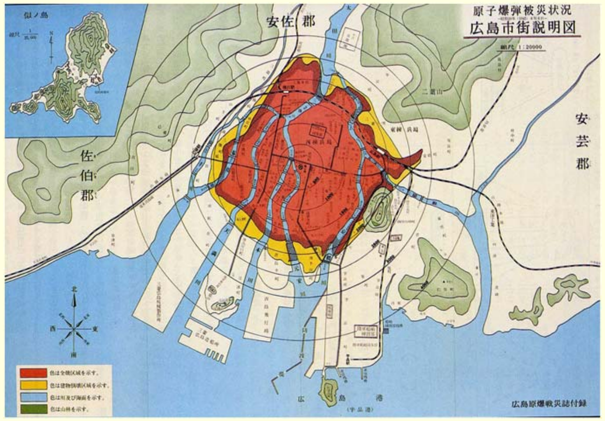
20th Hiroshima International Symposium

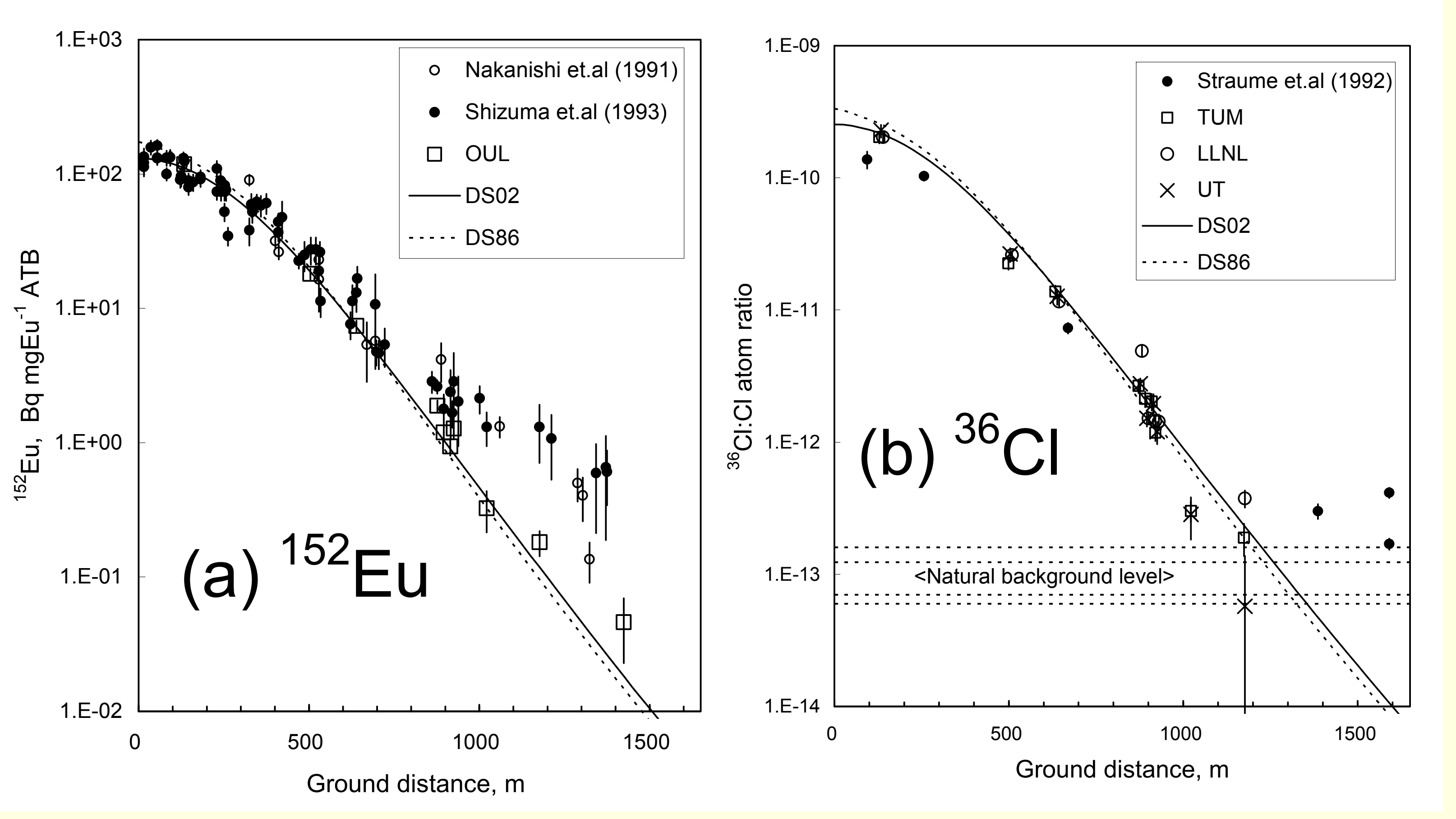
Contribution of Neutron-Induced Radionuclides with Shorter Half-lives than Al-28 to External Radiation by the Atomic Bombings in Hiroshima and Nagasaki

Imanaka T, Fukutani S, Taguchi Y, Granovskaya E, Hoshi M, Endo S



January 10-11, 2016
Coral Hotel in Miyajima, Hiroshima

As a result of the efforts elaborating DS02, we are confident that neutron activation measurement can be reconstructed by calculation



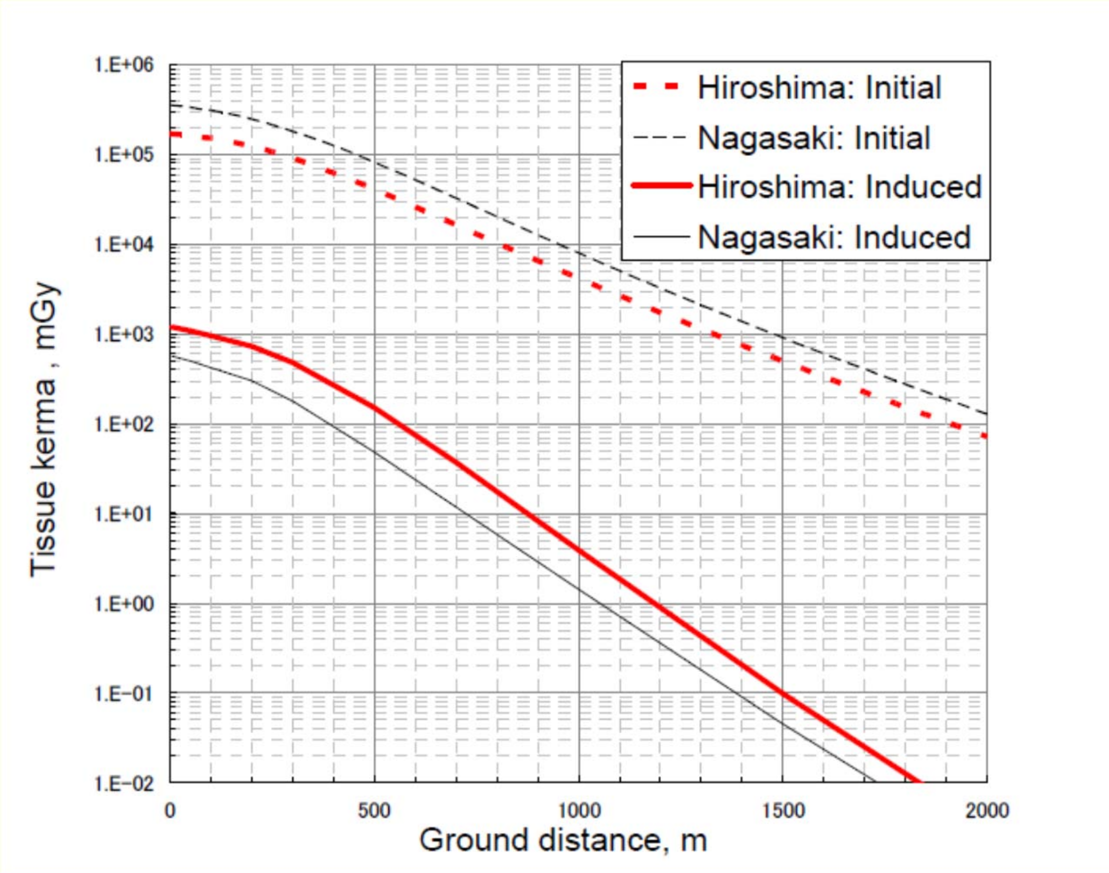
Hoshi et.al REB2008

Today's contents

1. **Previous work-1: Neutron induced radiation exposure to early entrants from the ground.**
2. **Previous work-2: Validation of elemental composition of soil etc. in Hiroshima/ Nagasaki**
3. **New topics: Contribution of neutron-induced radionuclides with shorter half-lives than Al-28**

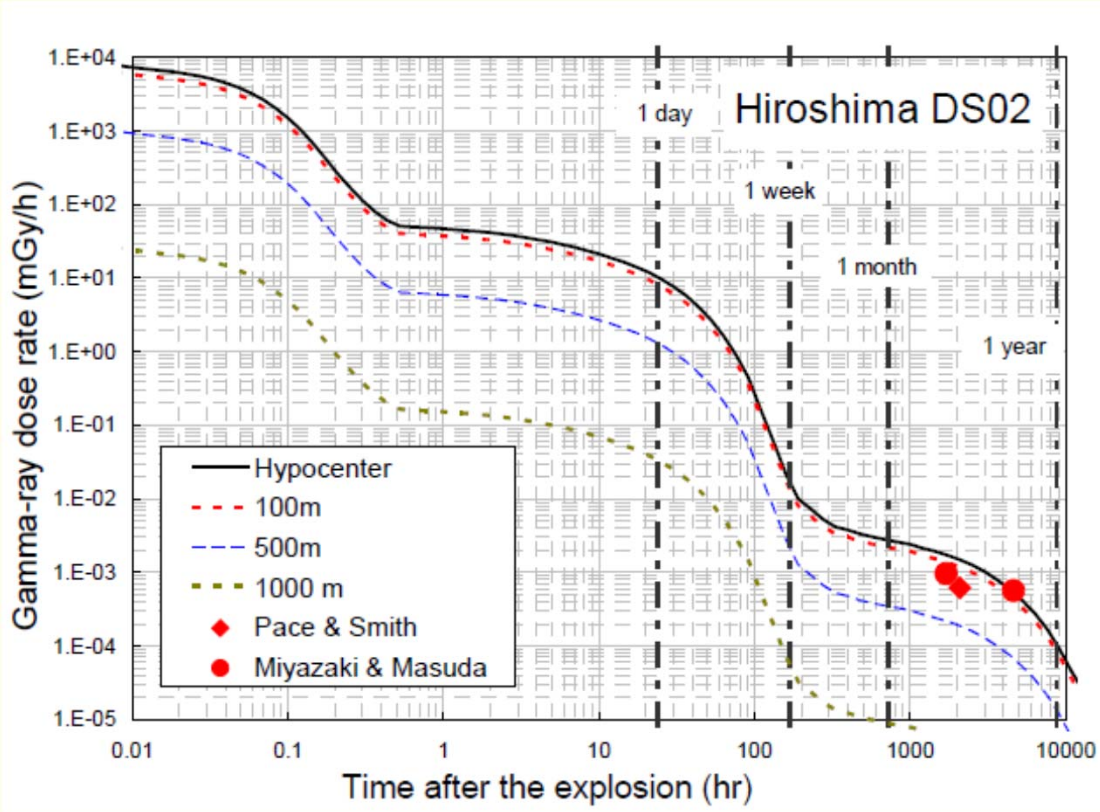
Previous work-1:

Neutron induced radiation exposure to early entrants



Initial radiation from the explosion vs neutron-induced radiation from the ground (infinite cumulative after the explosion)

Previous work-1:
Neutron induced radiation exposure to early entrants



Time dependent change of exposure rate after the explosion.

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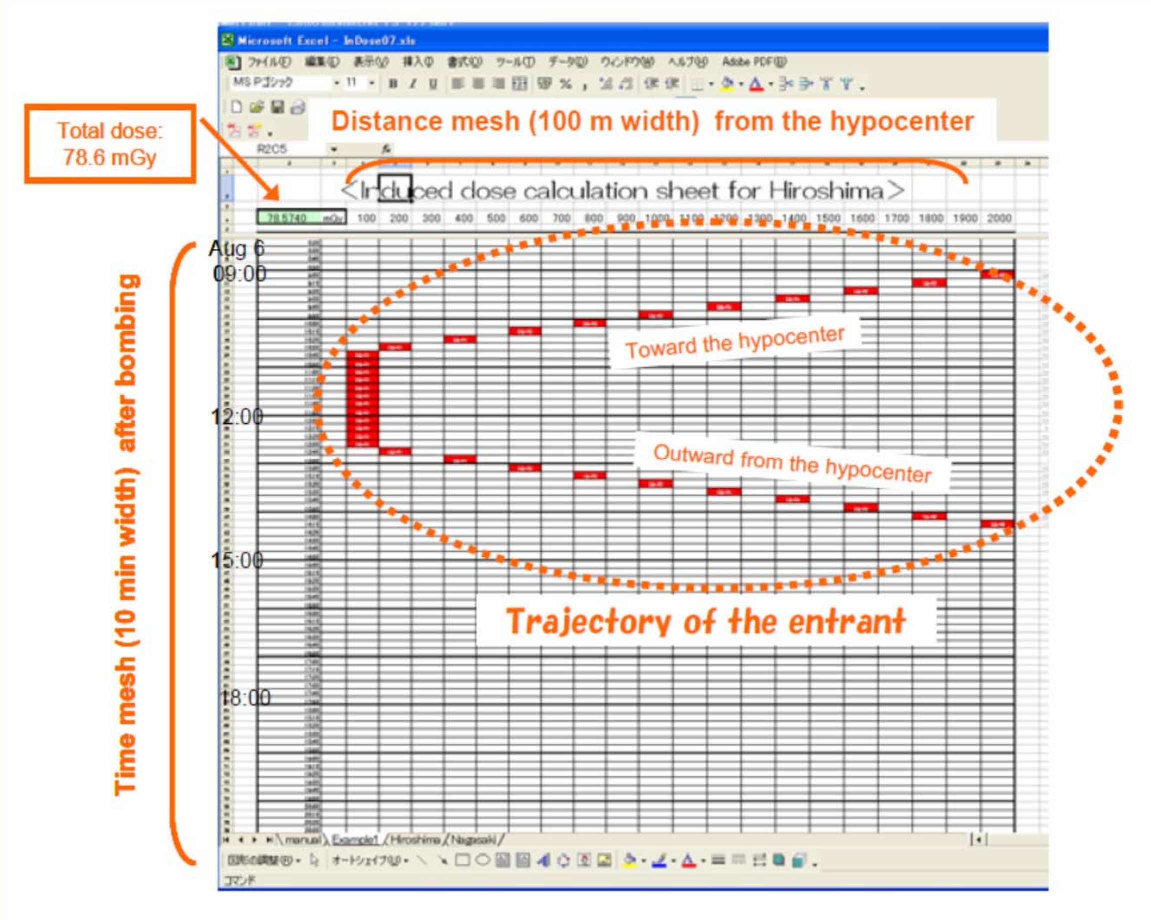
Previous work-1:
Neutron induced radiation exposure to early entrants

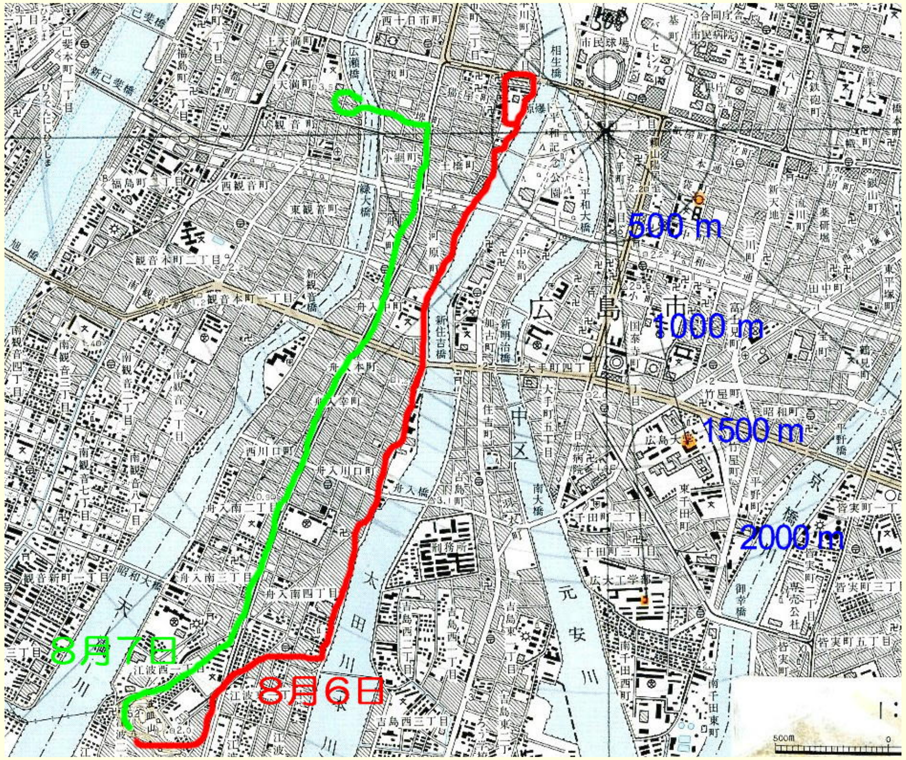


Excel tool calculating external radiation due to neutron-induced radionuclides in the ground.

Imanaka et.al RPD2011

Previous work-1:
Neutron induced radiation exposure to early entrants

- Application of Excel tool-1
  21 yr old female



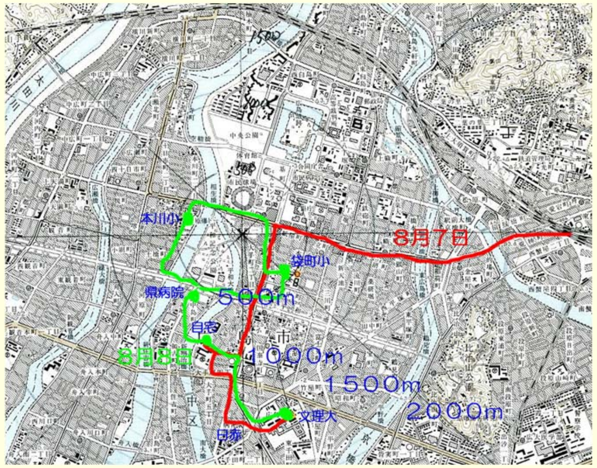
- August 6: 23.5 mGy

- August 7: 0.17 mGy

✦ **Total dose: 24 mGy**

Previous work-1:
Neutron induced radiation exposure to early entrants

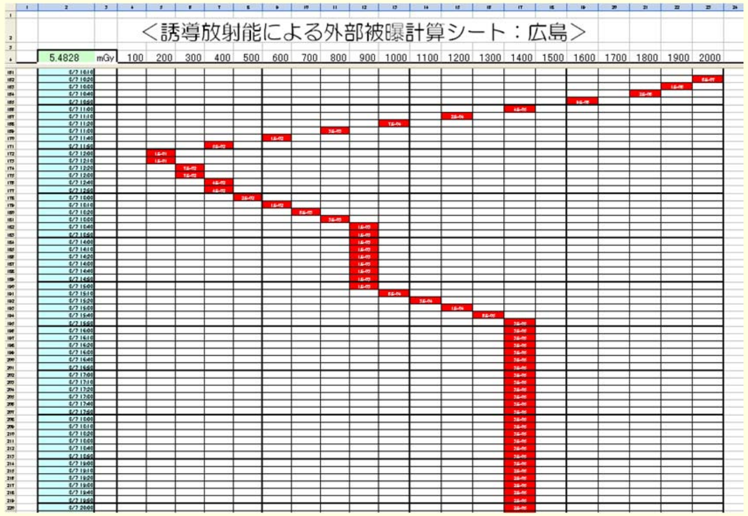
➢ **Application of Excel tool-2**
19 yr old female



Date of record: March 29, 1954

Symptoms	Day of onset	Level of symptoms					Duration or comments
		Mild	Moderate	Severe	Not stated	None	
発熱 Fever	1 week later			✓			1 week 8/13-8/20
全身倦怠 Malaise	1 week later			✓			1 month 8/13-9/13
嘔吐 Vomiting						✓	
悪心 Nausea						✓	
食欲不振 Anorexia	Several days later		✓				~3 week 8/8-8/30
下痢（非血性） Diarrea (non bloody)	1 week later			✓			~10 daya 8/13-8/23
下痢（血性） Diarrea (bloody)					✓		?
咽喉痛 Sore throat	1 week later			✓			~1 week 8/13-8/20
口内痛 Sore mouth	1 week later			✓			1 week 8/13-8/20
歯肉痛 Sore gums	1 month later			✓			~2 week 9/6-9/20
歯齦出血 Bleeding gums	1 month later			✓			~2 week 9/6-9/20 (suppuration 化膿有り)
斑点出血 Purpura						✓	
その他の出血 Other bleeding						✓	
脱毛 Epilation	1 month later	✓					~2 week 30-35%

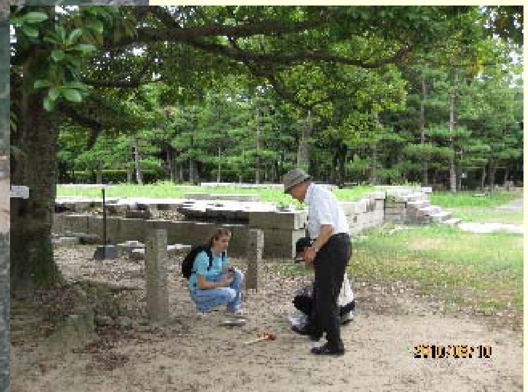
● **August 7: 5.5 mGy**



● **August 8 - 13: 3.9 mGy**

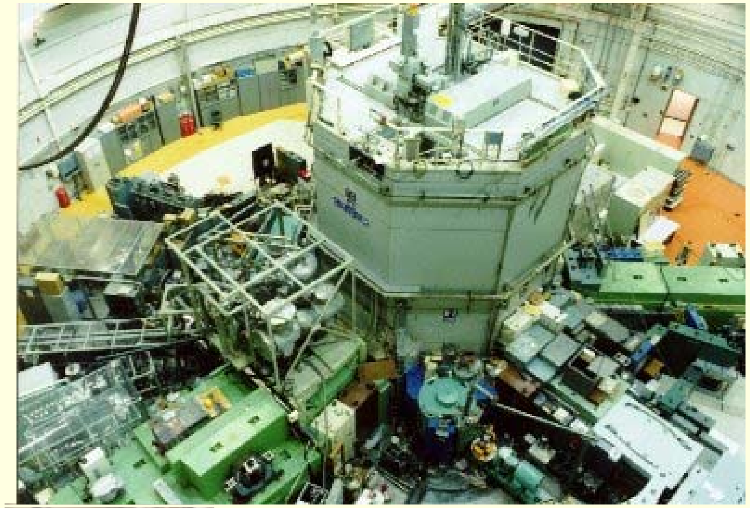
✦ **Total dose: 9.4 mGy**

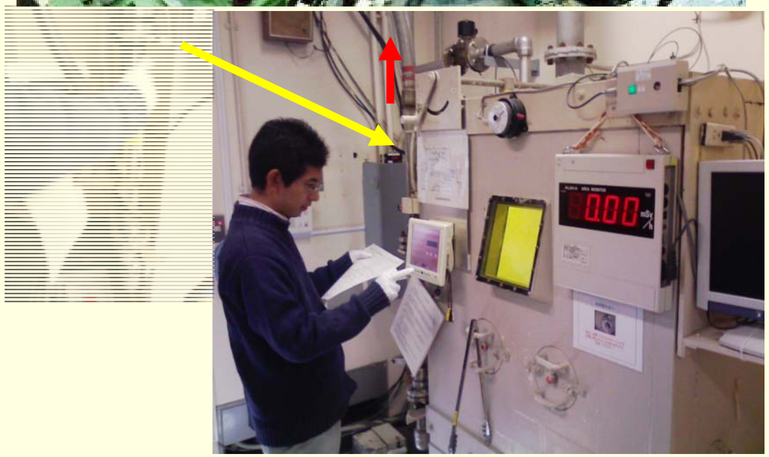
Previous work-2:
Validation of elemental composition of soil etc. in Hiroshima/Nagasaki



11 soil samples were taken in Hiroshima in August, 2010 for neutron-activation analysis at KUR.

Previous work-2:
Validation of elemental composition of soil etc. in Hiroshima/Nagasaki





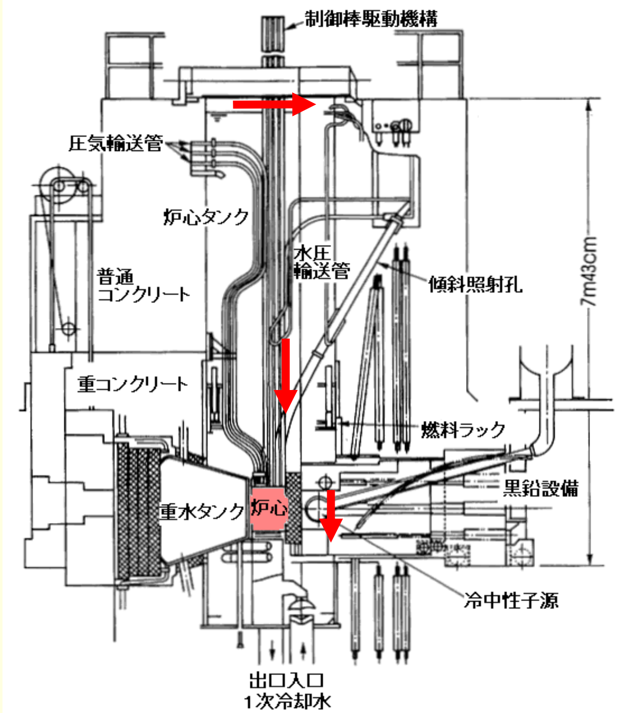


図１　ＫＵＲの垂直断面図
[資料提供]京都大学原子炉実験所

Neutron activation analysis at KUR (Kyoto University Reactor).
KUR is working since 1964. Imanaka is working there since 1976.

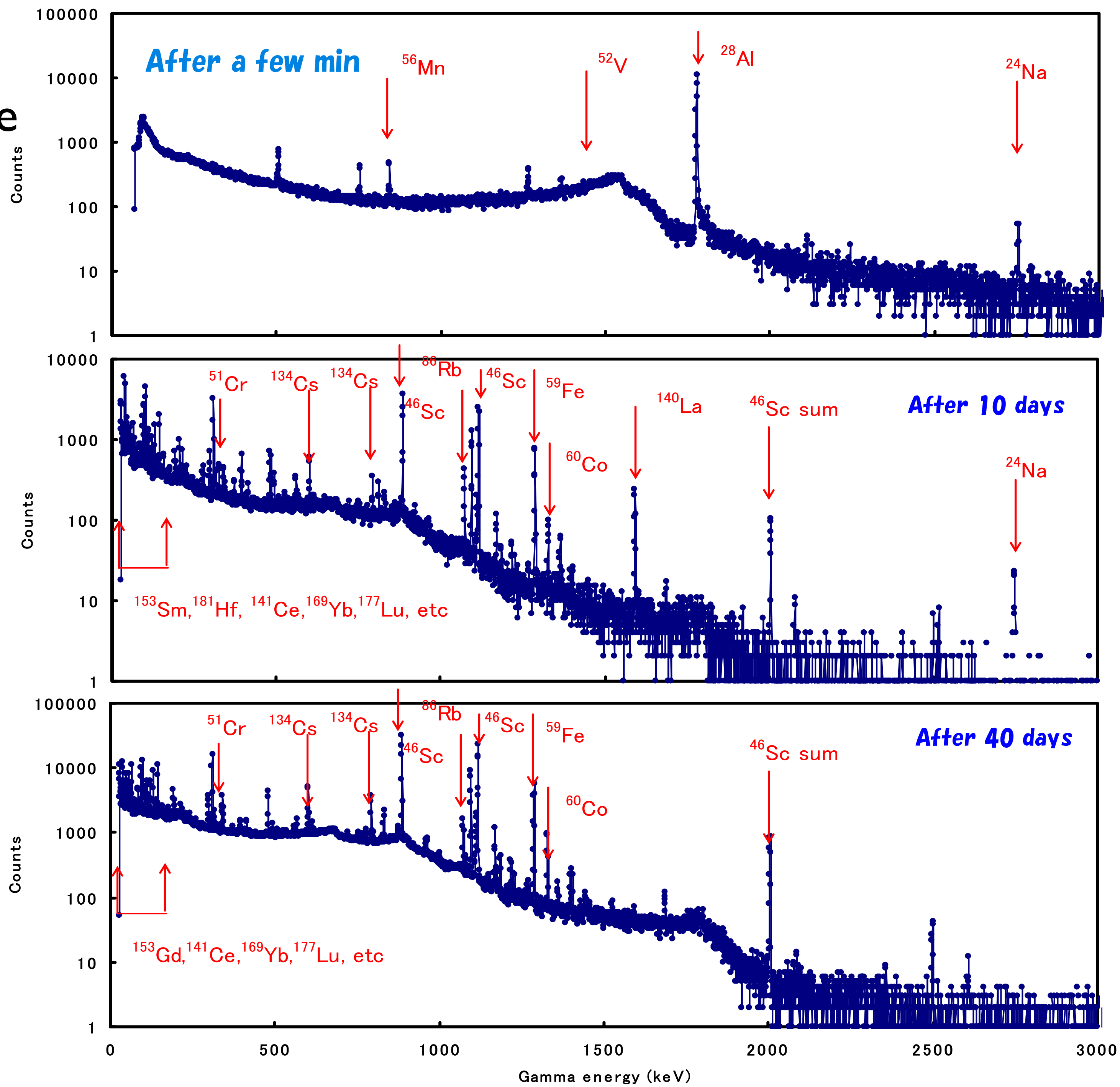
Gamma spectra of Nikitsu shrine

Nuclides :

^{28}Al、^{56}Mn、^{52}V
^{24}Na

^{153}Sm、^{75}Se、^{181}Hf、^{141}Ce、^{169}Yb、^{177}Lu、^{97}Rb、^{51}Cr、^{140}La、^{134}Cs、^{82}Br、^{134}Cs、^{46}Sc、^{86}Rb、^{60}Co、^{59}Fe

^{153}Gd、^{169}Yb、^{141}Ce、^{59}Fe、^{169}Yb、^{177}Lu、^{182}Ta、^{233}Pa、^{51}Cr、^{181}Hf、^{134}Cs、^{46}Sc、^{152}Eu、^{60}Co



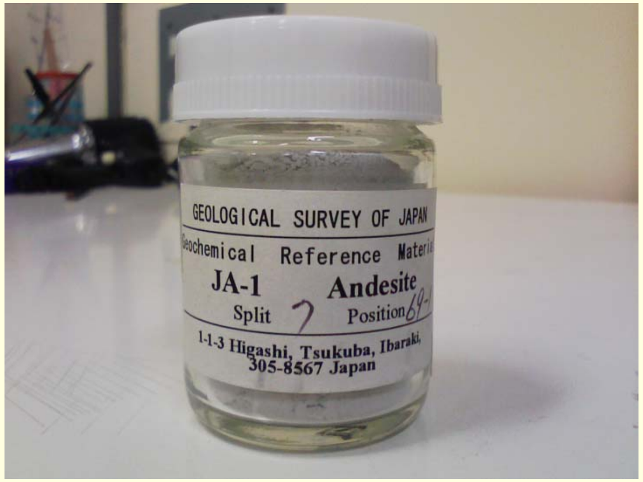
Previous work-2:
Validation of elemental composition of soil etc. in Hiroshima/Nagasaki

- Standard material method to obtain concentration of element *i* in neutron-activated samples

$$c_i^s = \frac{n_i^s(0)/m_s}{n_i^r(0)/m_r} c_i^r$$

$$n_i^{r,s}(0) = N_i^{r,s} / \int_{t_1}^{t_2} e^{-\lambda_i t} dt$$

$$= \lambda_i N_i^{r,s} / (e^{-\lambda_i t_1} - e^{-\lambda_i t_2})$$



Standard powder JA-1 from AIST made from andesite obtained in1982

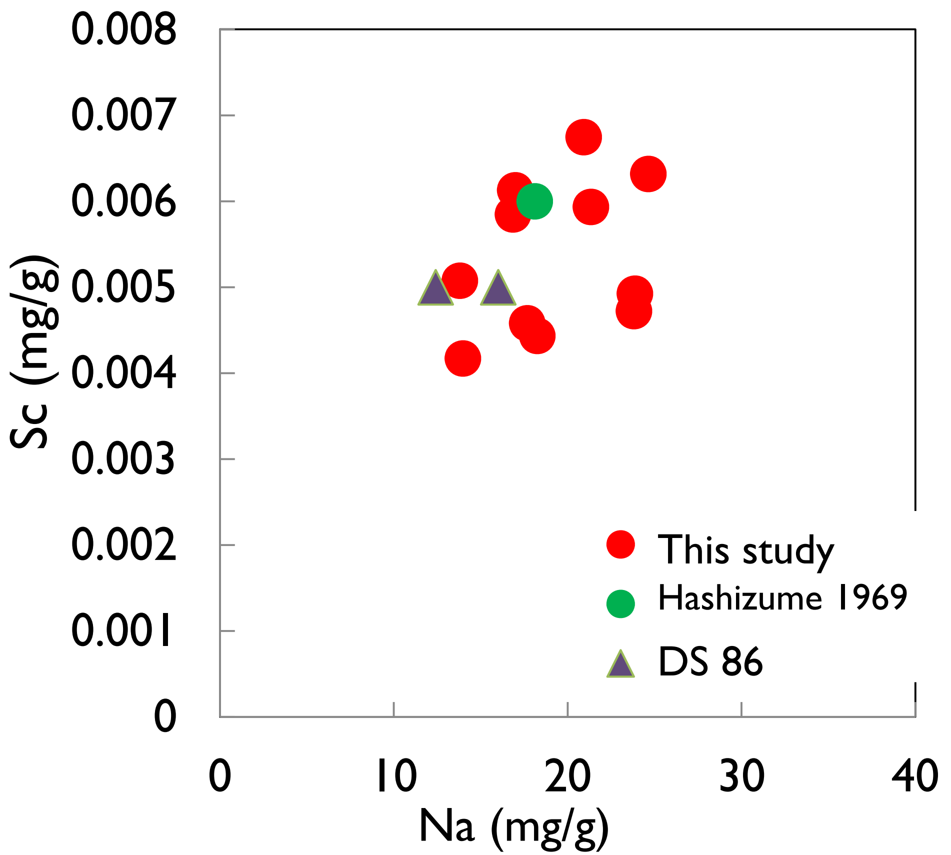
r : standard material

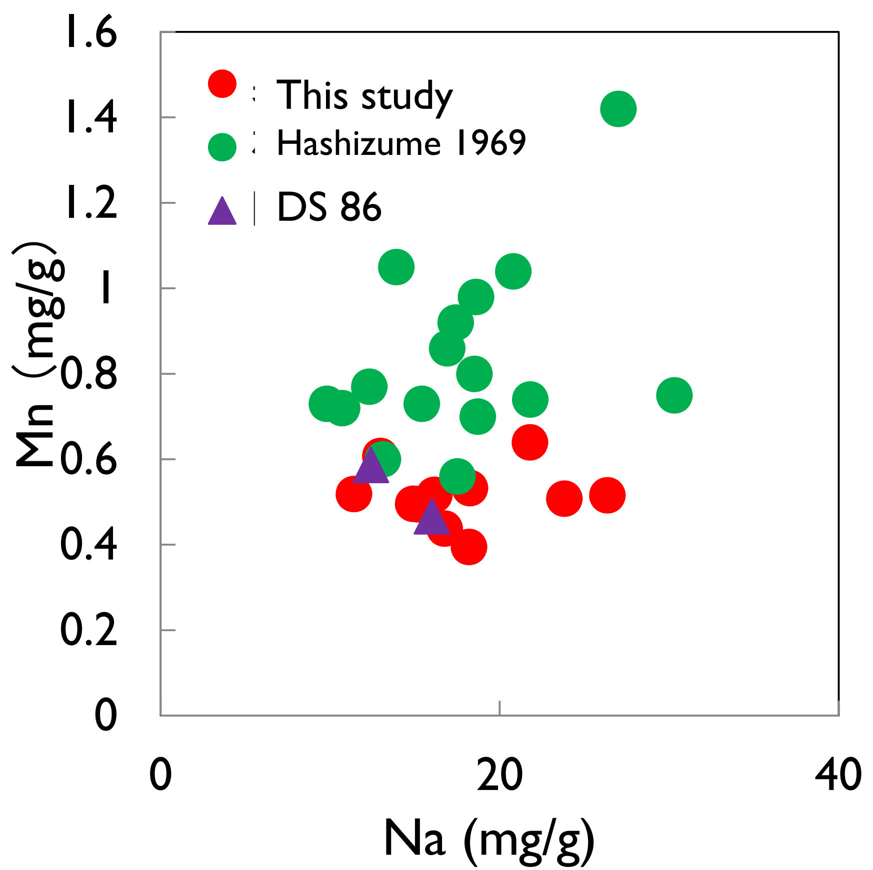
s : sample

Previous work-2:
Validation of elemental composition of soil etc. in Hiroshima/Nagasaki

	Atomic No	Average Concentration (ppm)			DS86 values (ppm)	
					Hiroshima castle	A-bomb dome
Na	11	19300	±	3900	16000	12400
Al	13	63300	±	8800	71000	64900
Sc	21	5.12	±	0.59	5	5
V	23	21.4	±	5.5	22.3	25.3
Cr	24	20	±	13	20.5	27.3
Mn	25	517	±	68	467	587
Fe	26	17100	±	2700	17700	20600
Co	27	4.13	±	0.95	3.7	3.8
Rb	37	137	±	16	230	225
Sr	38	45	±	17	88	70
Zr	40	105	±	42	41	35
Nb	41	2.0	±	1.2	7	5
Sb	51	1.87	±	0.21	1.4	0.8
Cs	55	4.4	±	0.6	5	5
La	57	27.4	±	6.4	23	21
Ce	58	88	±	21	40	36
Sm	62	3.7	±	1.0	3.4	3
Eu	63	0.81	±	0.12	0.9	0.9

Previous work-2:
Validation of elemental composition of soil etc. in Hiroshima/Nagasaki



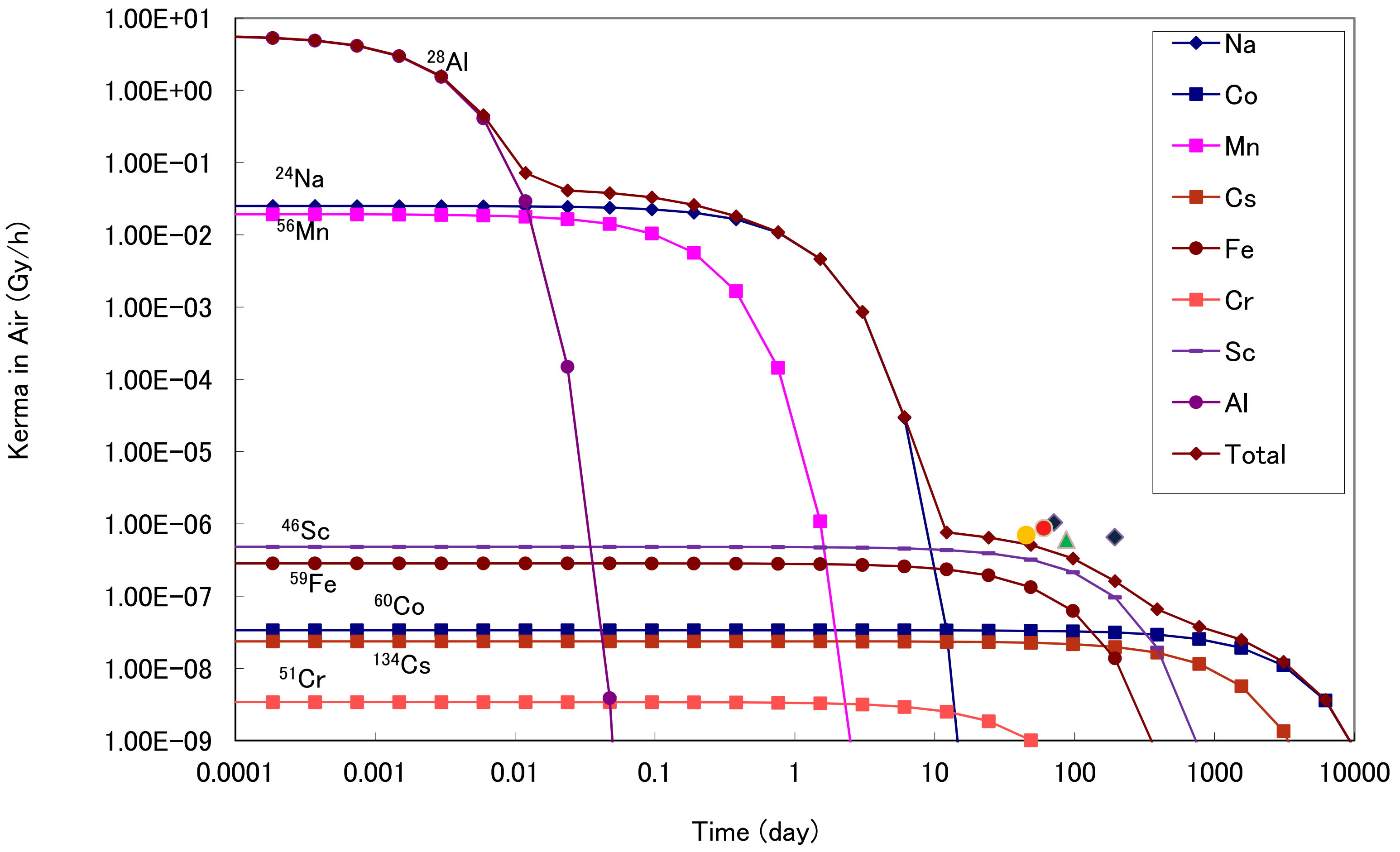


Average:

Sc：0.00512±0.0006 mg/g-soil、Na：19.3±3.9mg/g-soil、

Mn：0.517±0.068 mg/g-soil

Previous work-2:
Validation of elemental composition of soil etc. in Hiroshima/Nagasaki

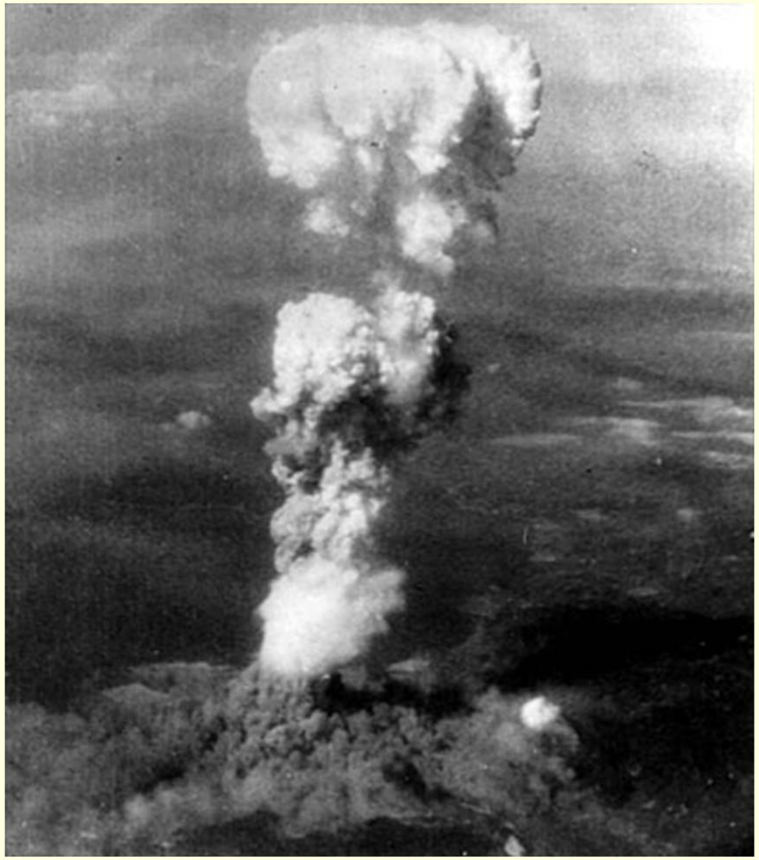


Radiation exposure rate after the bombing due to induced radionuclides in the ground: hypocenter in Hiroshima

Today's topic:
Contribution of neutron-induced radionuclides with shorter half-lives than Al-28

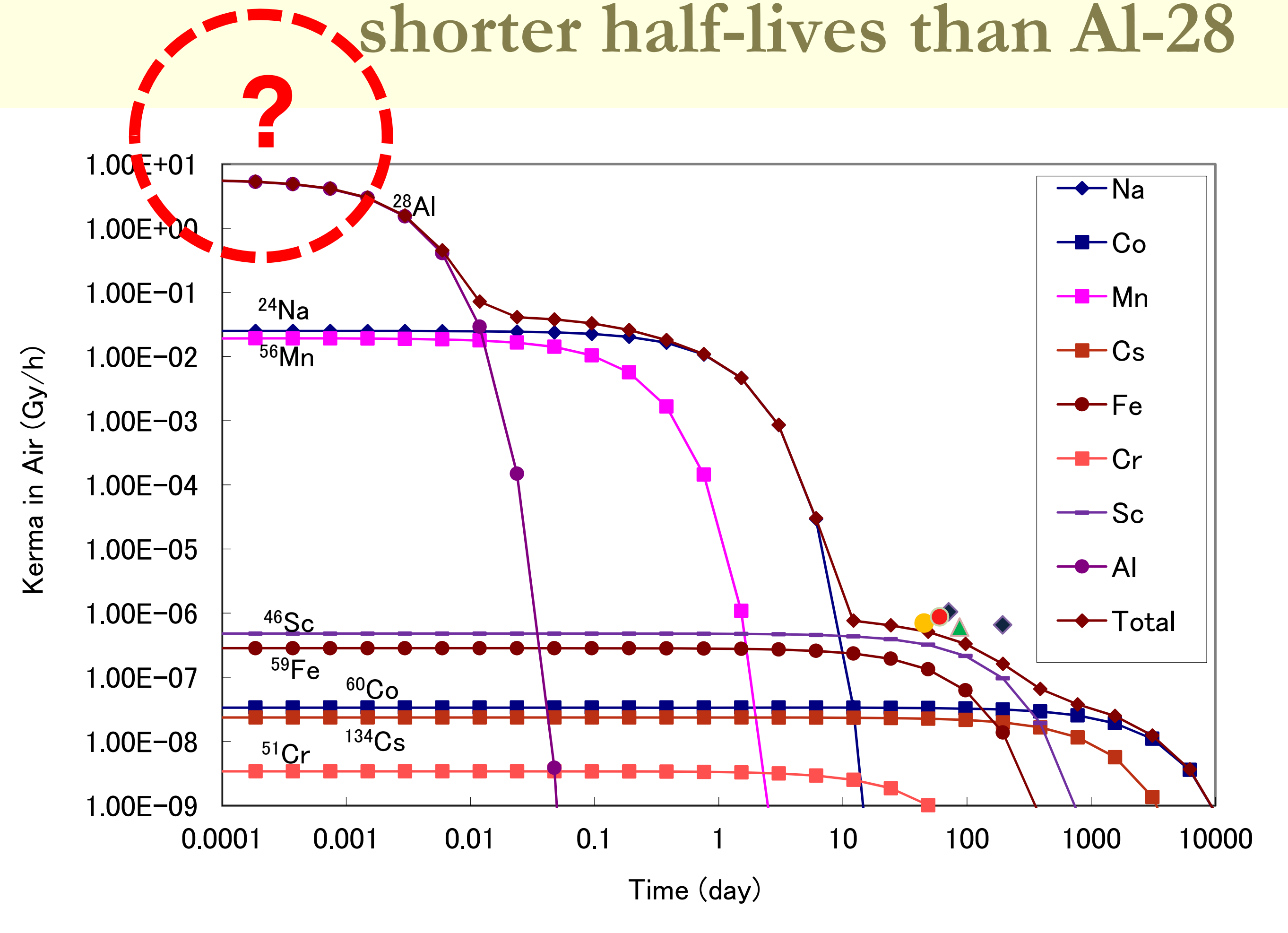
Nevada test
Buster-Jangle Charlie:
1950.10.31
Airdrop 14kt、 HOB:345m

Little Boy



We noticed during the discussion of the workshop at HPS in Sacramento in 2012 that the assessment of radiation exposure from the activated dust with short half-lives was not yet done, maybe, by anyone.

Today's topic:
Contribution of neutron-induced radionuclides with shorter half-lives than Al-28



Radiation exposure rate after the bombing due to induced radionuclides in the ground: hypocenter in Hiroshima

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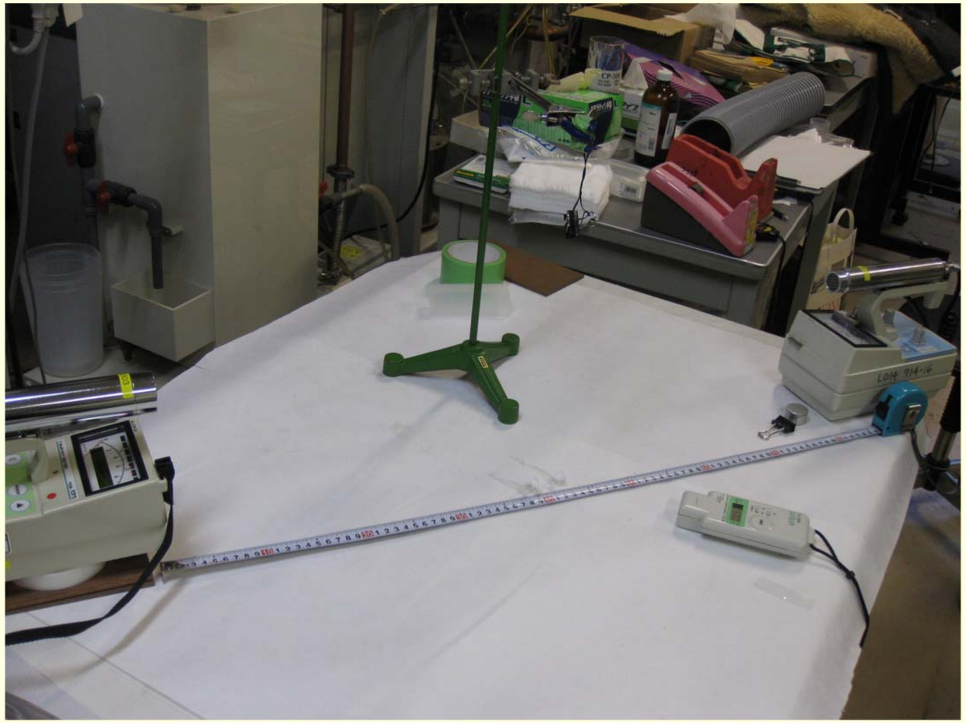

Experiment to observe the initial attenuation of activated soil for the first minutes after 10 sec irradiation by KUR, using GM and NAI survey meters.

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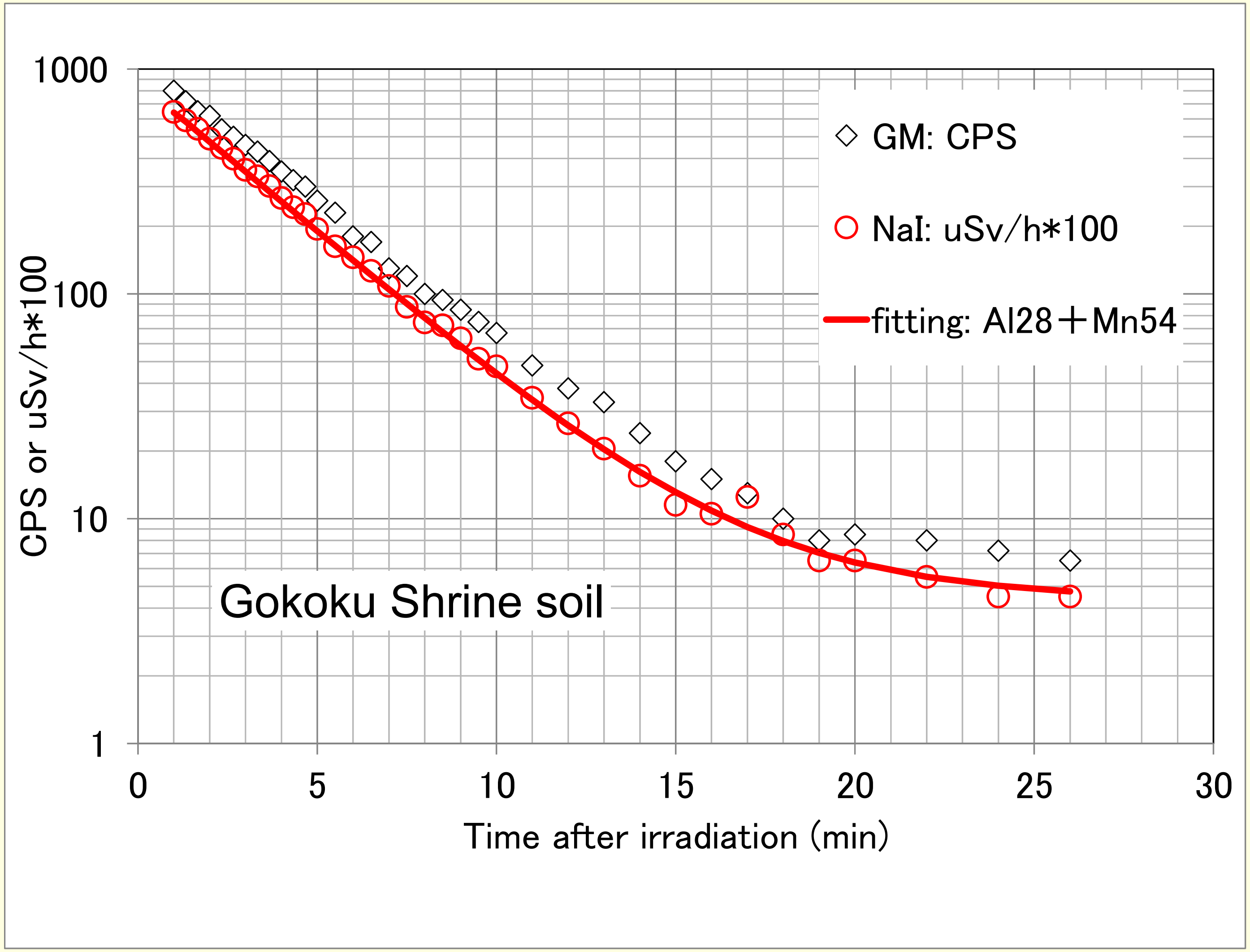
Contribution of neutron-induced radionuclides with shorter half-lives than Al-28



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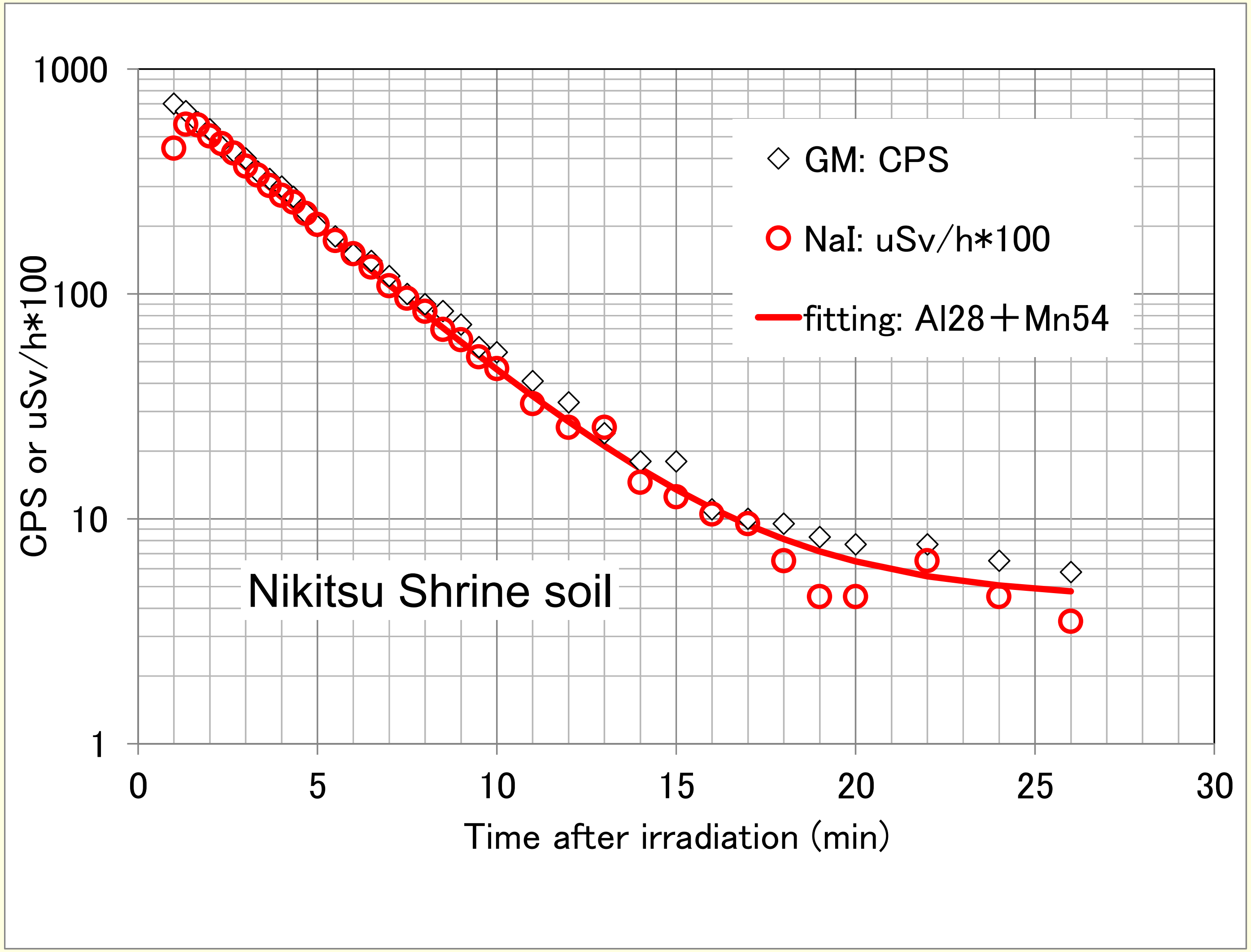

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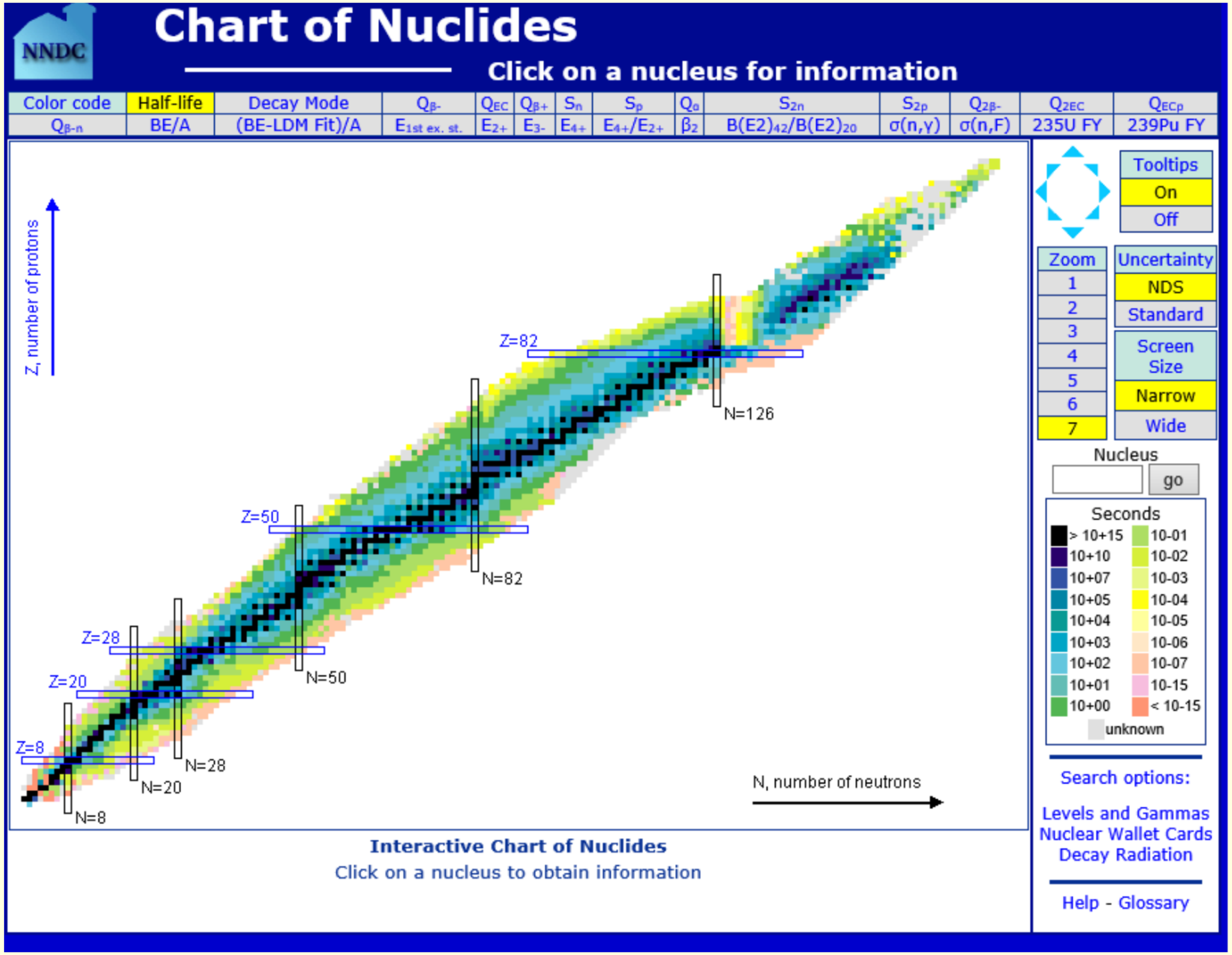

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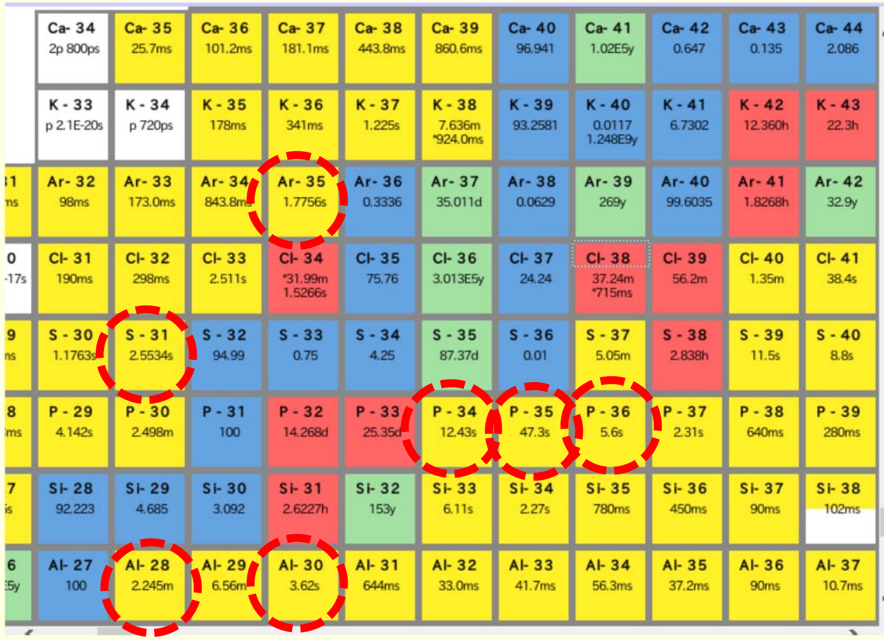

Today's topic:
Contribution of neutron-induced radionuclides with shorter half-lives than Al-28

JENDL Neutron X-section Table

9-F-19	100%									
Reaction	0.0253-eV	Maxwellian Average	g-factor	Resonance Integral	14-MeV	Fiss. Spec. Average				
total	3.751 (b)	4.233 (b)	1.128	–	1.741 (b)	3.610 (b)				
elastic	3.742 (b)	4.223 (b)	1.129	–	1.046 (b)	2.324 (b)				
inelastic	(E-thr = 115.8 keV)				164.2 (mb)	1.265 (b)				
(n,2n)	(E-thr = 10.99 MeV)				42.94 (mb)	8.615 (μb)	F-18	1.83h		
(n,na)	(E-thr = 4.226 MeV)				359.4 (mb)	4.614 (mb)	N-15	stable		
(n,np)	(E-thr = 8.417 MeV)				42.81 (mb)	13.20 (μb)	O-18	stable		
(n,nd)	(E-thr = 14.55 MeV)				–	31.83 (nb)	O-17	stable		
capture	9.570 (mb)	9.576 (mb)	1.001	19.47 (mb)	25.67 (μb)	211.7 (μb)	F-20	11.16s	1634 kev	100%
(n,p)	(E-thr = 4.251 MeV)				14.66 (mb)	1.163 (mb)	O-19	26.88s	1357 kev	50%
(n,d)	(E-thr = 6.074 MeV)				34.08 (mb)	75.92 (μb)	O-18	stable		
(n,t)	(E-thr = 7.959 MeV)				15.30 (mb)	30.23 (μb)	O-17	stable		
(n,a)	(E-thr = 1.603 MeV)				21.34 (mb)	14.65 (mb)	N-16	7.13s	6129 kev	67%

Today's topic:
Contribution of neutron-induced radionuclides with shorter half-lives than Al-28

	Target nuclide	Abundance, %	Reaction	Produced nuclide	Half life	Threshold energy of reaction	Cross section for fission spectrum
1	^{27}Al	100	n,g	^{28}Al	2.24 m	(thermal)	(228.8 mb)
2	^{15}N	0.364	n,g	^{16}N	7.13 s	(thermal)	(24.29 μb)
3	^{16}O	99.8	n,p	^{16}N	7.13 s	10.24 MeV	20.3 μb
4	^{19}F	100	n,g	^{20}F	11.2 s	(thermal)	(9.576 mb)
5	^{19}F	100	n,p	^{19}O	26.88 s	4.251 MeV	1.163 mb
6	^{19}F	100	n,a	^{16}N	7.13 s	1.603 MeV	14.65 mb
7	^{23}Na	100	n,a	^{20}F	11.2 s	4.035 MeV	673.9 μb
8	^{25}Mg	10	n,p	^{25}Na	59.1 s	3.176 MeV	1.681 mb
9	^{26}Mg	11	n,p	^{26}Na	1.08 s	8.228 MeV	18.24 μb
10	^{26}Mg	11	n,a	^{23}Ne	37.24 s	5.527 MeV	170.4 μb
11	^{34}S	4.25	n,p	^{34}P	12.4 s	4.445 MeV	800.5 μb
12	^{36}S	0.01	n,a	^{33}Si	6.18 s	4.065 MeV	54.12 μb
13	^{37}Cl	24.24	n,a	^{34}P	12.4 s	1.319 MeV	957 μb
14	^{54}Cr	2.365	n,p	^{54}V	49.8 s	6.376 MeV	10.68 μb
15	^{58}Fe	0.28	n,p	^{58}Mn	3.0 s	5.405 MeV	11.21 mb
16	^{80}Se	49.61	n,p	^{80}As	15.2 s	4.879 MeV	5.479 μb

Sixteen neutron reactions are chosen as candidates contributing to radiation exposure within a minute after the explosion.

Today's topic:

Contribution of neutron-induced radionuclides with shorter half-lives than Al-28

Preliminary results of neutron-induced radioactivity in soil at t=0.
Hypocenter. Fast fluence: $1.4*10^{11}$ Thermal fluence:$9.6*10^{12}$

Target nuclide	Abundance, %	concentration in soil, mg/g-soil	Reaction	Produced nuclide	Half life	Threshold energy of reaction	Cross section for fission spectrum	Initial radioactivity, Bq/g-soil	Relative radioactivity
^{27}Al	100	27	n,g	^{28}Al	2.24 m	(thermal)	(228.8 mb)	1.79E+07	10000
^{15}N	0.364	2	n,g	^{16}N	7.13 s	(thermal)	(24.29 μb)	6.63E+00	0
^{16}O	99.8	501	n,p	^{16}N	7.13 s	10.24 MeV	20.3 μb	5.35E+03	3
^{19}F	100	0.2	n,g	^{20}F	11.2 s	(thermal)	(9.576 mb)	3.61E+04	20
^{19}F	100	0.2	n,p	^{19}O	26.88 s	4.251 MeV	1.163 mb	2.74E+01	0
^{19}F	100	0.2	n,a	^{16}N	7.13 s	1.603 MeV	14.65 mb	1.30E+03	1
^{23}Na	100	16	n,a	^{20}F	11.2 s	4.035 MeV	673.9 μb	2.52E+03	1
^{25}Mg	10	2.54	n,p	^{25}Na	59.1 s	3.176 MeV	1.681 mb	1.79E+01	0
^{26}Mg	11	2.54	n,p	^{26}Na	1.08 s	8.228 MeV	18.24 μb	1.17E+01	0
^{26}Mg	11	2.54	n,a	^{23}Ne	37.24 s	5.527 MeV	170.4 μb	3.17E+00	0
^{34}S	4.25	0.7	n,p	^{34}P	12.4 s	4.445 MeV	800.5 μb	3.60E+00	0
^{36}S	0.01	0.7	n,a	^{33}Si	6.18 s	4.065 MeV	54.12 μb	1.15E-03	0
^{37}Cl	24.24	0.115	n,a	^{34}P	12.4 s	1.319 MeV	957 μb	3.65E+00	0
^{54}Cr	2.365	0.0205	n,p	^{54}V	49.8 s	6.376 MeV	10.68 μb	1.76E-04	0
^{58}Fe	0.28	17.7	n,p	^{58}Mn	3.0 s	5.405 MeV	11.21 mb	2.00E+02	0
^{80}Se	49.61	0.0012	n,p	^{80}As	15.2 s	4.879 MeV	5.479 μb	1.63E-04	0

Today's topic:
Contribution of neutron-induced radionuclides with shorter half-lives than Al-28

- Dose rate and cumulative dose in air
1 m above ground at hypocenter in Hiroshima

Neutron reaction	Material concentration	Radioactivity Concentration Bq/m^3	DCF*, $(mSv/h)/(Bq/m^3)$	Dose rate (t=0) mSv/h	Cumulative dose mSv
$^{27}Al(ng)^{28}Al$ in soil	1g-soil/m^3	1.8×10^7	3.2×10^{-7}	5.8	0.31
$^{15}N(ng)^{16}N$ in air	80% of air	5.5×10^6	9.3×10^{-7}	5.1	0.015
$^{16}O(np)^{16}N$ in air	20% of air	3.1×10^6	9.3×10^{-7}	2.9	0.008
			<Total>	14	0.33

*DOE-STD-1196-2011

Summary

- More important neutron-induced radionuclide than Al-28 was not found with short half-life just after the bombing.
  - Detailed analysis is needed for ^{16}N production in air.
- A external dose rate of 14 mSv/h was obtained at t=0 due to neutron-induced radioactive dust and air at the hypocenter, which led to a cumulative dose of 0.33 mSv.

Memorial for the victims of the third investigating team from Kyoto University by Makurazaki Typhoon on Sep 17, 1945

枕崎台風による遭難

京都大学調査班

敗戦の年は気象異変の多い年でもあった。中でも9月17日四国・中国地方を襲った「枕崎台風」は広島県下にも大きな被害を及ぼし，広島県の被害は死者 1,199 名，行方不明 897 名，流失家屋 1,297 戸，全壊家屋 2,101 戸の記録を残した。この台風による山津波で大野陸軍病院は，本館，病棟などが押し流され，多くの遭難者を出した。

回　　想

木 村 毅 一

90　山津波に潰滅した大野陸軍病院（左端の山より決潰した）

「原子爆弾：写真と記録」仁科記念財団(1973)

Thanks for your attention!