, Phys. Rev. 59, 109, 1941. Sinma and Yamasaki, Phys. Rev. 59, 402, 1941.