GAMMA SPECTRA AFTER NUCLEAR WEAPON DETONATION

NKS TEMEDET: TECHNICAL CHALLENGES IN METROLOGICAL (*NOT METEOROLOGICAL!!!*) RESPONSE TO A NUCLEAR DETONATION

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NKS TEMEDET - BACKGROUND

Hiroshima – detonation on 6 August 1945

Early measurments:

- August 8, 1945: Dr Nishina, General Headquarters, various samples and sent them to Tokyo by plane.
- August 10, 1945 : Dr Asada, Osaka Imperial University leaf electrode and a GM counter, Hiroshima city, in-situ and soil sample measurements. From Ground Zero out to some km from GZ.
- August 10, 1945 : Drs Arakatsu, Kimura and Shimizu, Kyoyo Imperial University, arrived at took soil samples and went back to Kyoto by the night train.
- August 13, 1945: Drs Shimizu, Ishiwari and Kondo, Kyoto Imperial University, took soils, metals, insulators and bones from more than 100 points in Hiroshima.
- Other surveys through August, October and into January 1946 and for years after.

- Sampling and measurement on August 11, 1945. Natural BG: 27 cpm• •

No.	Location	Counts/min
1	Gokoku shrine	120
2	Chugoku army headquarters	40
3	Entrance of the west parade ground	90
4	Hatchbori	37
5	Near Koi-station (bridge)	90
6	Ujina	37
7	Mukainada station	Slightly less than natural
8	East parade ground	• •
9	Yokogawa bridge	• •
10	Near Koi station	• •

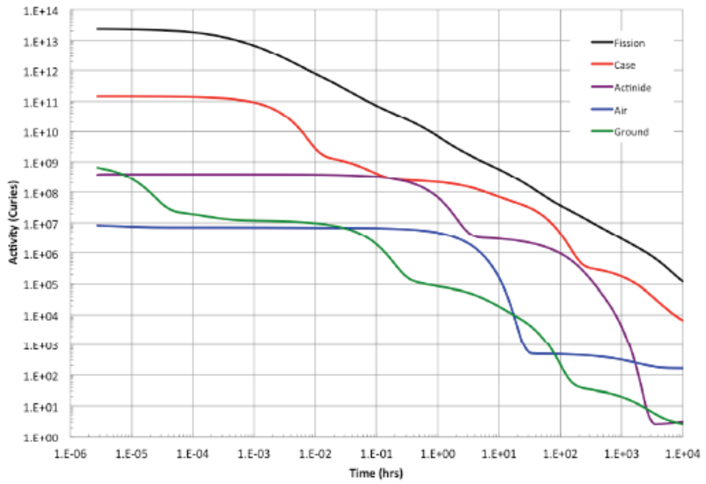
No	Sample place	Direction and distance from the hypocenter	β-ray activity
1	Logistics centre	SE•• 2.5 km	no
2	East foot of Mt. Hijiyama	SE••••2.5 km	no
3	Shrine at west foot of Mt. Hijiyama	E•••• 2.0 km	no
4	West side of Kojin bridge	ENE•• 2.5 km	Weak 11• 13
5	East side of Hiroshima station	NE•• 2.5 km	no
6	East parade ground	NE•• 2.5 km	no
7	In Nikitsu shrine	ENE•• 2.0 km	no
8	Hakushima-Higashinaka-machi	NNE•• 2.0 km	no
9	Near the gate of 5th engineering battalion	N•••• 2.5 km	Weak 8• 10
10	East side of Yokogawa st.	NNW••2.5 km	Weak 8• 10
11	South side of Yokogawa st.	NNW••2.5 km	no
12	West side of Tenma br.	W•••• 1.5 km	no
13	East side of Fukushima br.	W•••• 2.5 km	Weak 12• 14
14	East side of Koi br.	W•••• 3.0 km	no
15	300 m south-west of Koi st.	W•••• 3.5 km	no
16	East side of Asahi br.	W•••• 3.5 km	Strong 106
17	Near postal office in Minmai-Kanon	SW•• 2.5 km	no
18	Funairi-Kawaguchi-Cho	SSW•• 2.2 km	no
19	Firing range	SSW•• 3.0 km	no
20	Yoshijima airport	SSW•• 2.5 km	no
21	HgI and Sulphur at Engineering School	S•••• 2.0 km	no
22	AgNO3 at high-school	SSE•• 2.0 km	no
23	Ujina 9-chome	SSE•• 4.0 km	no
24	Ujina 4-chome	SSE•• 4.5 km	no

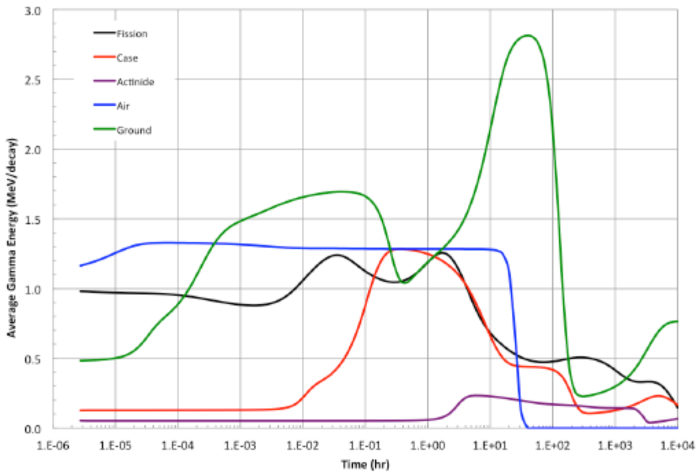
NKS TEMEDET – THE QUESTION

If a weapon is used - how would it be for us making the sort of measurements made in August 1945 but using todays equipment ?

NKS TEMEDET – THE QUESTION

- Instruments are better (?) today
- Instruments are used in different ways today
- Dwindling collective experience with «fresh fallout» from reactor accidents
- Dwindling or never existent experience with fresh weapons fallout
- Some specific challenges possibly presented by weapons





Isotope	Half Life	Activity % @ 100 days	Activity % @ 1 year	Activity % @ 10 years
Sr-89	50 d	11%	3%	
Sr-90	29 y	0.2%	3%	**36%**
Y-91	59 d	**22%**	7%	
Zr-95	66 d	**19%**	2%	
Ru-103	40 d	**19%**	2%	
Ru-106	369 d	3%	**24%**	0.5%
Cs-137	30 y	0.3%	3%	**46%**
Ce-141	33 d	14%	0.7%	
Ce-144	284 d	8%	**34%**	0.2%
Pm-147	2.6 y	1.4%	13%	14%

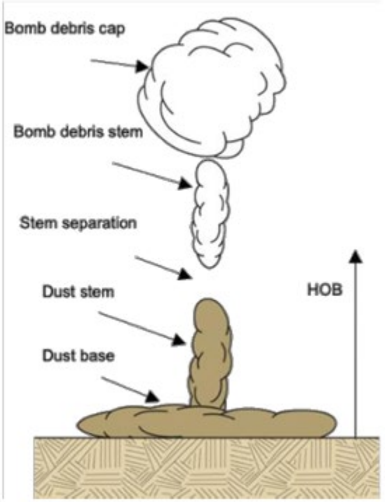
NKS TEMEDET - FOCUS

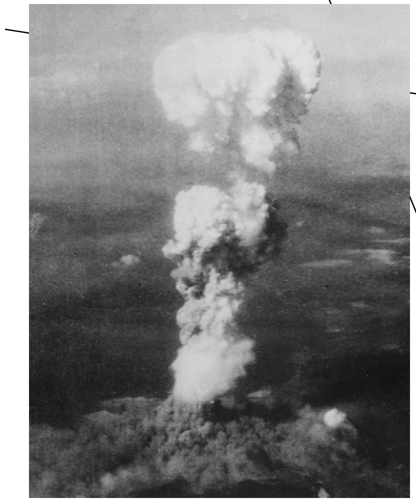
Obviously – going to be a simulation.

What to simulate?

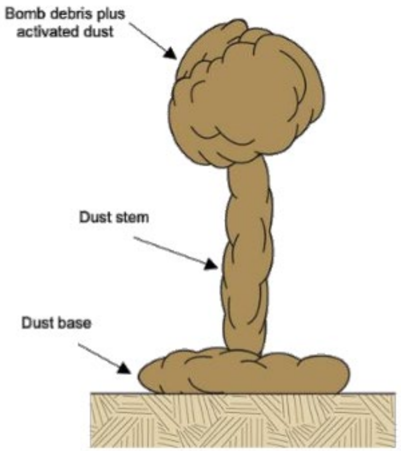
Two events chosen - Regime 2¤ and Regime 6¤ primarily due to the differences in the nature of the residual radiation.

The first produces only activation products near the hypocentre, the second produces activation products *and* fission product fallout over a wide area.





Regime 2 events, the fireball does not reach the surface and the cloud cap contains only bomb debris. The lofted dust is radioactive due to neutron activation of the soil. No cratering occurs. *The residual radiation in the vicinity of ground zero is due to activation of the ground*.



Regime 6 events, Large amounts of dust are immediately drawn into the cloud cap where it is mixed with bomb debris. Bomb debris and molten soil condense onto dust lofted into the cloud, producing significant local fallout.

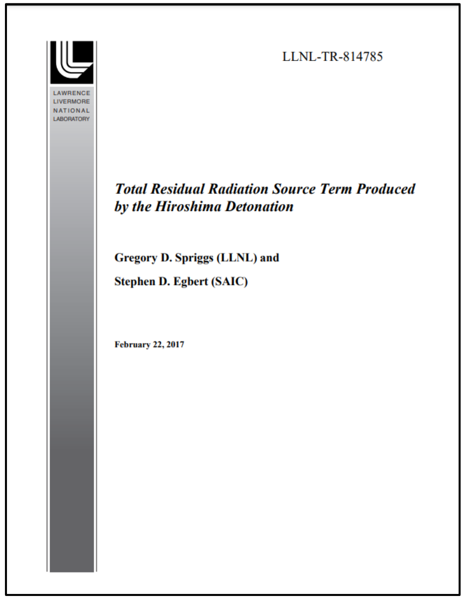
¤G.D. Spriggs, S.J. Neuscamman, J.S. Nasstrom, K.B. Knight. *Fallout Cloud Regimes*, LLNL-JRNL-813959, August 26,2020

NKS TEMEDET – SOURCE TERM

The source term chosen was the Hiroshima weapon.

16 kT at 600 m height (Regime 2),   16 kT at 10 m height (Regime 6).

Hiroshima chosen as extensive data commonly available.


LLNL-TR-814785

LAWRENCE LIVERMORE NATIONAL LABORATORY

Total Residual Radiation Source Term Produced by the Hiroshima Detonation

Gregory D. Spriggs (LLNL) and

Stephen D. Egbert (SAIC)

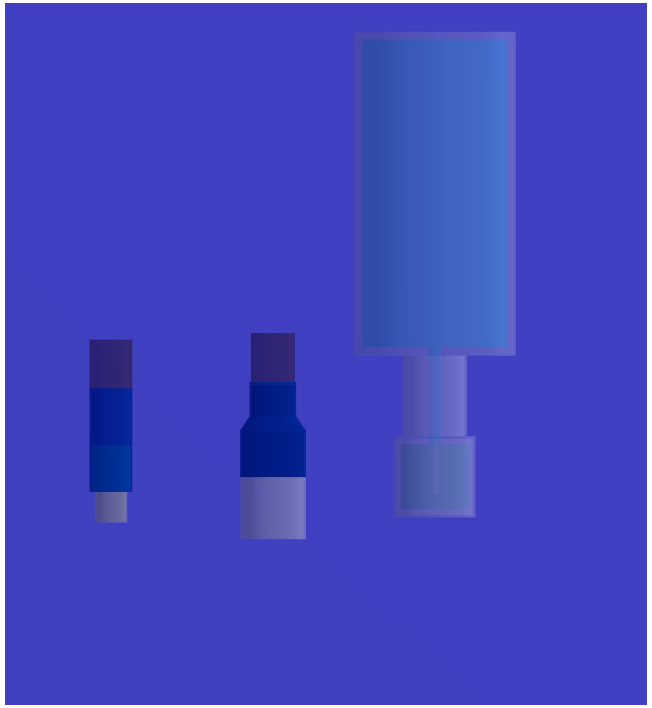
February 22, 2017

Components:

- **Activated weapon casing fragments** - not included as qualitatively similar to activated ground
- **Unfissioned nuclear material** - not included as it has been the subject of previous NKS work
- **Neutron activated air** - not included as it dissipates/decays quickly
- **Neutron activated ground** - included
- **Fission products** - included

NKS TEMEDET – MEASUREMENT GEOMETRIES

Three standard detectors were focussed upon: standard ca. 40% HPGe, standard 3 inch NaI, standard 1.5 inch LaBr positioned 1 m above the ground facing down (in-situ) or 10 m above the ground facing down (drone type measurement). Measurement time based on distance from GZ and time after detonation.



Simulations were performed with GEANT4, physics lists were QGSP_BIC_HP plus PENELOPE plus Radioactive Decay.

For all cases, the lower energy limit was 10 keV and the range cut-off for gamma photons was 0.001 cm at which point the remaining energy was dumped locally.

Dispersal calculations for Regime 6 calculated with the SILAM model at STUK.

NKS TEMEDET – REGIME 2

For Regime 2 – the source term was essentially that that reported after the Hiroshima bombing.

Little or no fission fallout, substantial contributions from neutron activation.

For TEMEDET the following distances and time periods after detonation were focussed on:

	3 days after detonation			30 days after detonation		100 days after detonation	
	Distance from GZ m			Distance from GZ m		Distance from GZ m	
	200	**1000**	**1500**	**200**	**1000**	**200**	**1000**
HPGe	4 s	240 s	1500 s	150 s	2000 s	80 s	2000 s
NaI	4 s	240 s	1500 s	150 s	2000 s	80 s	2000 s
LaBr	4 s	240 s	1500 s	150 s	2000 s	80 s	2000 s

NKS TEMEDET – REGIME 2

3 days				30 days			100 days		
Isotope	MBq/m² 200 m	MBq/m² 1000 m	MBq/m² 1500 m	Isotope	MBq/m² 200 m	MBq/m2 1000 m	Isotope	MBq/m² 200 m	MBq/m² 1000 m
Na-24	1.11E+01	6.19E-02	1.24E-03	Pa-233	1.52E-01	1.22E-03	Fe-55	1.03E-01	2.57E-04
K-42	2.44E+00	1.36E-02	2.71E-04	Fe-55	1.35E-01	1.08E-03	Co-60	5.65E-02	1.41E-04
Np-239	1.91E-01	1.06E-03	2.13E-05	Sc-46	8.74E-02	6.99E-04	Sc-46	3.61E-02	9.03E-05
La-140	1.68E-01	9.32E-04	1.86E-05	Co-60	7.22E-02	5.78E-04	Mn-54	3.22E-02	8.05E-05
Sm-153	1.45E-01	8.05E-04	1.61E-05	Fe-59	6.01E-02	4.80E-04	Cs-134	2.46E-02	6.15E-05
Pa-233	6.79E-02	3.77E-04	7.55E-06	Rb-86	5.14E-02	4.11E-04	Ta-182	1.93E-02	4.81E-05
Eu-152m	5.63E-02	3.13E-04	6.26E-06	Mn-54	4.78E-02	3.82E-04	Pa-233	1.54E-02	3.85E-05
Cu-64	5.26E-02	2.92E-04	5.85E-06	Hf-181	4.65E-02	3.72E-04	Fe-59	1.37E-02	3.44E-05
Y-90	3.57E-02	1.98E-04	3.97E-06	Ar-39	4.54E-02	3.64E-04	Hf-181	9.98E-03	2.49E-05
Fe-55	3.15E-02	1.75E-04	3.51E-06	Cr-51	4.48E-02	3.59E-04	Eu-152	7.95E-03	1.99E-05
Ga-72	3.12E-02	1.73E-04	3.46E-06	Ta-182	3.89E-02	3.11E-04	Zn-65	4.84E-03	1.21E-05
Rb-86	3.08E-02	1.71E-04	3.43E-06	Cs-134	3.29E-02	2.63E-04	Cr-51	4.78E-03	1.20E-05
Sc-46	2.49E-02	1.38E-04	2.76E-06	Eu-152	9.97E-03	7.98E-05	Hf-175	2.44E-03	6.10E-06
Sc-47	2.44E-02	1.36E-04	2.71E-06	Zn-65	7.55E-03	6.04E-05	Eu-154	2.33E-03	5.82E-06
As-76	2.22E-02	1.23E-04	2.46E-06	Hf-175	6.73E-03	5.39E-05	Rb-86	2.04E-03	5.11E-06
Fe-59	2.06E-02	1.15E-04	2.29E-06	Cs-131	3.68E-03	2.94E-05	Tb-160	1.11E-03	2.78E-06
Cr-51	1.97E-02	1.09E-04	2.18E-06	Tb-160	2.99E-03	2.39E-05	Ag-110m	2.94E-04	7.36E-07
Co-60	1.68E-02	9.31E-05	1.86E-06	Eu-154	2.94E-03	2.35E-05	Co-58	2.33E-04	5.81E-07
Hf-181	1.63E-02	9.05E-05	1.81E-06	Ba-131	2.09E-03	1.67E-05	Sb-124	2.07E-04	5.18E-07
Mn-54	1.16E-02	6.46E-05	1.29E-06	Sb-124	6.52E-04	5.22E-06	Nb-95	1.26E-04	3.14E-07
Ta-182	1.05E-02	5.81E-05	1.16E-06	Co-58	6.36E-04	5.09E-06	Zr-95	9.03E-05	2.26E-07
Ba-135m	7.80E-03	4.33E-05	8.66E-07	Sc-47	6.19E-04	4.95E-06	Se-75	8.45E-05	2.11E-07
Cs-134	7.73E-03	4.30E-05	8.59E-07	Ag-110m	4.57E-04	3.66E-06	Sr-85	7.18E-05	1.80E-07
Zn-69	4.90E-03	2.72E-05	5.45E-07	Np-239	4.19E-04	3.35E-06	Sr-89	6.25E-05	1.56E-07
Sb-122	4.59E-03	2.55E-05	5.10E-07	Zr-95	2.69E-04	2.15E-06	Cs-131	5.87E-05	1.47E-07
Zn-69m	4.57E-03	2.54E-05	5.08E-07	Sr-89	2.35E-04	1.88E-06	Eu-155	5.12E-05	1.28E-07
Eu-152	2.30E-03	1.28E-05	2.56E-07	Sr-85	2.11E-04	1.69E-06	Ba-133	1.66E-05	4.16E-08
Ba-131	2.26E-03	1.26E-05	2.51E-07	Y-90	1.92E-04	1.54E-06	Ba-131	1.32E-05	3.29E-08
Hf-175	2.00E-03	1.11E-05	2.22E-07	Se-75	1.67E-04	1.34E-06	Sm-151	1.30E-05	3.25E-08
Zn-65	1.87E-03	1.04E-05	2.08E-07	Nb-95	1.40E-04	1.12E-06	Kr-85	9.20E-06	2.30E-08
Ba-133m	1.49E-03	8.29E-06	1.66E-07	Eu-155	6.55E-05	5.24E-07	Ca-41	5.66E-06	1.42E-08
Tb-160	8.81E-04	4.89E-06	9.79E-08	Sm-153	5.90E-05	4.72E-07	Y-91	5.54E-06	1.39E-08
Eu-154	6.79E-04	3.77E-06	7.55E-08	Xe-133	3.89E-05	3.11E-07	Cl-36	4.00E-06	1.00E-08
Br-82	6.71E-04	3.73E-06	7.46E-08	Ca-47	3.76E-05	3.01E-07	Ag-110	4.00E-06	1.00E-08
Cs-131	4.97E-04	2.76E-06	5.52E-08	Nb-92m	2.76E-05	2.21E-07	H-3	1.68E-06	4.20E-09
Ca-47	4.45E-04	2.47E-06	4.95E-08	Sb-122	2.65E-05	2.12E-07	Rb-84	1.63E-06	4.09E-09
Sb-124	2.02E-04	1.12E-06	2.24E-08	Ba-133	2.09E-05	1.67E-07	Nb-95m	1.03E-06	2.58E-09
Co-58	1.88E-04	1.04E-06	2.09E-08	Y-91	1.79E-05	1.43E-07	Hg-203	7.07E-07	1.77E-09
Cu-67	1.79E-04	9.92E-07	1.98E-08	La-140	1.71E-05	1.37E-07	Lu-177m	5.80E-07	1.45E-09
Xe-133	1.75E-04	9.75E-07	1.95E-08	Sm-151	1.61E-05	1.29E-07	Pu-239	4.49E-07	1.12E-09
Hf-180m	1.63E-04	9.07E-07	1.81E-08	Kr-85	1.16E-05	9.26E-08			
Mo-99	1.45E-04	8.07E-07	1.61E-08	Rb-84	1.08E-05	8.64E-08			
Tc-99m	1.41E-04	7.81E-07	1.56E-08	Cs-136	8.82E-06	7.05E-08			
Xe-133m	1.34E-04	7.47E-07	1.49E-08	Ca-41	7.02E-06	5.62E-08			
Ag-110m	1.13E-04	6.27E-07	1.25E-08						

NKS TEMEDET – REGIME 6

For Regime 6 – the source term was essentially that that reported after the Hiroshima bombing by Spriggs and as incorporated in the SILAM model.

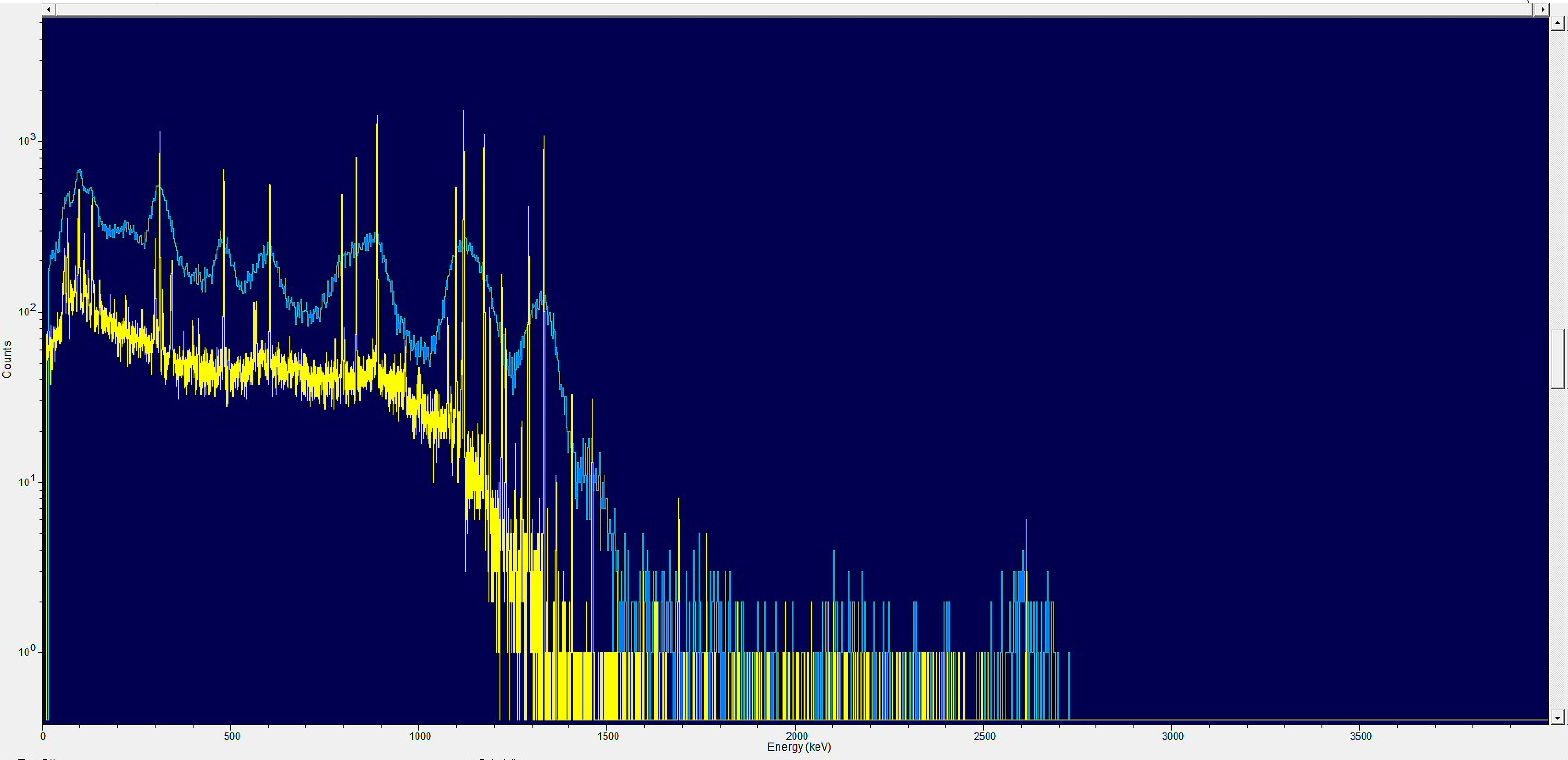
At the distances used in TEMEDET little or no activation product fallout, substantial fission product fallout.

For TEMEDET the following distances and time periods after detonation were focussed on:

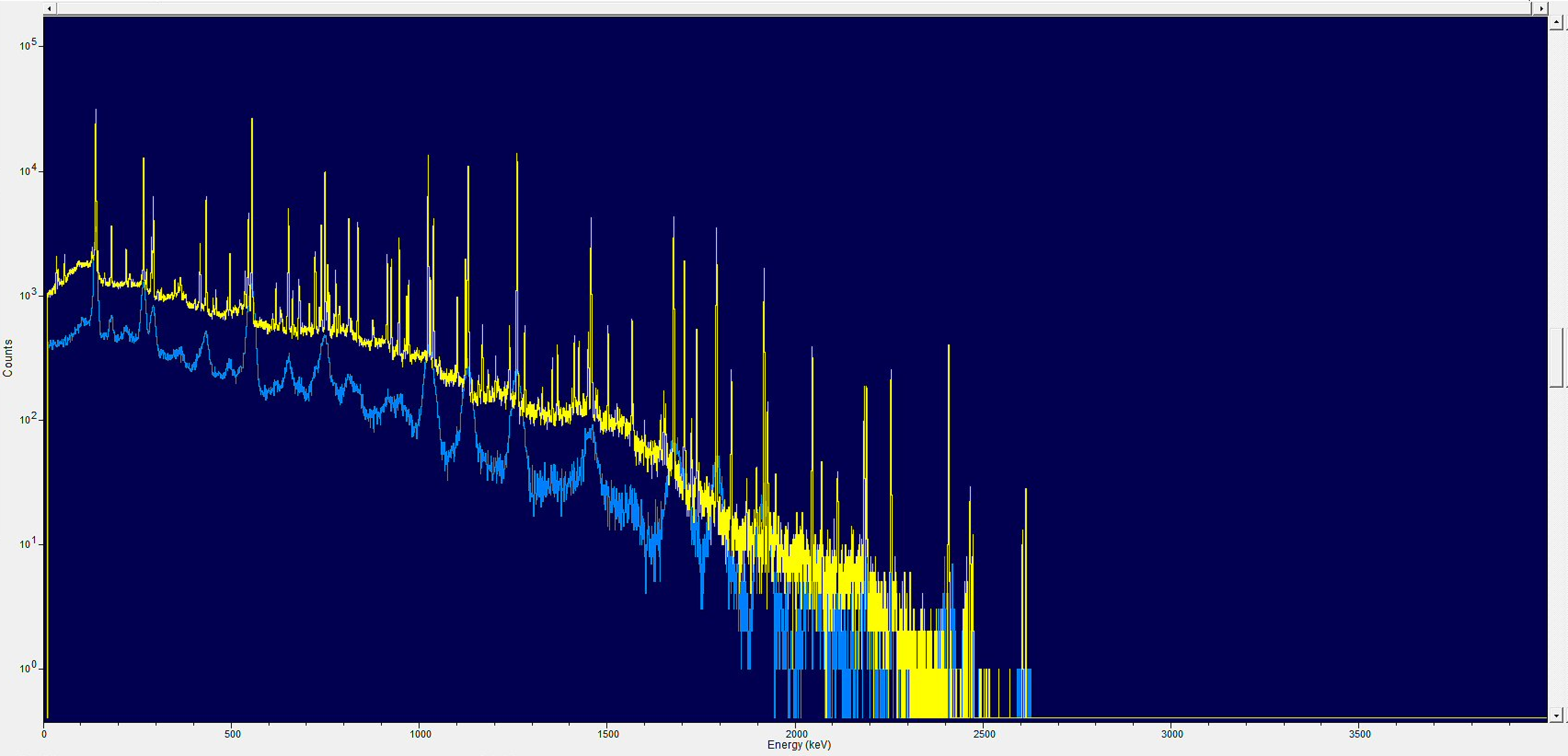
	3 days after detonation			30 days after detonation			100 days after detonation			1 year after detonation		
	Distance from detonation km			Distance from detonation km			Distance from detonation km			Distance from detonation km		
	5	**50**	**200**	**5**	**50**	**200**	**5**	**50**	**200**	**5**	**50**	**200**
HPGe	1 s	10 s	100 s	1 s	5 s	100 s	1 s	5 s	100 s	1 s	5 s	100 s
NaI	1 s	10 s	100 s	1 s	5 s	100 s	1 s	5 s	100 s	1 s	5 s	100 s
LaBr	1 s	10 s	100 s	1 s	5 s	100 s	1 s	5 s	100 s	1 s	5 s	100 s

Fission product ground values after 3 days			
Isotope	MBq/m^2 @ 5 km	MBq/m^2 @ 50 km	MBq/m^2 @ 200 km
Ba-140	3.09E+01	1.68E+00	7.23E-02
Ce-141	1.46E+01	7.95E-01	3.42E-02
Ce-143	1.10E+02	5.99E+00	2.58E-01
Ce-144	5.56E+00	3.02E-01	1.30E-02
Co-58	4.58E-01	2.49E-02	1.07E-03
Cs-137	6.55E-03	3.56E-04	1.53E-05
I-131	4.21E+00	2.29E-01	9.85E-03
I-135	5.56E+02	3.02E+01	1.30E+00
La-141	1.39E+02	7.57E+00	3.26E-01
Mn-54	6.18E-02	3.36E-03	1.45E-04
Mo-99	2.96E+02	1.61E+01	6.92E-01
Ru-103	1.64E+01	8.91E-01	3.84E-02
Sb-128	2.72E+00	1.50E-01	6.40E-03
Sb-129	8.39E+01	4.56E+00	1.96E-01
Sb-130	1.06E-05	5.75E-07	2.47E-08
Sn-128	6.40E-03	3.47E-04	1.50E-05
Sr-89	9.18E+00	4.99E-01	2.15E-02
Sr-91	4.46E+02	2.43E+01	1.04E+00
Te-131	7.09E-01	3.85E-02	1.66E-03
Te-132	6.91E-01	3.75E-02	1.62E-03
Y-93	1.41E+03	7.64E+01	3.29E+00
Zr-95	2.64E+01	1.44E+00	6.17E-02
La-140	8.09E-05	4.41E-06	1.89E-07
Pr-143	4.41E+00	2.40E-01	1.03E-02
Tc-99	1.40E-06	7.66E-08	3.29E-09
Te-129	4.74E+01	2.58E+00	1.11E-01
Y-91	7.83E+00	4.28E-01	1.83E-02
Nb-95	1.23E-01	6.67E-03	2.87E-04

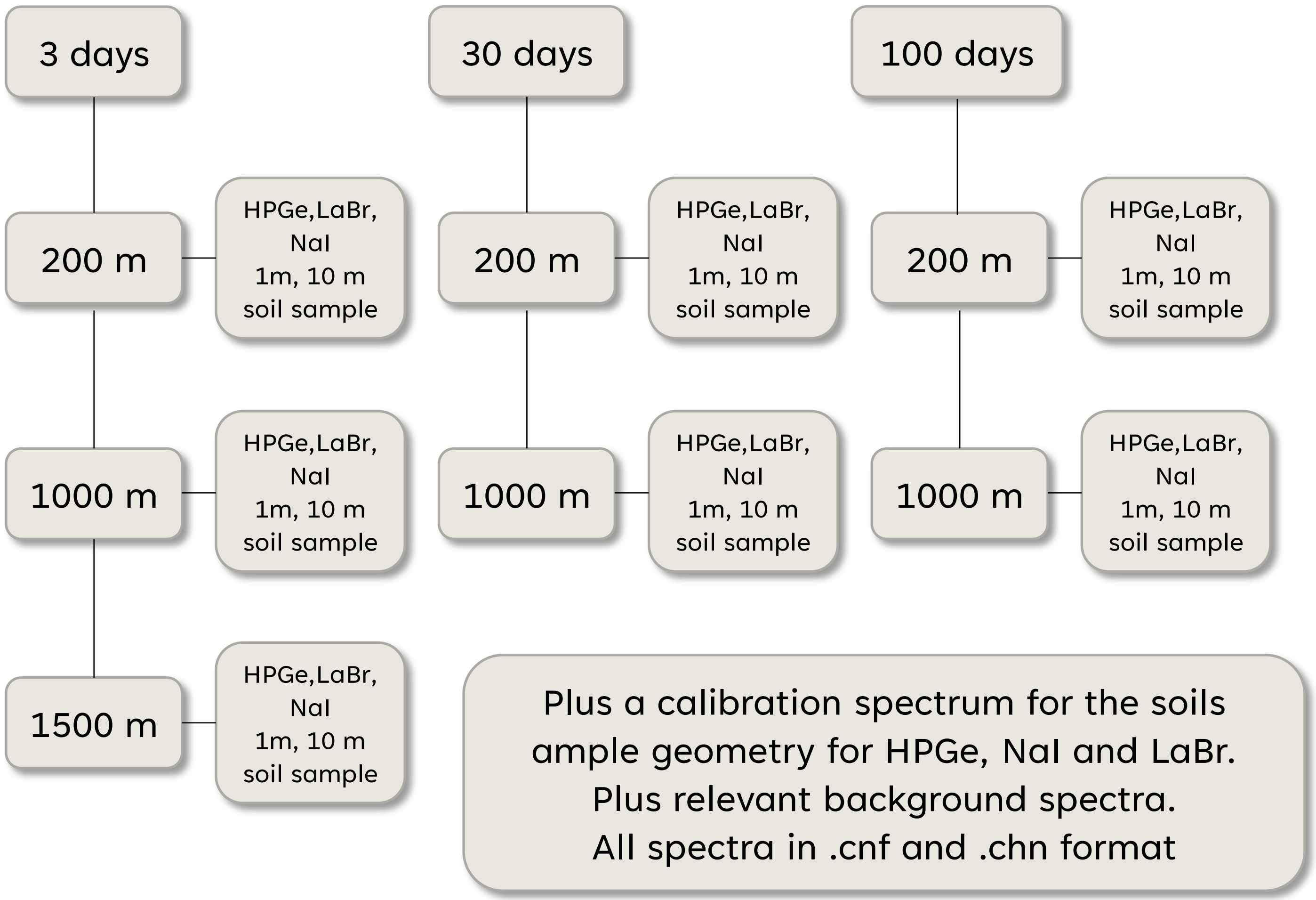
REGIME 2. 200 METERS, 30 DAYS, 1 METER HEIGHT, HPGE AND NAI



REGIME 6. 5 KM, 3 DAYS, 1 METER HEIGHT, HPGE AND LABR

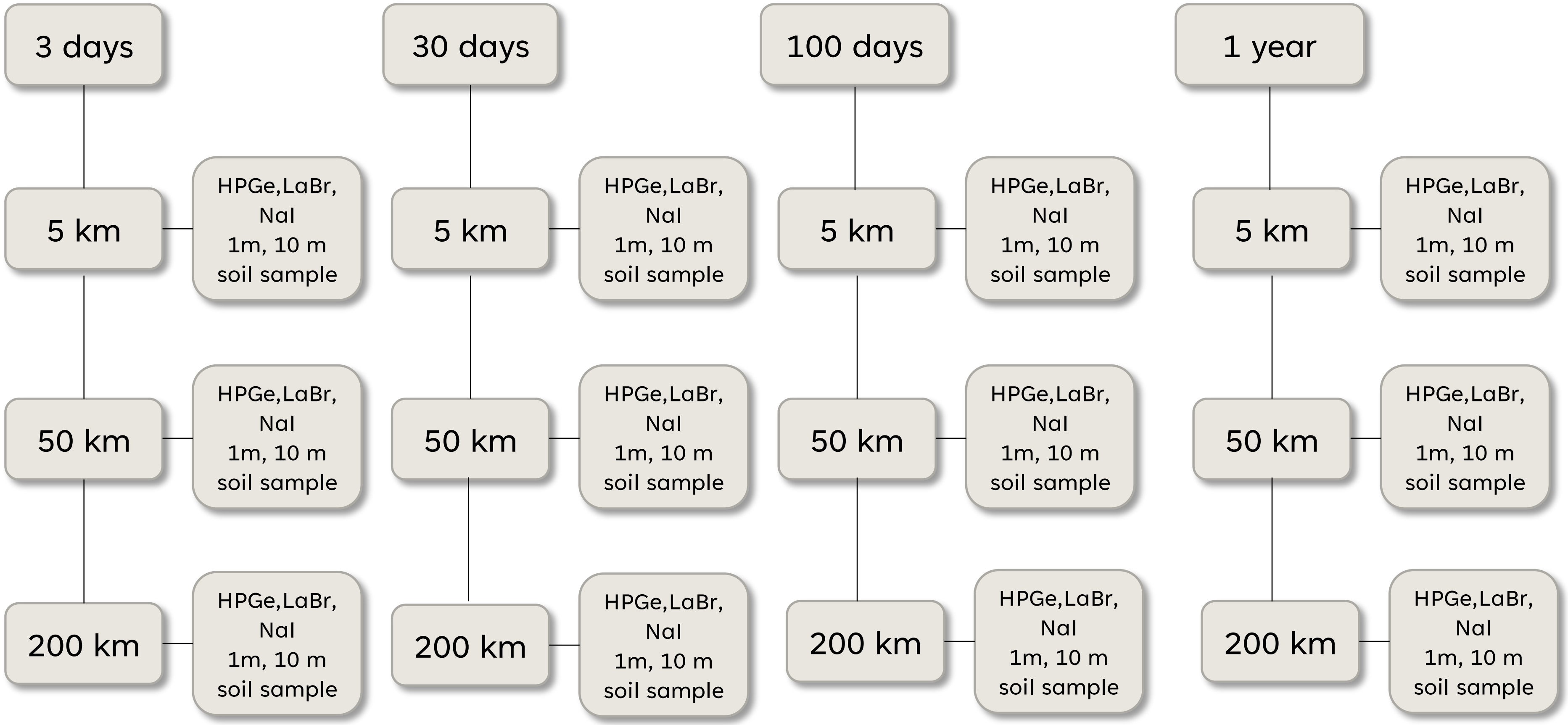


Regime 2



3 days
30 days
100 days
200 m
HPGe,LaBr, NaI 1m, 10 m soil sample
1000 m
HPGe,LaBr, NaI 1m, 10 m soil sample
1500 m
HPGe,LaBr, NaI 1m, 10 m soil sample
200 m
HPGe,LaBr, NaI 1m, 10 m soil sample
1000 m
HPGe,LaBr, NaI 1m, 10 m soil sample
200 m
HPGe,LaBr, NaI 1m, 10 m soil sample
1000 m
HPGe,LaBr, NaI 1m, 10 m soil sample
Plus a calibration spectrum for the soils ample geometry for HPGe, NaI and LaBr.
Plus relevant background spectra.
All spectra in .cnf and .chn format

Regime 6



Plus a calibration spectrum for the soils sample geometry for HPGe, NaI and LaBr.
Plus relevant background spectra.
All spectra in .cnf and .chn format

NKS TEMEDET – CAVEATS

Probably unlikely to have «pure» Regime 2 or Regime 6 source term – some mixture of both in reality?

The Hiroshima Regime 2 source term probably does not represent the relative proportions of isotopes produced in a modern European cityscape?

Summation, detector saturation and similar effects not included.

Many isotopes with insignificant gamma emissions or very low activities included in data sets.

Background included even where not evident in final spectra.

In-situ measurements qualitative only –restrictions on realism due to simulation over such large geometries.

Quantitative information was provided by «soil samples» – simulated samples of soil taken at the same distances and times as the in-situ information with the isotope activity data converted over to Bq/sample.

Calibration information provided for an identical soil sample containing calibration nuclides.

NKS TEMEDET – PITFALLS

For Regime 6 – the isotope assemblage is qualitatively similar to a conventional fresh fallout accident scenario

Most practitioners should be prepared for, in not expierienced with, such analyses.

For Regime 2 – the isotopes featured are perhaps not what most practitioners are familiar or experienced with ?

Reliance on library driven routines will be vulnerable to how comprehensive the library is (what isotopes are present and what lines are featured for them).

A mixture of Regime 2 with some Regime 6 in addition to perhaps components (bomb casings etc) not featured in TEMEDET could be a real head scratcher for many............

NKS TEMEDET – CURRENT STATUS

Majority of spectra complete – quality checking

Some revisions necessary for Regime 6 – ongoing forward to November

Report due in December 2023

All spectra and report should be up on the NKS repository some time in early 2024

ACKNOWLEDGEMENTS

Many thanks to the consortium members and Alexander Mauring from IFE for checking some data!

Thanks to Roy and NKS for hosting another Gamma seminar!

Questions?