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UNITED STATES ATOMIC ENERGY COMMISSION

M-7081 (DEL.)

AN ESTIMATE OF NEUTRON-INDUCED RADIOACTIVITY
IN SOIL FROM WEAPON DETONATIONS

By

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Photostat Price \$ 1.80

Microfilm Price \$ 1.80

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

Division of Biology and Medicine
U. S. Atomic Energy Commission
Washington, D. C.

Technical Information Service Extension, Oak Ridge, Tenn.

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AN ESTIMATE OF NEUTRON-INDUCED RADIOACTIVITY
IN SOIL FROM WEAPON DETONATIONS

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May 15, 1958

During the recent period of interest in estimating the relative radioactive hazards from nuclear weapons it was necessary to estimate neutron-induced activity in soils. The estimate here is intended to establish an expected order of magnitude of resulting radioactivity and relative production of stable and radioactive isotopes in soil.

For this estimate Nevada Test Site soil is used because of the accurate data available for it. This soil does not appear to be greatly different from what may be assumed to be an average soil. The elements which may be more or less anomalous in NTS soil are listed below.(1).

% by wt.

<u>Element</u>	<u>NTS Soil</u>	<u>Range</u>	<u>Possible "Average"</u>
Ca	5.7	0.5 - 10	4
Ti	0.2	0.1 - 2	0.6
K	2.5	0.1 - 3	1
Fe	1.9	0.2 - 12	3
I	0	< 0.2	0.1
S	0	< 5	0.1

Other elements may be present in trace amounts. Except where soils are greatly different from NTS soil, reasonably good estimates of individual isotopes may be made for other than NTS soil by direct proportion of percentages abundance.

This estimate is based on the following assumptions.

1. One MT weapon (100%) fusion detonated at the surface of NTS soil.
2. Induced activity is produced through thermal neutron reactions.
3. Density of soil is 1.18 g/cm³ (2), and composition is as stated in the tables below.
4. Nuclear and physical data for the soil constituents were obtained.

Estimates based on the assumptions above are listed in the tables below. It is seen that during the first few minutes most of the activity is due to Al²⁸. After the decay of Al²⁸ sodium and manganese produce essentially all of the gamma activity. Phosphorus accounts for a substantial portion of the beta activity after decay of the shorter-lived isotopes.

TABLE I

NEUTRON-INDUCED ACTIVITY IN NTS SOIL

Nuclide	%by wt. in soil	σ barns	Product	% of product in soil	Half-life	Effective Gamma energy (Mev)	Effective Beta Energy (Mev)
H ¹	1.000	0.52	H ²	35.47	S		
Cl ³⁵	0.800	0.0045	Cl ³⁶	0.03	S		
— O ¹⁶	50.160	0.0009	O ¹⁷	0.32	S		
Na ²³	1.600	0.6	Na ²⁴	4.67	15.0h	4.14	1.39
Mg ²⁴	0.631	0.033	Mg ²⁵	0.10	S		
Mg ²⁵	0.080	0.27	Mg ²⁶	0.10	S		
Mg ²⁶	0.089	0.05	Mg ²⁷	0.018	9.6m	0.94	1.62
Al ²⁷	6.800	0.22	Al ²⁸	6.18	2.3m	1.80	3.01
Si ²⁸	26.200	0.1	Si ²⁹	10.44	S		
Si ²⁹	0.886	0.1	Si ³⁰	0.34	S		
Si ³⁰	1.334	0.1	Si ³¹	0.30	2.62h		1.5
P ³¹	0.100	0.2	P ³²	0.08	14.3d		1.71
K ³⁹	2.32	3.0	K ⁴⁰	19.97	16.1 X 10 ⁸ y	1.45*	1.4*
K ⁴¹	0.18	1.0	K ⁴²	0.49	12.44h	1.51**	3.04
Ca ⁴⁰	5.52	0.22	Ca ⁴¹	3.40	(?)		
Ca ⁴²	0.0365	40.00	Ca ⁴³	3.88	S		
Ca ⁴³	0.010	0.41	Ca ⁴⁴	0.01	S		
Ca ⁴⁴	0.122	0.69	Ca ⁴⁵	0.21	152d		0.254
Ca ⁴⁸	0.0115	1.1	Ca ⁴⁹	0.03	8.5m	2.7	2.7
Ti ⁴⁶	0.0159	0.6	Ti ⁴⁷	0.02	S		
Ti ⁴⁷	0.0155	1.6	Ti ⁴⁸	0.06	S		
Ti ⁴⁸	0.147	8.0	Ti ⁴⁹	2.73	S		
Ti ⁴⁹	0.011	1.8	Ti ⁵⁰	0.04	S		
Ti ⁵⁰	0.0107	0.14	Ti ⁵¹	0.003	6m	0.353***	2.1
Mn ⁵⁵	0.04	13.0	Mn ⁵⁶	1.06	2.6h	1.62	2.09
Fe ⁵⁴	0.112	2.3	Fe ⁵⁵	0.54	2.9ly	(K-capture)	
Fe ⁵⁶	1.740	2.6	Fe ⁵⁷	9.07	S		
Fe ⁵⁷	0.0466	2.4	Fe ⁵⁸	0.22	S		
Fe ⁵⁸	0.0014	0.98	Fe ⁵⁹	0.003	46d	1.2	0.36

S: stable isotope

(?): K-capture, half-life several months to 2 X 10⁵ years.

* K/ β = 1.9

** 25% gamma emission.

*** 10.1% gamma emission.

TABLE II
PER CENT CONTRIBUTION TO TOTAL MEV/MIN GAMMA

Nuclide	Time after detonation								
	Zero time	10 min.	30 min.	1 hr	3 hr	10 hr	1 day	3 days	6 days
Na ²⁴	0.442	8.12	68.055	70.732	78.245	93.055	98.755	99.437	99.444
Mg ²⁷	0.0362	0.2231	0.0268	-					
Al ²⁸	99.406	85.635	-						
K ⁴⁰	-								
K ⁴²	0.005	0.0939	0.7824	0.7707	0.8536	0.979	0.909	0.582	0.296
Ca ⁴⁹	0.196	1.530	0.7731	0.0644	-				
Ti ⁵¹	0.0005	0.0005	0.0008	-					
Mn ⁵⁶	0.0228	4.099	50.741	28.488	20.925	5.972	0.361	-	
Fe ⁵⁹	-			0.0001	0.0002	0.0037	0.008	0.007	0.192

TABLE III
PER CENT CONTRIBUTION TO TOTAL MEV/MIN BETA

Nuclide	Time after detonation								
	Zero time	10 min.	30 min.	1 hr	3 hr	10 hr	1 day	3 days	6 days
Na ²⁴	0.0888	1.755	27.542	30.123	38.039	63.235	80.548	98.409	59.676
Mg ²⁷	0.0373	0.3546	0.464	0.0583	-				
Al ²⁸	99.467	91.843	-						
Si ³¹	0.0586	1.138	16.036	15.556	13.103	5.241	0.379	-	
P ³²	-	0.0016	0.0258	0.0285	0.0393	0.0907	0.225	0.122	34.415
K ⁴⁰	-								
K ⁴²	0.0245	0.4823	7.598	7.778	9.914	15.923	17.720	1.370	4.257
Ca ⁴⁵	-		0.0009	0.001	0.0014	0.0034	0.0846	0.0912	1.552
Ca ⁴⁹	0.1172	0.982	0.933	0.0815	-				
Ti ⁵¹	0.0129	0.0801	0.0244	0.0008	-				
Mn ⁵⁶	0.1741	3.369	47.598	46.296	38.984	15.542	1.123	-	
Fe ⁵⁹	-			0.0002	0.001	0.002	0.006	0.007	0.102

TABLE IV
TOTAL MEV/MIN

Time	Beta	Gamma
Zero	5.63 X 10 ²⁴	3.37 X 10 ²⁴
10m	2.82 X 10 ²³	1.81 X 10 ²³
30m	1.79 X 10 ²²	2.16 X 10 ²²
1h	1.62 X 10 ²²	2.05 X 10 ²²
3h	1.16 X 10 ²²	1.69 X 10 ²²
10h	4.98 X 10 ²¹	1.008 X 10 ²²
1d	1.986 X 10 ²¹	4.82 X 10 ²¹
3d	1.809 X 10 ²⁰	5.33 X 10 ²⁰
6d	1.005 X 10 ¹⁹	1.80 X 10 ¹⁹

TABLE V
DISINTEGRATIONS PER MINUTE AT ZERO TIME

Isotope	dpm γ	dpm β
Na ²⁴	3.596 X 10 ²¹	3.596 X 10 ²¹
Mg ²⁷	1.296 X 10 ²¹	1.296 X 10 ²¹
Al ²⁸	1.862 X 10 ²⁴	1.862 X 10 ²⁴
Si ³¹	-	2.20 X 10 ²¹
P ³²	-	2.694 X 10 ¹⁸
K ⁴⁰	1.07 X 10 ¹¹	5.64 X 10 ¹⁰
K ⁴²	1.137 X 10 ²⁰	4.54 X 10 ²⁰
Ca ⁴⁵	-	6.65 X 10 ¹⁷
Ca ⁴⁹	2.446 X 10 ²¹	2.446 X 10 ²¹
Ti ⁵¹	4.696 X 10 ¹⁹	3.465 X 10 ²⁰
Mn ⁵⁶	4.71 X 10 ²¹	4.71 X 10 ²¹
Fe ⁵⁹	3.138 X 10 ¹⁶	3.138 X 10 ¹⁶