NKS-400
ISBN 978-87-7893-488-8

Early Phase Source Term Estimation From Gamma Spectra (EPHSOGAM)

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December 2017

Abstract

As evidenced by the Fukushima Accident and events during 2017 in relation to ^{131}I and ^{106}Ru, estimation of the release term in the early phases of a nuclear accident is fraught with difficulties. Provision of an early estimate of quantitative and qualitative information regarding a release establishes a firm foundation for early actions and underpins the ultimate response measures implemented. Early phase monitoring data facilitates the drawing of conclusions regarding the nature of a release, its duration, possible location etc. The EPHSOGAM activity was aimed at the provision of a fit-for-purpose, robust and comprehensive virtual exercise for personnel involved in early phase response. The activity involved the dissemination of technical materials, derived from a simulated incident, from which participants were required to generate an estimate of the release location, amount of activity released and any other information they were fit to provide. The technical data included meteorological and gamma spectrometric data typically available in the aftermath of an incident and the activity tested various aspects of the abilities of the participant organisations. A description of the materials provided, their development and the participants responses are provided. The results highlight the complex interplay between a variety of factors affecting the participants abilities with respect to release location and characterisation of the release.

Key words

Dispersion modelling, back-trajectories, gamma spectrometry

NKS-400
ISBN 978-87-7893-488-8
Electronic report, December 2017
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Nordic nuclear safety research

20 December 2017

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Final Report from the NKS-B Project EPHSOGAM (Contract: AFT/B(17)1).

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable inputs of the participants to EPHSOGAM and the NKS for support through its B-programme.

DISCLAIMER

1. Introduction

The Fukushima Accident of 2011 exemplified problems in relation to the estimation of release terms in the early phase of a nuclear accident. Despite the fact that knowledge of the amount of radioactivity released and qualitative information as to the suite of nuclides involved is fundamental to a robust and effective reponse for countries to which contamination may be transported, the period after the Fukushima Accident provided adequate and stark evidence that generation of such information is far from simple. Even in situations where the operator and responsible authorities are in control of the incident, a lack of information in the early phases of an accident can pose severe challenges for those tasked with predicting the possible impact of the accident on their own countries. Less dramaatic but nonetheless significant, the events during early 2017 [1] in relation to an unidentified release of ^{131}I and again during the autumn of the same year with respect to widespread detections of ^{106}Ru [2] served to highlight the problem in identifying and quantifiying source terms.

Two approaches are possible in the matter of estimating various aspects of an accident, such as release term or the location and time of an accident in cases when such information is not known with certainty. The reactor parameters and processes occurring during the accident may be modelled or described although this approach is hampered by, as seen during the Chernobyl Accident, a lack of information or understanding as to what is actually happening, or has happened, during the release phase of the event. For an instance where the location or time of the accident is unknown, such as with a submarine or similar, such approaches may be poorly positioned to provide the information ncessary to efficiently handle the consequences of the releasse. Alternatively, inverse modelling approaches can combine data generated from radioactivity monitoring with atmospheric dispersion models with subsequent optimisation of the final release estimate by iteratively improving upon the agreement between the model outputs and the empirical data. Irrespective of which approach is adopted, for practitioners in organisations with responsibility in this area, exercise opportunities are few and far between. Recourse if often drawn to previous accidents and incidents and the literature is replete with examples of how, in years after various accidents, attempts have been made to utilise such events in improving and fine-tuning various methodologies.

[1] http://www.irsn.fr/EN/newsroom/News/Pages/20170213_Detection-of-radioactive-iodine-at-trace-levels-in-Europe-in-January-2017.aspx

[2] http://www.irsn.fr/EN/newsroom/News/Pages/20171004-Detection-ruthenium-106-in-the-air-in-Europe.aspx

A possible alternative approach is to utilise a "synthetic" incident whereby the known (in terms of activity, nuclide composition, location, time, height etc.) release term is generated a priori, appropriate data related to this synthetic release are subsequently generated and this data is then used to test how well various methodolgies perform in relation to the objective of estimating various characteristics of the release. EPHSOGAM was organised to adopt this approach. The aim of the EPHSOGAM activity was be the provision of a high quality, fit for purpose data assemblage simulating a release event and which participants could then use to attempt to provide information as to the release.

On a practical level, EPHSOGAM functioned by disseminating data to participants by electronic means, based upon which, and the analysis therof, the participants were required to produce an estimate of the released activity and characteristics of the release event. Data to be disseminated included the approximate location of the event being simulated (in effect being confined to the wider European area for practical purposes), date and approximate time, meteorological data and measurement data. This measurement data consisted primarily of simulated/synthetic gamma spectrometric data and information as to sampling, instrument etc. Measurement data was generated at a number of hypothetical locations and times. Geographical coordinates for measurement stations were provided. Meteorological data for a defined period was acquired by the participants using their own systems prior to the actual activity.

The participants were required to analyse the spectrometric data to form an estimate of the air concentrations of identified nuclides. This data was then to be used with whatever models or means the participants had at their disposal to generate an estimate (plus uncertainties) of the amount of activity released by the "accident/incident". The ESPHOGAM activity took place at a pre-arranged time and participants were time constrained with respect to reporting. Participants were requested to provide full and detailed reports as well as reporting upon experiences, difficulties etc. Data was provided to participants in standard formats where possible and pre-exercise communication with participants were conducted to ensure data was of a format amenable to participants.

In total 15 participants from 12 countries registered to participate in EPHSOGAM, 7 participants from 7 countries managing to submit final results.

1.1 Technical details

The EPHSOGAM activity simulated 4 scenarios wherein radioactivity was detected on air filter samples at a number of measurement locations for each scenario. The 'operators' of the stations requested assistance from the participant and sent gamma spectral data for the stations. The goal of the activity was, for each of the 4 scenarios, to provide an estimate of the location of the release, the time of the release, the nature of the release with respect to qualitative and quantitative information and any other information the participants would like to provide. In particular and in addition to the above, the organizers were interested in how participants approached the problem of identifying release locations and details.

Each scenario involved 3 monitoring stations. Coordinates of the locations of these stations were provided - stations were randomly picked and did not represent actual real-world locations of monitoring stations. The stations were "sampling" for different periods of time and had "sampled" different volumes of air. The time periods during which each station was sampling were also provided. Total Gamma Dose Rate data was provided for three of the scenarios. Gamma spectra were provided for each of the stations in each of the scenarios.

In developing the release sources effort was expended in ensuring that the release locations corresponded with actual facilities from which a release may occur or locations from where a release could potentially occur. No attention was paid as to whether or not those facilities were actually operating during the EPHSOGAM time period. EPHSOGAM attempted to utilize realistic source terms with respect to amounts released and what was released for each scenario. For practicality, the entire suite of possible isotopes from a source term could not been utilized. This was in relation to the limitations of both the the system used for simulating dispersal of the isotopes and practicalities in relation to generating spectra. The most significant nuclides from a gamma spectrometry/dose point of view were chosen (so for example, an isotope with insignificant gamma emissions relative to other isotopes would not have been included even if the release of that isotope was much greater than the stronger gamma emitting isotopes). Isotopes with half-lives less than an hour or so were, generally, not included. No attempt was made to ensure correctness with respect to various mother/daughter or other isotope relationships. Decay between emission and sampling was included. For the purpose of the activity it was assumed that the monitoring stations were using a super efficient filter paper with 100% retention of particulate isotopes. For isotopes with gaseous and particulate forms, it was assumed that all the isotope was present in particulate form.

There was no reduction of sampling rate with time. The sampling times and rates of air sampling were not intended to be realistic. The times during which the samplers were active were simplified to some extent and tended to be a little "ideal" with respect to plume passage etc.

The gamma data was simulated as having been drawn from a very standard HPGe detector. The "detector" and its electronics were the same for all scenarios and all monitoring stations for simplicitys sake. The detector was a very standard coaxial HPGe detector, crystal size was 5.4 cm diameter and 5.1 cm in length. Endcap was aluminium, 3 mm from the crystal face. Nominal rel. efficiency was 22% and the resolution was 2.1 keV at 1332 keV. The MCA system was 4096 channels, zero was 0 keV, the gain was 0.75 keV/channel and the full scale energy was 3072 keV.There was no decay of gamma isotopes over the period of gamma counting – participants were instructed to switch off any type of decay corrections in their analysis routines. No accounting was made of mother-daughter ingrowth relationships over the gamma counting period - participants were instructed to switch off related routines in their analysis software. Gamma counting was considered as having taken place immediately after the sample was removed from the air sampler. The samples were counted at a distance of 10 cm from the detector so true coincidence summation did not have to be accounted for. It was assumed that no natural nuclides ended up on the air filters. The detectors (all of them, for all scenarios) were calibrated with a mixed standard isotope solution presented to the detector in exactly the same geometry and sample matrix as for the samples. The source consisted of (at the time of counting) 10000 Bq of each of the following:

^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{85}Sr, ^{88}Y, ^{60}Co and ^{137}Cs.

Nuclear data – the nuclear data used in EPHSOGAM was taken from the Table of Isotopes hosted at Lund University Sweden and accessed at http://nucleardata.nuclear.lu.se/toi/ and was correct as of June 2017. The relevant reference time for each spectrum could be considered as having been the time the count was started. EPHSOGAM tried to include the common gamma spectrum file formats for dissemination. For various reasons, only crucial information was included – channels, counts, live time, dead time, start time. The file naming format for the spectra was as follows: Scenario_X_Station_X.ext where X was the scenario and station number and .ext was the relevant extension. The calibration files were just called calibration.The formats included were: Ortec .chn and .spe, Canberra .cnf (renamed to .cnx),

an Excel type .csv, the CTBTO .phd format and the XML .n42 format. Specific spectral data as to each and every spectrum, except the calibrations spectrum, disseminated within EPHSOGAM is provided as Appendix 3.

General data provided included a brief description of the "problem" for each scenario. This included coordinates for each detector for each scenario, information as to when samples were taken etc etc. The informational material for each scenario as sent to the participants can be found in Appendix 1. General information as to how the materials were developed and provisos to be considered was also sent and this is contained within Appendix 2. For the purpose of EPHSOGAM, all the release scenarios were considered as having taken place over a specific time period. In this way, each participant could prepare their own system in advance of the activity and ensure they had relevant meteorological data to facilitate the analysis. The period chosen was that from the 20th of March 2017 (00:01[3]) to the 27th of March 2017 (23:59) and this was communicated to participants in advance. In terms of location, the scenarios – with respect to source locations and measurement station locations – were confined to the area within the red lines in Figure 1 and this was also communicated to the participants.

Figure 1. Geographical domain within which the EPHSOGAM scenarios were considered as having taken place.

[3] All times are given as UTC

1.2 Selection of the scenarios from an atmospheric dispersion perspective

Atmospheric dispersion models (ATM) need different meteorological weather prediction (NWP) model input as driver for the transport. Since NWP data is very large and delivered in different formats it was decided to inform all participants to store their NWP data for one week in March 2017. This solved the problem of data transfer and adaption of NWP data to different ATMs, but put restrictions on the site and date selection for the scenarios. The scenarios weather conditions should allow the transport to stay within the predefined domain, all weather conditions should be stable to be independent of the NWPs predictability and the scenarios should take part in different parts and while the measurements stations where arbitrary, the facilities emitting nuclear debris should be real.

As can be seen in Figure 2, the week from 20th March to 27th March started with stable, strong western winds in mid-latitudes in particular around the UK. The weather situation in the Mediterranean was throughout the complete week difficult with several lows, but it became more stable to the end of the week. Eastern Europe had throughout the week mostly western winds, while the wind in central europe change slow direction with influence from a low pressure system over the UK. The weather maps where in addition supported by daily run dispersion model runs over 5 places arbitrarily distributed throughout Europe.

With this information, it was simple to decide on Scenario 2 / Sizewell as West-European scenario at the beginning of the week. The Eastern scenario (Scen. 4 Rivne) was then decided to be during a time with slight Southern winds at the beginning of the week, in order to avoid transported particles to leave the weather domain. The scenario of the submarine in the Mediterranean had to happen at the end of the week even if the weather conditions were still slightly difficult. Scenario 3 / Grafenrheinfeld was meteorological not very import, since all participating parties were informed about the origin at the beginning of the exercise.

To ensure the feasibility of reverse modelling the scenarios with different NWP models, the scenarios have been have been verified by using model-runs using the Norwegian ATM SNAP (Severe Nuclear Accident Programme) with both HIRLAM meteorology in 12km

resolution and with the ECMWF IFS High Resolution driver meteorology at 0.1° resolution in forward and reverse runs (Figure 3).

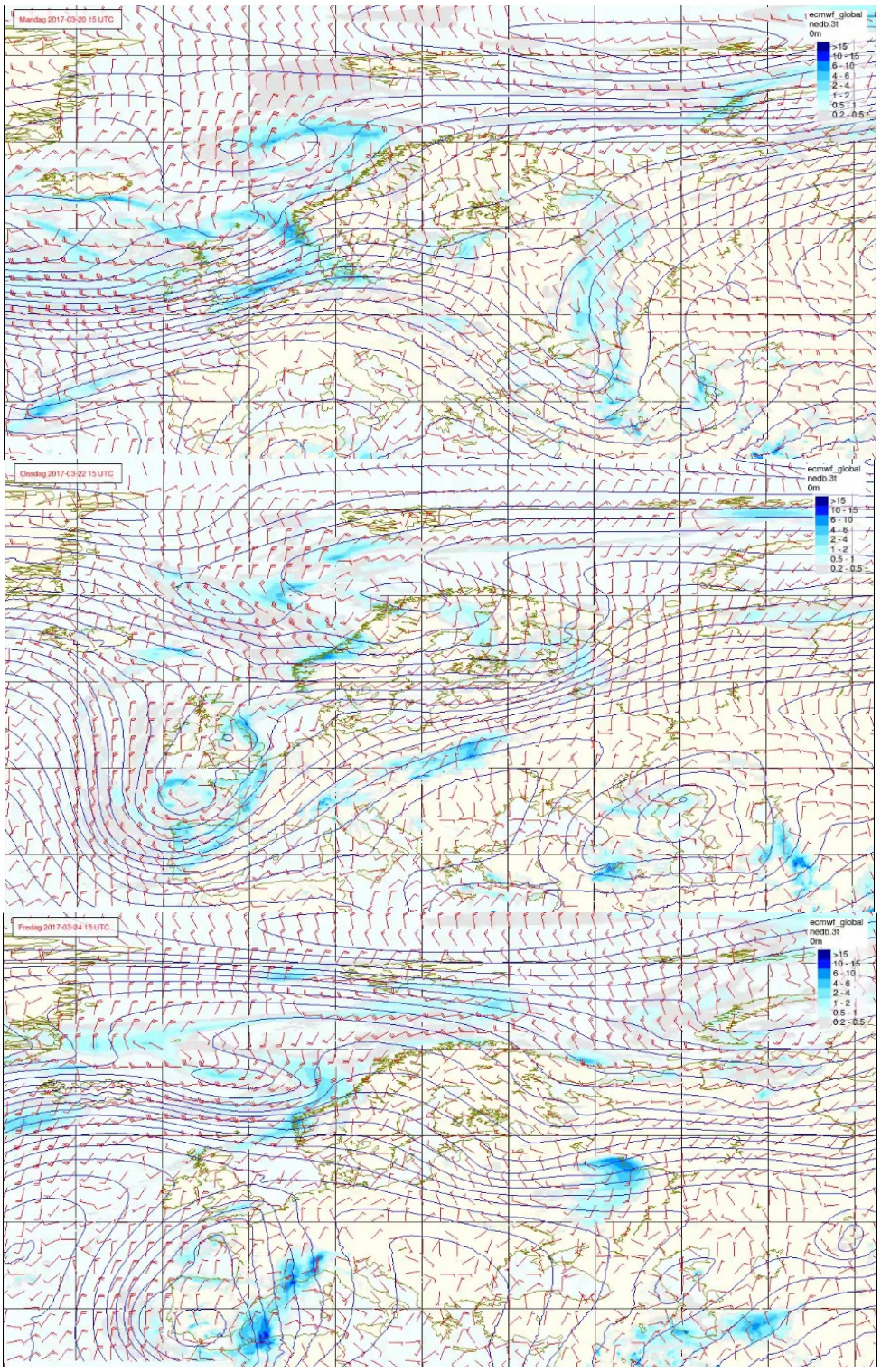


Figure 2: Wind, precipitation and Z500 for different dates in the predefined week in March 2017

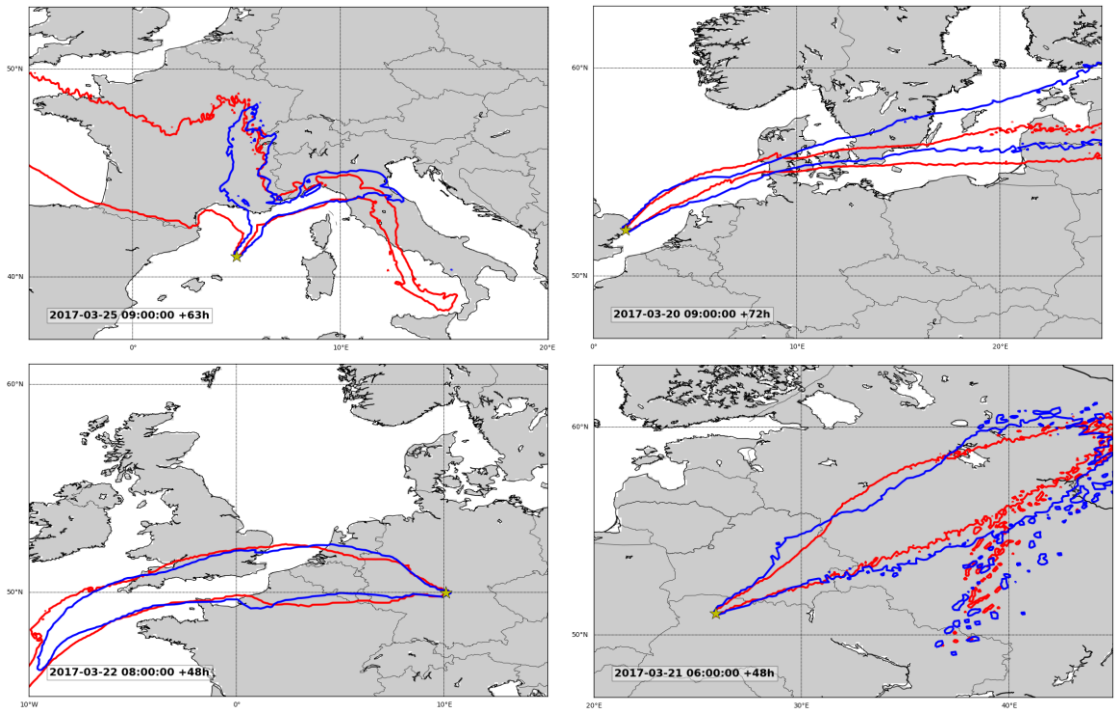


Figure 3: Comparison of forward dispersion model calculations using EC IFS (red) and HIRLAM 12(blue) as meteorological driver for SNAP.

For the purpose of reporting, participants were asked to communicate the following in any manner that was convenient for them.

For each Scenario.

1. Where they thought the release occurred – a GPS coordinate, a circle drawn in Google Earth, a facility name, etc.
2. When they thought the release occurred.
3. What isotopes they thought were released and how much of each.
4. Any other observation or conclusion they would like to draw – how the release developed over time, etc etc.

For each Scenario and Station

1. What isotopes were in the sample
2. the concentrations of those isotopes in the sample in Bq/m^3

2. Scenario 1

Scenario 1 was based around a release from the reactor of a nuclear powered submarine at a location in the Mediterranean Sea near Spain. The release was at the location 5 E, 41 N and took place over 6 hours starting at 09:00 on the 25th of March 2017. The location of the release and the 3 associated monitoring stations are provided in Figure 4.

Figure 4. Release point and monitoring stations for Scenario 1.

The release was modelled as having taken place at 10 m above sea level and to have progressed steadily over 6 hours (no variation with release over time). The source term for Scenario 1 was based upon the information in Reistad and Povl (2006) [4]. The three measurement points for Scenario 1 were as detailed in Table 1. Ten nuclides were selected for Scenario 1 based upon their contribution to the gamma spectrum – nuclides with a low relative contribution were not included. The list of nuclides and the released amounts are detailed in Table 2, average air concentrations at each station are detailed in Table 3. Details as to the variation of dose rates at each measurement station of Scenario 1 are detailed in Appendix 1.

[4] Reistad, Ole, and Povl L. Olgaard, April 2006, Inventory and Source Term Evaluation of Russian Nuclear Power Plants for Marine Applications, report NKS-139, NKS, on line [http://130.226.56.167/nordisk/publikationer/1994_2004/NKS-139.pdf].

		Sampling period		Sampled hours	Sampling volume per hour	Total sampled volume m^3	Total Seconds
		Time/Date Start	Time/date Stop				
Location 1	04°46'25''E 43°19’50"N	25.03.2017 22:00	27.03.2017 15:00	41.00	400.00	16400	147600.00
Location 2	09°41’07"E 44°23’57"N	26.03.2017 11:00	26.03.2017 23:00	12.00	500.00	6000	43200.00
Location 3	03°31’23"E 45°06’56"N	26.03.2017 08:00	27.03.2017 23:00	39.00	300.00	11700	140400.00

Table 1. Measurement location details for Scenario 1.

Isotope	Total Release Bq	Hour 1 Bq	Hour 2 Bq	Hour 3 Bq	Hour 4 Bq	Hour 5 Bq	Hour 6 Bq
I-133	9.16E+14	1.53E+14	1.53E+14	1.53E+14	1.53E+14	1.53E+14	1.53E+14
I-132	4.75E+14	7.92E+13	7.92E+13	7.92E+13	7.92E+13	7.92E+13	7.92E+13
La-140	1.5E+14	2.51E+13	2.51E+13	2.51E+13	2.51E+13	2.51E+13	2.51E+13
Te-132	4.61E+14	7.68E+13	7.68E+13	7.68E+13	7.68E+13	7.68E+13	7.68E+13
I-131	3.49E+14	5.82E+13	5.82E+13	5.82E+13	5.82E+13	5.82E+13	5.82E+13
Ru-103	2.43E+14	4.05E+13	4.05E+13	4.05E+13	4.05E+13	4.05E+13	4.05E+13
I-135	8.77E+13	1.46E+13	1.46E+13	1.46E+13	1.46E+13	1.46E+13	1.46E+13
Zr-97	6.8E+13	1.13E+13	1.13E+13	1.13E+13	1.13E+13	1.13E+13	1.13E+13
Zr-95	7.2E+13	1.2E+13	1.2E+13	1.2E+13	1.2E+13	1.2E+13	1.2E+13
Nb-97	6.94E+13	1.16E+13	1.16E+13	1.16E+13	1.16E+13	1.16E+13	1.16E+13
Nb-97m	6.44E+13	1.07E+13	1.07E+13	1.07E+13	1.07E+13	1.07E+13	1.07E+13

Table 2. Isotopes, total releases and release rates for Scenario 1.

Isotope	Location 1 Bq/m^3	Location 2 Bq/m^3	Location 3 Bq/m^3
I-133	5.28	0.40	0
I-132	0.08	0.000325	0.000239
La-140	3.09	0.54	0.38
Te-132	9.76	1.76	1.69
I-131	3.05	0.49	0.40
Ru-103	5.79	1.20	1.49
I-135	0.19	0.01	0
Zr-97	0.99	0.10	0.10
Zr-95	1.77	0.33	0.36
Nb-97	0.00077	0.000000159	0.00000028120

Table 3. Average concentrations over the sampling periods for the three measurement locations of Scenario 1.

3. Scenario 2

Scenario 2 was based on a large scale, acute release from the Sizewell B power plant in the United Kingdom at 1.61861 E 52.21389 N (see Figure 5). The release was simulated as having commenced on the 20th of March at 00:00 and was considered as having occurred at a height of 30 m and lasted for a period of 1 hour. The three measurement points for Scenario 2 were as detailed in Table 5. The list of nuclides and the released amounts are detailed in Table 6. Details as to the variation of dose rates at each measurement station of Scenario 2 are detailed in Appendix 1.

Figure 5. Release point and monitoring stations for Scenario 2.

		Sampling period		Sampling volume per hour	Sampled hours	Total sampled volume m^3	Total Seconds
		Time/Date Start	**Time/date Stop**				
Location 1	08 ° 24’46" E 55 ° 22’26" N	20.03.2017 19:00	20.03.2017 21:00	600	2	1200	7200
Location 2	12 ° 59’38" E 55 ° 48’25" N	21.03.2017 00:00	21.03.2017 06:00	1000	6	6000	21600
Location 3	21 ° 07’38" E 55 ° 42’06" N	21.03.2017 08:00	21.03.2017 11:00	500	3	1500	10800

Table 5. Measurement location details for Scenario 2.

Isotope	Total Inventory Bq	Total release Bq
I-134	7.4996E+18	4.4998E+18
I-132	4.8597E+18	2.9158E+18
I-135	6.4491E+18	3.8695E+18
I-133	6.9241E+18	4.1545E+18
I-131	3.3159E+18	1.9895E+18
Te-132	4.7866E+18	1.9146E+18
La-140	6.2299E+18	2.4920E+17
Zr-97	5.8280E+18	2.3312E+17
Te-131m	4.8414E+17	1.9366E+17
Zr-95	5.8645E+18	2.3458E+17

Table 6. Isotopes, total inventory and total release for Scenario 2.

4. Scenario 3

Scenario 3 was a large scale. prolonged release from the Grafrheinfeld facility in Germany at 10.185 E. 49.984 N. The simulated release commenced on the 22nd of March at 08:00 and was considered as having occurred at a height of 30 m and to have progressed over a period of 12 hours. The release point and measurement stations for Scenario 3 are depicted in Figure 6. The source term used as the basis for the EPHSOGAM source term in this scenario was that as detailed in NKS-353[5]

Figure 6. Release point and measurement stations for Scenario 3.

For the purposes of EPHSOGAM, participants were notified in advance of the location of the release point for this scenario. The aim in providing this information was to facilitate participants checking that their systems were functioning correctly and to allow adjustment of a range of parameters relevant to the other scenarios. The isotopes and temporal development of the release are as provided in Table 7. Details of the measurement stations for Scenario 3 are as detailed in Table 8. Details as to the variation of dose rates at each measurement station of Scenario 3 are detailed in Appendix 1.

[5] M. Dowdall, J. E. Dyve, S. Cordt Hoe, et al. Nordic Nuclear Accident Consequence Analysis (NORCON): Final Report, NKS-353 ISBN 978-87-7893-437-6, Available at: http://www.nks.org/scripts/getdocument.php?file=111010213303775

Isotope	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12	Total Bq
I -132	5.17E+16	2.87E+16	2.79E+16	8.38E+15	1.57E+16	1.65E+16	5.03E+16	9.66E+16	6.15E+16	3.49E+15	4.39E+15	6.95E+15	3.72E+17
I-133	4.53E+16	2.38E+16	2.22E+16	6.45E+15	1.18E+16	1.20E+16	3.55E+16	6.60E+16	4.07E+16	2.21E+15	2.71E+15	4.15E+15	2.73E+17
I -131	3.94E+16	2.21E+16	2.16E+16	6.62E+15	1.26E+16	1.34E+16	4.19E+16	8.21E+16	5.31E+16	3.08E+15	3.92E+15	6.31E+15	3.06E+17
I-135	1.22E+16	5.02E+15	3.61E+15	1.05E+15	1.91E+15	1.94E+15	5.71E+15	1.06E+16	6.49E+15	3.51E+14	4.29E+14	6.53E+14	5.00E+16
Te-132	4.38E+16	1.87E+16	2.31E+16	9.42E+15	1.12E+16	1.63E+15	2.99E+15	3.76E+15	3.94E+15	2.42E+15	1.89E+15	4.43E+15	1.27E+17
Cs-134	3.85E+15	2.30E+15	2.16E+15	8.09E+14	1.31E+15	1.42E+15	4.08E+15	8.49E+15	7.37E+15	3.76E+14	4.46E+14	7.43E+14	3.34E+16
Cs-137	3.30E+15	1.97E+15	1.85E+15	6.94E+14	1.13E+15	1.21E+15	3.50E+15	7.28E+15	6.32E+15	3.23E+14	3.82E+14	6.37E+14	2.86E+16
Ba-140	4.69E+14	6.41E+14	1.58E+16	1.76E+15	3.19E+15	2.20E+15	6.74E+14	4.81E+13	9.59E+05	5.87E+12	2.80E+05	2.95E+05	2.48E+16
I-134	3.89E+14	9.09E+13	1.14E+09	3.31E+08	6.04E+08	6.13E+08	1.80E+09	3.34E+09	2.05E+09	1.11E+08	1.35E+08	2.06E+08	4.79E+14
Zr-95	3.53E+09	2.17E+10	1.35E+15	3.86E+12	3.76E+05	1.93E+05	6.39E+11	4.71E+04	3.74E+04	1.33E+04	1.14E+04	6.32E+11	1.36E+15
Sb-127	1.20E+11	1.10E+09	1.51E+14	6.83E+13	1.67E+13	1.36E+13	1.95E+13	1.68E+13	1.29E+13	4.75E+12	3.81E+12	8.74E+12	3.16E+14
La-140	0.00E+00	0.00E+00	4.40E+13	8.58E+11	2.66E+10	1.19E+04	7.83E+10	3.23E+10	3.45E+03	1.27E+10	2.53E+10	1.61E+10	4.51E+13
Ce-144	2.26E+09	1.39E+10	8.68E+14	2.48E+12	2.42E+05	1.24E+05	4.11E+11	3.04E+04	2.42E+04	8.60E+03	7.37E+03	4.09E+11	8.71E+14
Ru-103	2.56E+10	5.49E+10	2.27E+09	5.53E+07	3.13E+01	1.03E+01	4.36E+00	5.43E+07	5.41E+07	7.00E-01	5.37E+07	6.07E-01	8.30E+10

Table 7. Isotopes, release per hour and total release for Scenario 3.

		Sampling period		Sampled hours	Sampling volume per hour	Total sampled volume m³	Total Seconds
		Time/Date Start	Time/date Stop				
Location 1	08°41’16"E 50°11’44"N	22.03.2017 1200	22.03.2017 18:00	6.00	100.00	600	21600.00
Location 2	05°59’29"E 51°08’05"N	22.03.2017 22:00	23.03.2017 09:00	11.00	150.00	1650	39600.00
Location 3	03°18’30"E 51°69’31"N	23.03.2017 09:00	23.03.2017 17:00	8.00	200.00	1600	28800.00

Table 8. Measurement location details for Scenario 3.

5. Scenario 4

Scenario 4 was a reality based scenario and differed from the others in being a relatively small release with a low number of isotopes. During the period from the 4th of October 2016 to the 10th of the same month, traces of three isotopes were detected on air filters over Germany. The isotopes observed were Mn-54 at levels of approximately 0.156 µBq/m³, Co-58 at levels of approximately 0.024 µBq/m³ and Co-60 at levels of approximately 0.081 µBq/m³. Analysis at the time indicated a possible source in the area of Ukraine. This observation was used to form the basis of Scenario 4 with a release of these three nuclides being simulated from the Rivne power plant (25.88305 E 51.3330 N) on the 21st of March 2017 at 06:00 (Figure 7). Release details are provided in Table 9, details of the locations and sampling periods of the measurement locations for Scenario 4 being provided in Table 10.

Isotope	Total release Bq
Mn-54	1.0E+12
Co-58	1.54E+11
Co-60	5.19E+11

Table 9. Isotope and releases for Scenario 4. .

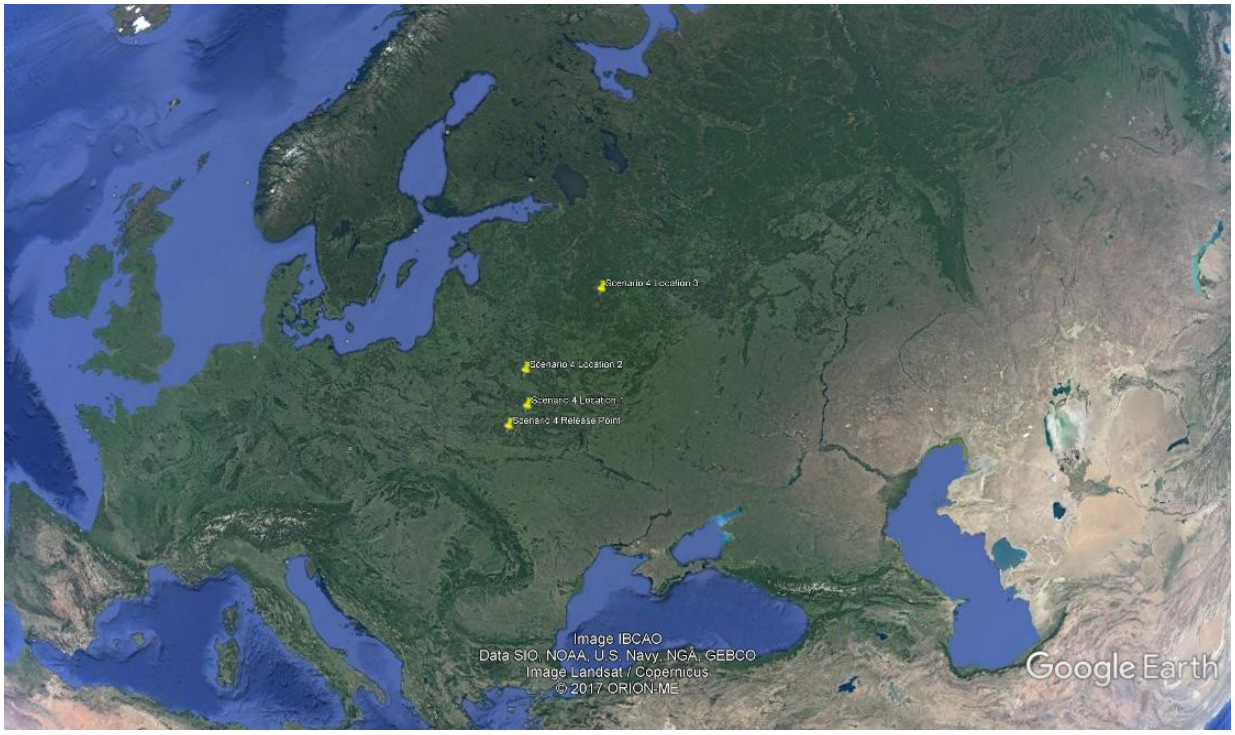


Figure 7. Release point and measurement stations for Scenario 4.

		Sampling period		Sampled hours	Sampling volume per hour	Total sampled volume m^3	Total Seconds
		Time/Date Start	**Time/date Stop**				
Location 1	27°07’10"E 52°05’24"N	21.03.2017 11:00	21.03.2017 14:00	3.00	800.00	2400	10800.00
Location 2	29°50’37"E 53°28’22"N	21.03.2017 14:00	22.03.2017 19:00	19.00	500.00	9500	68400.00
Location 3	32°41’42"E 56°19’52"N	22.03.2017 06:00	22.03.2017 15:00	9.00	600.00	5400	32400.00

Table 10. Measurement location details for Scenario 4.

6. Identification and Quantification of Isotopes

Scenario 1

The isotope asemmblage of Scenario 1 presented a fairly standard gamma spectrum (see Figure 8) for all three measurement stations and no severe difficulties should have been encountered in either identifying or quantifying the isotopes present. Results for the three measurement locations as reported by participants are tabulated in Tables 11,12 and 13.

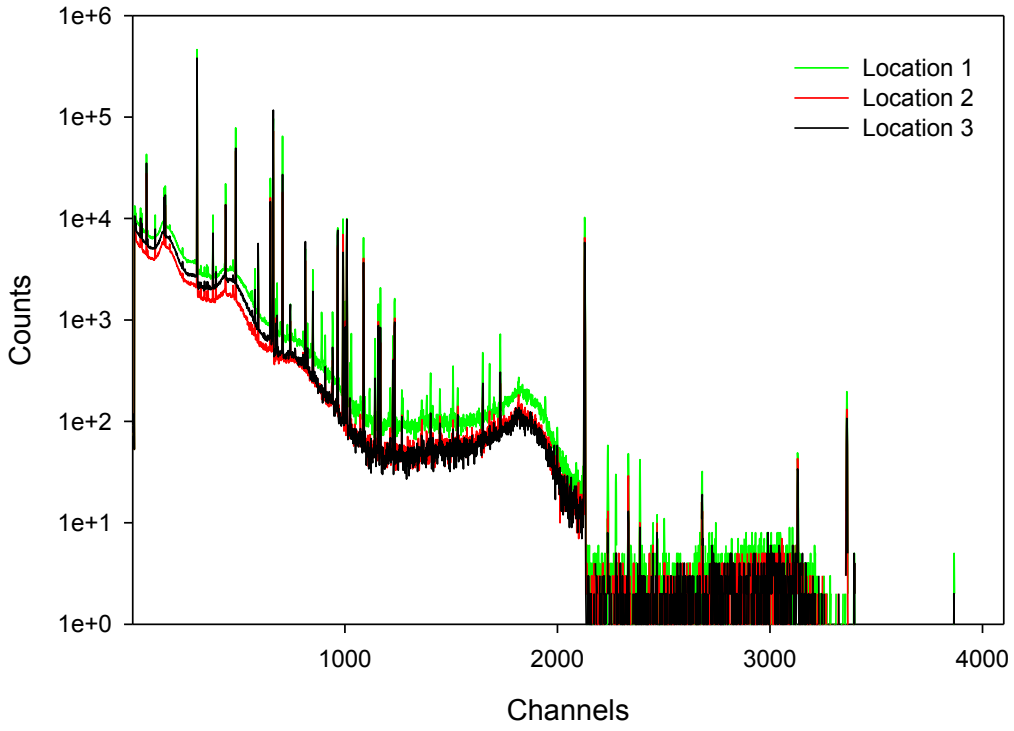


Figure 8. Spectra of the three locations for Scenario1.

Participants reported a variety of analysis packages ranging from standard commercial suites to inhouse developed software. It was observed by a number of participants that a number of expected isotopes (such as Cs-137) were not present but it was not reported by any participant that this absence – a practical consideration in development of the materials – influenced their decisions with respect to identfying the potential source of the simulated release. A number of false positives were reported by participants, including but not limited to, Ce-145, Xe-133, Y-91m and Zr-89. Activity estimates were in the main reasonable – the majority of participants were close to the actual values for

all isotopes at each location and the magnitude of the errors in the estimates relative to the true values would have been unlikely to result in significant problems at later stages of the activity (such as identifying the source of the release). Participant B appeared to have consistently larger than average errors in the estimates and also reported a significantly larger number of false positives indicating a possible problem with the analysis routine employed.

		A		B	C	D	E	F	G
Isotope	**Actual Bq/m³**	**Manual Bq/m³**	**Auto. Bq/m³**	**Bq/m³**	**Bq/m³**	**Bq/m³**	**Bq/m³**	**Bq/m³**	**Bq/m³**
I-133	5.28	5.23	9.48	18.13	5.4	1.05	4.40	5.21	5.40
I-132	0.08	0.074	0.072	0.17	0.077	0.01	-	0.73	0.0665
La-140	3.09	3.04	4.09	5.65	3.0	0.445	3.03	3.08	3.10
Te-132	9.76	9.97	-	5.14	9.5	1.2	8.49	10.1	4.37
I-131	3.05	2.95	3.08	7.71	2.9	0.332	3.01	2.99	3.207
Ru-103	5.79	5.66	5.51	18.95	5.76	0.822	5.94	5.82	5.902
I-135	0.19	0.16	0.89	0.26	0.195	0.096	-	0.207	0.183
Zr-97	0.99	0.98	2.05	2.3	0.97	0.214	0.792	0.985	0.934
Zr-95	1.77	1.71	1.74	4.16	1.8	0.185	1.78	1.79	1.805
Nb-97	7.7E-03	-	-	-	-	-	-	-	-

Table 11. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 1 Location 1.

Isotope	Actual Bq/m³	A Manual Bq/m³	A Auto. Bq/m³	B Bq/m³	C Bq/m³	D Bq/m³	E Bq/m³	F Bq/m³	G Bq/m³
I-133	0.40	0.39	0.50	1.43	0.41	0.518	0.415	0.394	0.417
I-132	3.2E-03	-	-	-	-	-	-	-	-
La-140	0.54	0.53	0.60	1.0	0.53	0.602	0.536	0.533	0.5445
Te-132	1.76	1.79	-	0.98	1.8	1.906	1.59	1.81	0.869
I-131	0.49	0.48	0.49	1.4	0.47	0.504	0.495	0.488	0.519
Ru-103	1.20	1.18	1.20	4.01	1.2	1.593	1.27	1.21	1.228
I-135	0.01	0.005	0.014	-	0.01	0.015	-	-	-
Zr-97	0.1	0.19	0.25	0.46	0.19	0.258	0.202	0.19	0.185
Zr-95	0.33	0.33	0.35	0.79	0.35	0.349	0.36	0.34	0.342

Table 12. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 1 Location 2.

Isotope	Actual Bq/m³	A Manual Bq/m³	A Auto. Bq/m³	B Bq/m³	C Bq/m³	D Bq/m³	E Bq/m³	F Bq/m³	G Bq/m³
I-133	0.46	0.39	0.33	1.62	0.48	0.867	0.475	0.455	0.476
I-132	0.00034	-	-	-	-	-	-		-
La-140	0.38	0.41	0.0009	0.7	0.37	0.533	0.375	0.373	0.3798
Te-132	1.69	1.72	-	0.92	1.74	2.052	1.55	1.75	0.793
I-131	0.40	0.39	0.33	1.18	0.39	0.431	0.405	0.396	0.4213
Ru-103	1.49	1.47	1.50	4.94	1.55	2.077	1.56	1.51	1.530
I-135	0.0044	0.003	0.016	-	-	-	-	-	-
Zr-97	0.1	0.097	0.2	0.23	0.1	0.207	0.102	0.0973	0.0916
Zr-95	0.36	0.35	0.35	0.84	0.37	0.375	0.365	0.36	0.366

Table 13. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 1 Location 3.

Scenario 2

Scenario 2 (see Figure 9) differed from that of Scenario 1 in that the spectra were representative of much higher concentrations of isotopes although the assemblage was similar to that of the former scenario.

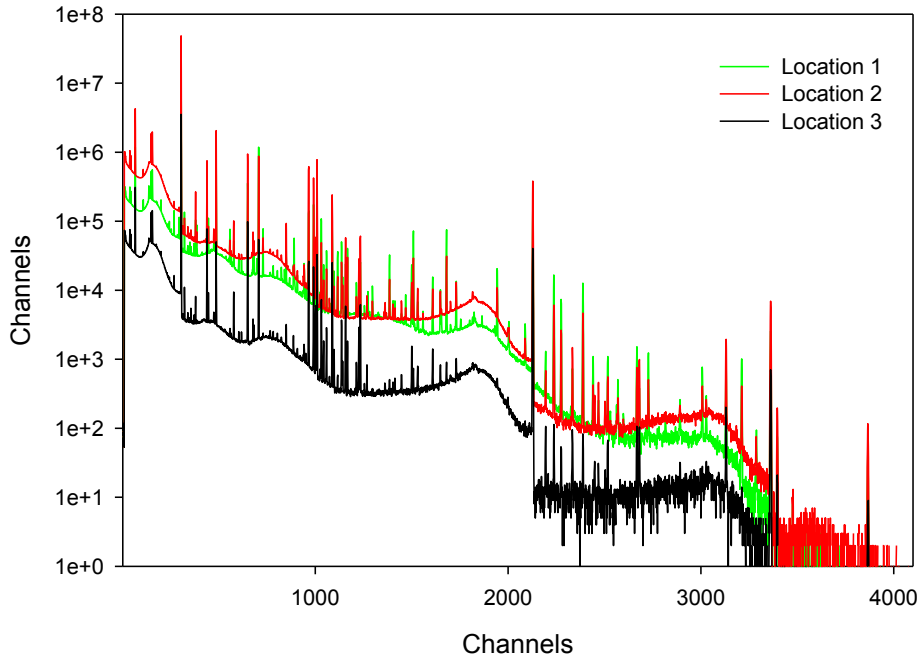


Figure 9. Spectra of the three locations for Scenario2.

The differences between spectra with respect to counts for the three stations were more obvious than for Scenario 1. Participant results are tabulated in Tables 14, 15 and 16.

Isotope	Actual Bq/m³	A Bq/m³	B Bq/m³	C Bq/m³	D Bq/m³	E Bq/m³	F Bq/m³	G Bq/m³
I-131	368.9	363	1644	370	380.9	379	366	378.7
I-132	56.1	56.3	415	62.6	57.34	-	56.4	58.69
I-133	1311.1	1300	4942	1422.5	1527	1330	1290	1397
I-134	0.968	-	32	-	-	0.786	-	-
I-135	749.4	752	2166	790.4	791	758	776	774
La-140	585.6	572	1303	587	558.3	578	579	593
Te-131m	274	371		340	380.7	264	369	396
Te-132	3797.2	3870	1610	3733	3948	3390	3930	260.4
Zr-95	420.8	410	978	427	433.2	416	424	422.7
Zr-97	235.5	235	636	241	279.4	242	232	345.8

Table 14. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 2 Location 1.

Isotope	Actual	A	B	C	D	E	F	G
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
I-131	220.7	215	373	213.2	230.5	222	219	234.1
I-132	1.9	1.6	54	2.1	2.03	-	1.92	2.22
I-133	189.3	187	828	201.8	234.6	194	187	195.3
I-135	54.4	54.8	397	58.1	83.13	57.9	54.8	57.38
La-140	316.9	310	571	313.1	292.3	317	314	319.4
Te-131m	25.9	35.0	-	35.1	38.35	27.7	35	36.3
Te-132	2805.6	2860	4606	2955	2978	2830	2910	3435.5
Zr-95	380.6	368	881	383.6	389	384	382	380.4
Zr-97	117	115	373	113.6	141.8	118	110	127.8

Table 15. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 2 Location 2.

Isotope	Actual	A	B	C	D	E	F	G
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
I-131	20.3	20.0	88	19.9	20.74	20.9	20.1	21.45
I-132	0.03	-	348	-	-	-	-	-
I-133	47.2	46.4	181	48.7	51.08	47.5	46.2	47.4
I-135	3.6	-	9.0	3.6	4.677	3.62	3.48	3.45
La-140	133.3	1.3	241	131.2	138.34	133.0	132.0	134.8
Te-131m	16.3	22.1	-	21.3	22.48	16.8	22.2	22.56
Te-132	815.3	827	-	801	845.9	728	844.0	120.3
Zr-95	64.0	14.8	147	64.1	64.62	64.0	64.1	63.5
Zr-97	23.6	23.6	65	23.8	26.64	24.2	23.3	24.9

Table 16. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 2 Location 3.

Participants reported no significant problems in correct identification and quantification of the isotopes represented in the spectra. As for Scenario 1, Participant B had some difficulties with overestimation of the isotopes activities for all three stations.

Scenario 3

Scenario 3 represented a situation where air concentrations of the isotopes differed by an order of magnitude between the three stations (Figure 10). Qualitatively the spectra exhibited little difference from those of Scenario 2 with respect to complexity. Quantitative results are provided in Table 17, 18 and 19. Participant B consisitently overestimated air concentrations for all three stations and Participant E underestimated concentrations for Station 1. Participant G reported abberant values for I-132 and Ba-140 (Station 1), Te-132 (Stations 2 and 3) . Otherwise, quantitative results were in relatively good agreement with actual values.

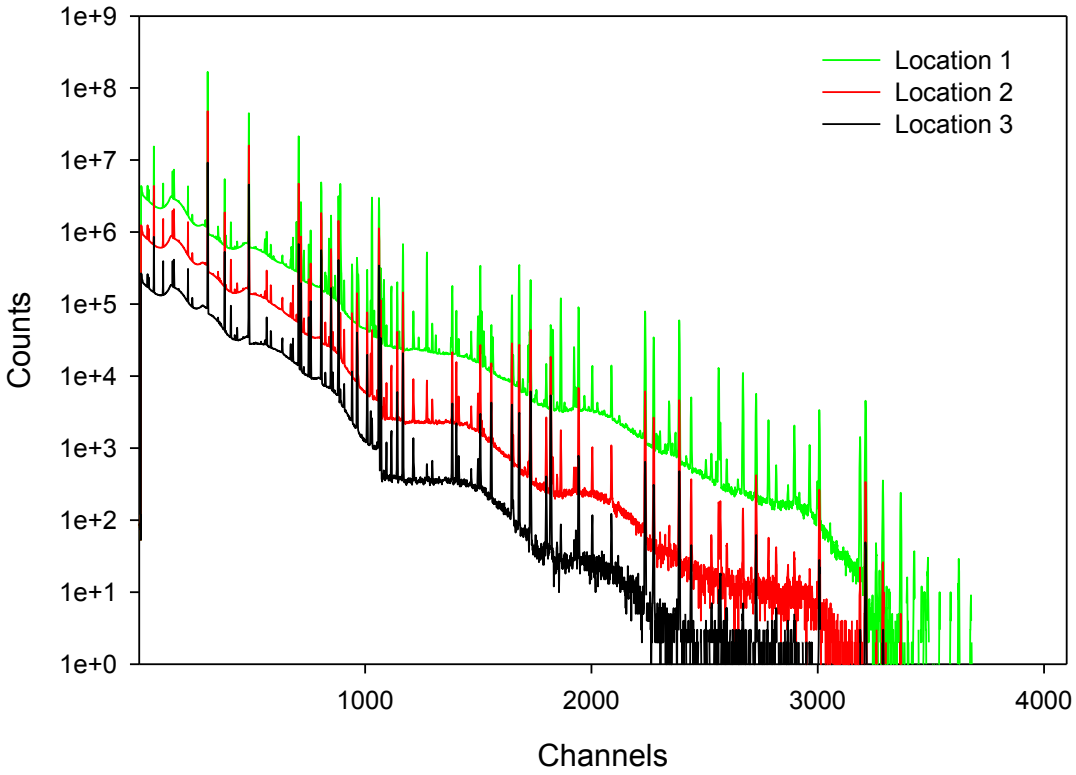


Figure 10. Spectra of the three locations for Scenario 3.

Isotope	Actual	A	B	C	D	E	F	G
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
I-131	48611	47300	177631	48423	50730	1910	49400	51161
I-132	10870	10900	467280	19226	13130	1.93	11500	19083
I-133	47546	47100	219447	53337	60910	569	46800	52956
I-134	3.11	-	-	-		-	-	
I-135	7069	7070	27792	9189	10090	23.2	7140	8879
Ba-140	17486	17100	24511	17128	18100	495	17600	5800
Cs-134	9968	9730	22459	10414	10130	435	9940	10141
Cs-137	8130	8080	22427	8078	8242	403	8400	8110
Te-132	96806	98800	153052	100607	104100	1730	1E+05	127619
Zr-95	1262	1220	226	1242	454.1	-	1430	1225.2

Table 17. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 3 Location 1.

Isotope	Actual	A	B	C	D	E	F	G
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
I-131	6295	6120	17084	6200	10860	6230	6240	6578
I-132	51	48.8	6846	61	54.94	63.4	48.8	52.71
I-133	3801	3760	19619	3929	4908	3910	3750	3929
I-134	0.00003	-	-	-	-	-	-	-
I-135	200	202	1063	221.9	345.6	216	202	214.8
Ba-140	2182	2160	5311	2099	2247	2100	2160	1456
Cs-134	1387	1360	2951	1403	1431	1390	1380	1403
Cs-137	1364	1360	3770	1356	1388	1370	1360	1363
Te-132	10003	10200	7095	10015	10860	9500	10400	5038
Zr-95	127	124	269	124.8	126.7	125	149	123.3

Table 19. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 3 Location 2.

Isotope	Actual	A	B	C	D	E	F	G
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
I-131	1871	1810	2322	1843	1931	1910	1850	1966
I-132	2.13	1.5	8	2.3	2.216	1.93	2.1	2.29
I-133	564	558	1981	576	676.7	569	555	568.6
I-134	23.0	-	-	-	--	-	-	-
I-135	23.0	22.6	35	23.9	36.57	23.2	-	23.3
Ba-140	504	499	1547	480	521.4	495	499	415.4
Cs-134	436	427	1013	437	444.7	435	436	437.2
Cs-137	402	402	1116	401.6	409.3	403	403	403.5
Te-132	1987	2030	1281	1961	2121	1730	2060	1008
Zr-95	35	33.5	-	33.8	33.15	-	43.9	33.14

Table 20. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 3 Location 3.

Scenario 4

From a qualitative and quantitative perspective, Scenario 4 should have presented the easiest task for participants as the spectra were relatively simple with a limited numberof clearly defined peaks (See Figure 11) although there was a significant difference with respect the strength of the signals between the three.

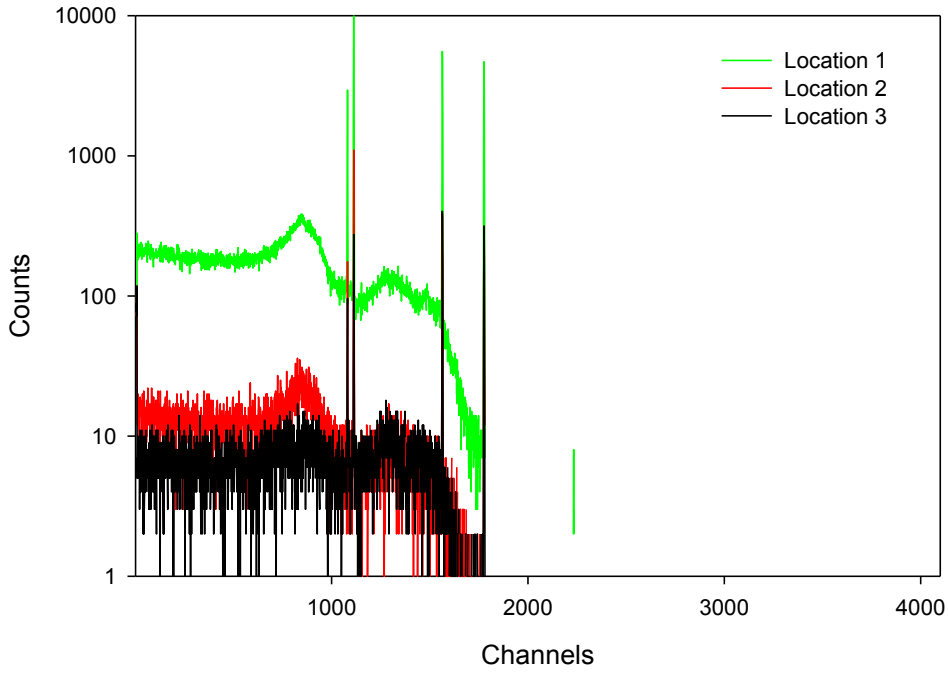


Figure 11. Spectra of the three locations for Scenario 4.

Quantitatively (see Tables 21, 22 and 23), the majority of reported results were in good agreement with the simulated values, any deviations being of little consequence from an emergency preparedness or reponse perspective. Unlike for the previous scenarios, there was no evidence displayed of any consistent pattern of over or underestimation for any of the participants with the exception of Participant B.

Isotope	Actual Bq/m^3	A Bq/m^3	B Bq/m^3	C Bq/m^3	D Bq/m^3	E Bq/m^3	F Bq/m^3	G Bq/m^3
Mn-54	0.642	0.63	1.2	0.647	0.64	0.639	0.65	0.637
Co-58	0.107	0.1	0.210	0.107	0.11	0.106	0.11	0.105
Co-60	0.362	0.36	0.45	0.36	0.36	0.358	0.36	0.3588

Table 21. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 4 Location 1.

Isotope	Actual Bq/m^3	A Bq/m^3	B Bq/m^3	C Bq/m^3	D Bq/m^3	E Bq/m^3	F Bq/m^3	G Bq/m^3
Mn-54	0.0107	0.01	0.020	0.0105	0.0105	0.0104	0.01	0.0104
Co-58	0.0016	0.0016	0.003	0.00156	0.0016	0.00161	0.0016	0.00153
Co-60	0.0062	0.0064	0.008	0.00628	0.00627	0.00617	0.0063	0.00625

Table 22. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 4 Location 2.

Isotope	Actual Bq/m^3	A Bq/m^3	B Bq/m^3	C Bq/m^3	D Bq/m^3	E Bq/m^3	F Bq/m^3	G Bq/m^3
Mn-54	0.0046	0.0044	0.009	0.00465	0.00445	0.00461	0.0046	0.00456
Co-58	0.0055	0.0015	0.003	0.00135	0.00149	0.00145	0.0014	0.00139
Co-60	0.00143	0.011	0.014	0.0112	0.01122	0.0111	0.011	0.0119

Table 23. Participant responses (A through G) for qualitative and quantitative analysis of the spectra for Scenario 4 Location 3.

7. Identification of Release Point, Time and Duration

A significant part of the EPHSOGAM exercise was with respect to the participants capacities to identify or estimate the point of release based on the information to hand. It should be noted that the EPHSOGAM activity featured aspects that were perhaps overly simplistic and other aspects that were perhaps overly complex. Examples of the former include the fact that facets of the problem of source identification that would be present in the real world were not represented in the EPHSOGAM materials. With respect to the latter, the EPHSOGAM materials were limited – sources of information that could be used in a real life situation were not present. In an actual event, the amount of data that could be used in estimating the release point would be significantly larger than was present in EPHSOGAM. Such data would include wider networks of detectors that would be present both within any one country and the pooling of data from the measurement networks of a number of countries.

Participant A conducted dispersion calculations using an in-house developed dispersion model with inverse modelling capability, the inverse models being run for all the 3 stations for each scenario. Once the location was estimated, the model was again run in forward mode to check the location. Participant B employed an in-house developed dispersion and trajectory model running in inverse mode for each of the 3 stations for each scenario. Participant C provided no information as to how estimates of location were made. Participant D employed the back trajectory capabilities of the HYSPLIT model with forward dispersion trajectories being determined using RODOS. Participant E emploted RIMPUFF and JRODOS for estimating release location. Participant F employed an inhouse developed model for trajectory determination and Participant G employed RIMPUFF/ARGOS and an inhouse model.

Scenario 1.

Scenario 1 presented some difficulties for participants in that the release was associated with a submarine and not a nuclear facility at a fixed location. For the period in question (March 2017), the meteorological situation in that region was relatively complex which would also have presented problems for some participants. All participants were able to identify the general location of the release as being in the western Meditteranean and then attempted to determine which facilities were present in the general area. Concrete candidates suggested included the Cofrentes nuclear power plant, CEA facilities at

Cadarache, naval ports at Toulon and Cartagena, the Vandellos and Asco nuclear power plants and French and Swiss power plants. Participant F, in refusing to specifiy a particular facility and instead maintaining that the release came from "release location along the East to South coast of Spain, Western part of the Mediterranean Sea" was perhaps closest to arriving at the correct assignation. No participant however provided evidence of having considered a vessel at sea, although assignation of naval ports as possible locations was, it is assumed, indicative of an awareness of the potential for a release from a vessel. Examples of information supporting participant efforts in locating the release point are provided in Figure 12.

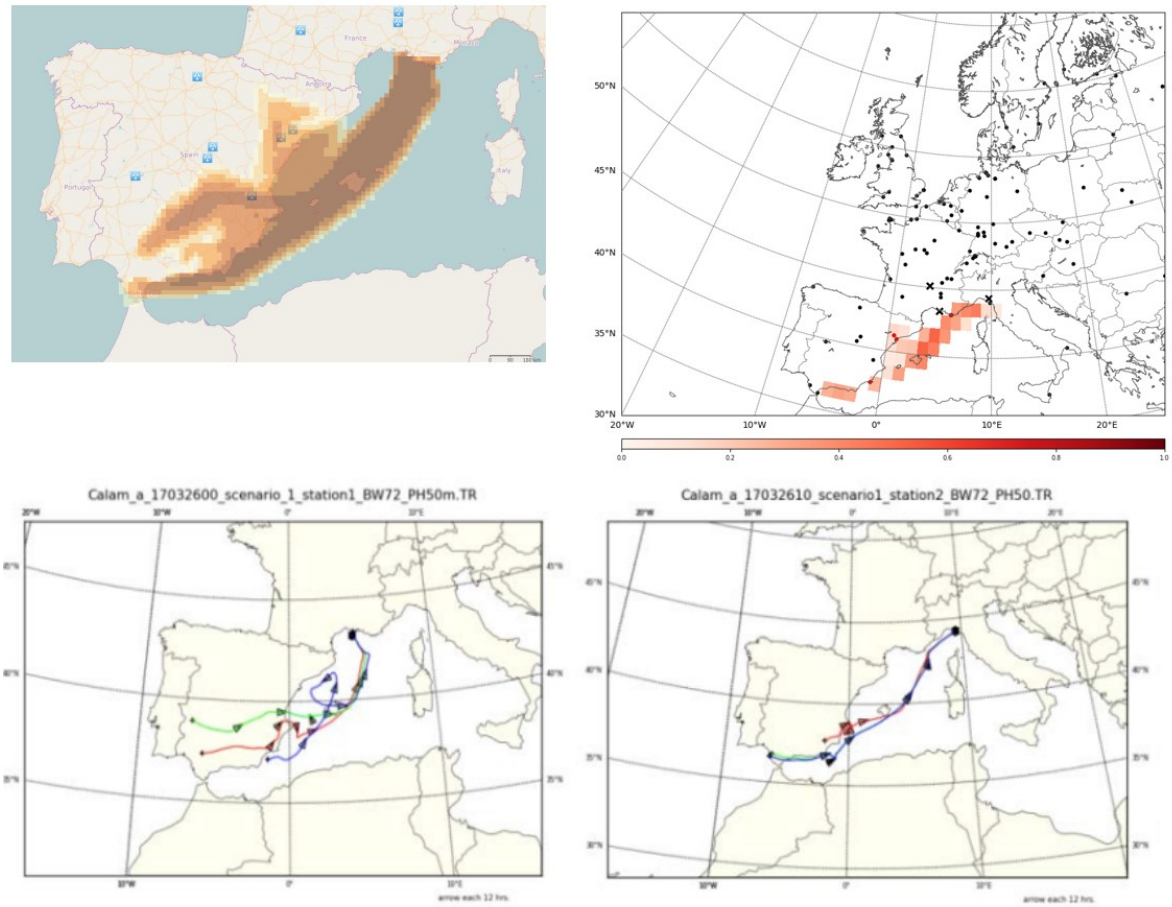


Figure 12. Examples of reports receieved from participants for assessing the location of the release of Scenario 1.

Of equal importance in assigning a source to a particular release is an estimate of the time at which the release occurred. A number of participants were in a position to closely estimate the actual release period while other participants were obviously hampered in making this estimate by having chosen a probable release location some distance away from the release point which reduced the accuracy of the estimate. Some

participants were not able to produce any estimate. An overview of participants suggestions as to the time and duration of the release is provided in Table 24.

Simulated Date and Time	6 hours starting at 09:00 on the 25th of March 2017
A	30 hours starting at 00:00 on the 25th of March 2017
B	Unknown duration starting at 06:00 25th of March 2017
C	No estimate provided
D*	> 48 hour release starting at 04:00 on the 25th of March 2017
E	For Asco NPP: unknown duration starting at 01:00 on the 24th of March 2017 For Triscatin NPP: unknown duration starting at 02:00 on the 20th of March 2017
F	between 22:00 on the 22nd of March and 22:00 on the 23rd of March 2017
G	No estimate provided

Table 24. Participant estimates of date and time of the Scenario 1 release. Participant D provided a numberof candidate locations so the one closest to the actual was chosen for inclusion in this table.*

Scenario 2

Scenario 2 differed substantially from Scenario 1 in that the release point and the three monitoring stations were connected by a relatively simple meteorology on the day of the simulated releases. The release point was a land based facility of considerable size. Participants A, C, D (listed as possible site from 4) and E (listed as possible site from 5) either identified the facility (Sizewell NPP in the United Kingdom) or included it in a short list of nearby candidate sites (Bradwell, Hartlepool, etc). An overview of participants suggestions as to the time and duration of the release is provided in Table 25. Wrongly suggested sites included sites in the Netherlands (along the route of the simulated dispersion), France and the wrong parts of the United Kingdom. Examples of information supporting participant efforts in locating the release point are provided in Figure 13.

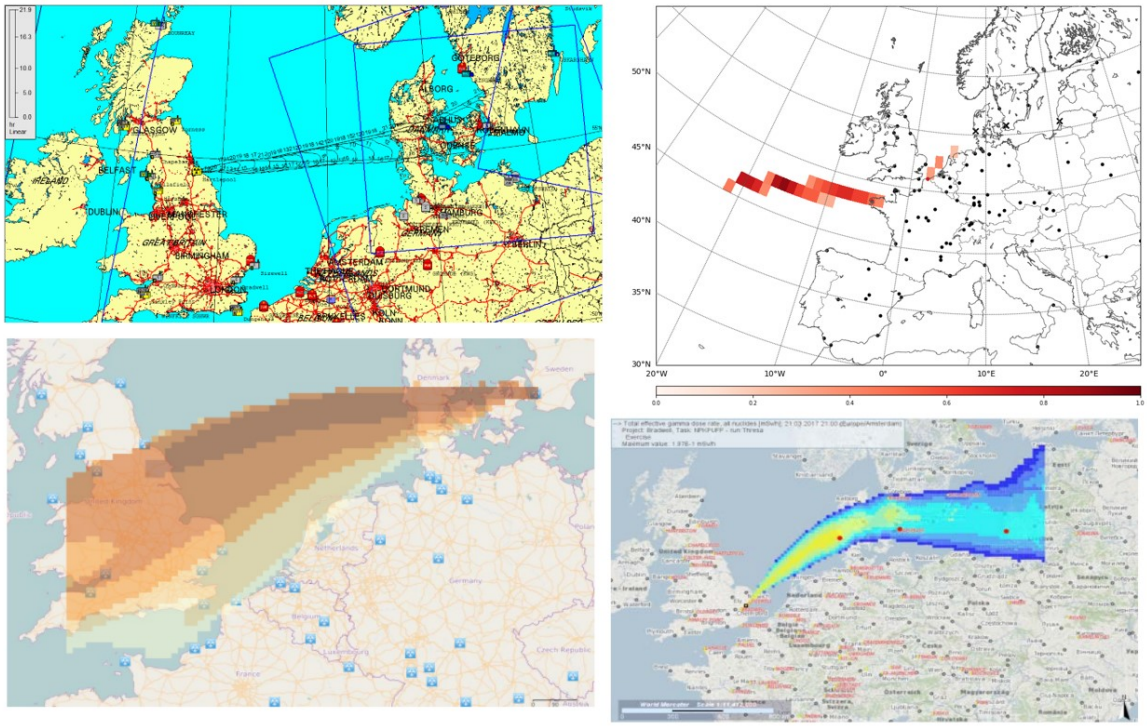


Figure 13. Examples of reports receieved from participants for assessing the location of the release of Scenario 2.

Simulated Date and Time	1 hour starting at 09:00 on the 20th of March 2017
A	36 hour release starting at 20:00 on the 19th of March 2017
B	Wylfa NPP : 03:00 – 06:00 on 20th of March 2017, Hartlepool NPP : 09:00 – 12:00 on 20th of March 2017, Torness NPP: 09:00 -13:00 on 20th of March 2017
C	6 hour release starting at 06.00 on the 20th of March 2017
D	Gravelines NPP: From 22:00 on 19th to 12:00 on the 20th of March 2017, Sizewell NPP: From 05:00 to 07:00 on the 20th of March 2017 La Hague: 04:00 on the 21st of March 2017
E	4 hour release starting at 02:00 on the 20th of March 2017
F	Bradwell: starting 07:00 on the 20th of March 2017
G	18 hour release starting at 14:00 on the 20th of March 2017

Table 25. Participant estimates of date and time of the Scenario 2 release.

Scenario 3

Scenario 3 was the one scenario in which the participants were provided with the location of the simulated release – the Grafenrheinfeld nuclear facility in Germany. The point of providing this information to the participants was that they could check the performance of their analysis routines and systems as part of the activity. All participants therefore reported Grafenrheinfeld as the source.

In estimating the time and duration of the release, the majority of participants recognized that the release was longer than the other scenarios and Participant A was in a position to hint at the complexity of the release in assigning two possible periods. The majority of participants were quite accurate with respect to determining the actual time of the release (see Table 26).

Simulated Date and Time	12 hour release starting at 08:00 on the 22nd of March 2017
A	5 hour release starting at 08:00 on the 22nd of March 2017 with a second release period from 9 to 15 hours after the start.
B	unestimated release duration but starting at 09:00 on the 22nd of March 2017
C	No estimate
D	5 hour release starting at 10:00 on the 21st of March 2017
E	releases between 07:00 and 15:00 on 22nd of March 2017
F	> 10 hour release starting at 05:00 on the 22nd of March 2017
G	4 hour release starting at 08:00 on the 22nd of March 2017

Table 26. Participant estimates of date and time of the Scenario 3 release.

Scenario 4

The simulated release of Scenario 4 was a short (1 hour) release having occurred on the 23rd of March 2017 at 06:00 on the grounds of the Rivne power plant in Ukraine (51.333 N 25.8831 E). Estimates of the location were obviously influenced by the isotope assemblage – the possibility being present that the source could have been an industrial Co-60 source with impurities or sa source from some other non-nuclear application. A Polish foundry and industrial facilities near Rivne were suggested by some participants, the others selecting Rivne itself as the most probably location for the

release. Examples of information supporting participant efforts in locating the release point are provided in Figure 13.

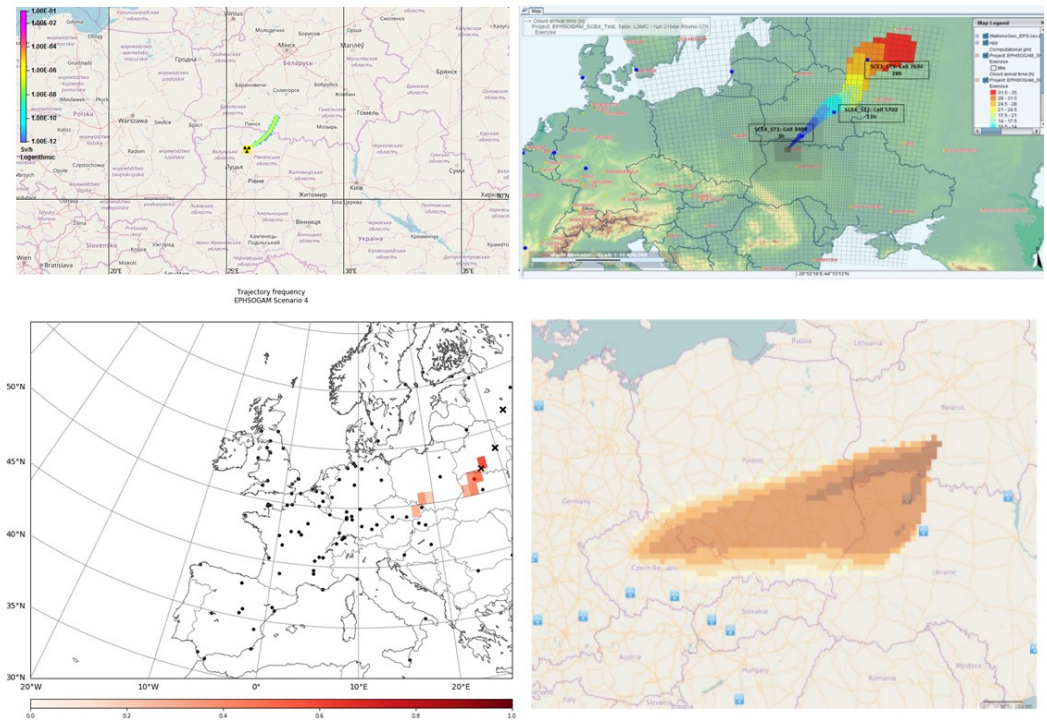


Figure 14. Examples of reports receieved from participants for assessing the location of the release of Scenario 4.

Estimation of the time and duration of the release were somewhat accurate – most participants could correctlu estimate that the release occurred early on the morning of the 21st of March but only a few were willing to estimate how long the release lasted for. Of these estimates one was aberrant to a significant degree (see Table 27).

Simulated Date and Time	1 hour release starting at 06:00 on the 21st of March 2017
A	Not estimated
B	"no more than a few hours before sampling" (first sampling occurred at 11:00 on the 21st of March 2017)
C	No estimate
D	20 hour release staring at 15:00 on the 20th of March 2017
E	release at 07:00 on the 21st of March 2017
F	3 hour release starting at 04:00 on the 21st of March 2017
G	release starting at 07:00 on the 21st of March 2017

Table 27. Participant estimates of date and time of the Scenario 4 release.

8. Estimation of Release Inventories

Estimation of release inventories is most probably the least exact estimate that can be produced in situations similar to those represented in EPHSOGAM. Participants were asked to attempt to estimate the amount of isotopes released and most made some attempts in this regard.

For Scenario 1, the total releases for the isotopes ranged between 1E+13 Bq and almost 1E+15 Bq. Participant A estimated of the order of 1E+17 Bq for each isotope released. Participant D had produced two estimates of release amount based on two locations near where they had estimated the release to have originated from. The estimated location nearest to the actual site was associated with estimated releases of (actual value in parentheses): I-131 7.14E+14 Bq (3.49E+14 Bq); I-133 1.65E+16 Bq (9.16 E+14 Bq); La-140 1.28E+15 Bq (1.5 E+14); Ru-103 7.89E+14 Bq (2.43E+14 Bq); Te-132 2.00E+15 Bq (4.61 E+14 Bq); Zr-95 1.74E+14Bq (7.2E+13 Bq); Zr-97 3.09E+15 Bq (6.4 E+14 Bq). These estimates can be regarded as perfectly serviceable for emergency preparedness purposes. The lack of an established release point hampered such calculations for some participants and this was noted as a reason behind not producing an estimate of released activity.

Scenario 2 involved a much larger release of activity and a release point that was potentially simpler to identify. Participant A produced a generic estimate that each isotope was released in amounts of the order of 1E+19, Participant D estimating individual activities for each isotope which were substantially below the actual simulated release. Participants G and F also underestimated the activities released but to a lesser extent than Participant D. All estimates for Scenario 2 are presented in Table 28.

Scenario 3 should, it may be argued, have been expected to produce better estimates of the released activity given that the participants knew in advance where the release had occurred, the actual time of release being an unknown. This is borne out to some extent by the estimates provided by the participants which are in most cases quite close to the actual values (see Table 29).

Isotope	Total release Bq	A	G	D	F
I-134	4.4998E+18	1E+19	-	-	-
I-132	2.9158E+18	1E+19	4,5E+16	-	-
I-135	3.8695E+18	1E+19	5,9E+17	7.E+15	-
I-133	4.1545E+18	1E+19	1,1E+18	3.E+15	-
I-131	1.9895E+18	1E+19	2.9E+17	4.E+14	4E16
Te-132	1.9146E+18	1E+19	2,0E+17	4.E+15	5E17
La-140	2.4920E+17	1E+19	4,6E+17	1.E+15	7E16
Zr-97	2.3312E+17	1E+19	2,7E+17	6.E+14	-
Te-131m	1.9366E+17	1E+19	3,0E+17	8.E+14	4e16
Zr-95	2.3458E+17	1E+19	3,2E+17	5.E+14	5E16

Table 28. Participant estimates of activity released in Scenario 2.

Isotope	Actual Bq	A	D	F	G
I -132	3.72E+17	1E+17	-	-	9.0E+16
I-133	2.73E+17	1E+17	1.17E+17	-	2.5E+17
I -131	3.06E+17	1E+17	3.15E+16	4E+16	2.4E+17
I-135	5.00E+16	1E+17	-	-	4.2E+16
Te-132	1.27E+17	1E+17	5.29E+16	-	6.0E+17
Cs-134	3.34E+16	1E+17	3.66E+15	2E+15	4.8E+16
Cs-137	2.86E+16	1E+17	2.97E+15	2E+15	3.8E+16
Ba-140	2.48E+16	1E+17	7.11E+15	7E+15	2.7E+16
I-134	4.79E+14	1E+17	-	-	-
Zr-95	1.36E+15	1E+17	1.67E+14	-	5.8E+15
La-140	4.51E+13	1E+17	-	-	-

Table 29. Participant estimates of activity released in Scenario 3

Scenario 4 had much lower activities than any of the other three, Participant A estimating a total release of the order of 1E+13 which is in good agreement with the actual amount (see Table 30).

Isotope	Total release Bq	A	D	F
Mn-54	1.0E+12	-	2.E+11	6E+11
Co-58	1.54E+11	-	3.E+10	1E+11
Co-60	5.19E+11	1E+13	9.E+10	3.6E+11

Table 30. Participant estimates of activity released in Scenario 4.

9. Discussion

The estimation of the possible location, time and duration and magnitude of a suspected release from a nuclear facility is a relatively complex matter involving the interpretation of a range of information types, each with differing levels of uncertainty, and the collation of such information to form a reliable estimate. The weight placed on any individual information source or type in making the final decision is a matter that is somewhat dependent on the analysts experience and this introduces a factor that is difficult to assess within the context of an exercise such as EPHSOGAM. There were three distinct but interrelated aspects to the exercise – correctly quantifying the isotope concentrations based on the monitoring information (the gamma spectra), tracing the source of the release using whatever meteorological or other systems the particopants had access to and producing an estimate of the time the release occurred, the duration of the release and the magnitude of the release based on the available information.

Identifying and quantifying the nuclides involved should not be a difficult task for analysts used to handling gamma spectrometric information. Nonetheless, the results provided indicated that it cannot be assumed that correct identification and quantification can be achieved in all instances. The results for EPHSOGAM in this respect are typical for other excercises that have been conducted in the past [6,7] and are

[6]Dowdall, M, 2009, Analysis of remotely accrued complex gamma ray spectra – proficiency test (REMSPEC). NKS-188, ISBN: 978-87-7893-255-6
http://www.nks.org/scripts/getdocument.php?file=111010111120128

[7] Dowdall, M., Andersson, K., Singh Sidhu, R., Pálsson, S. E., 2009, Proficiency Test in the Analysis of Gamma Spectra for Malevolent Radiological Situations (MALRAD), NKS-207, ISBN: 978-87-7893-276-1, http://www.nks.org/scripts/getdocument.php?file=111010111120177

indicative of the experience of the operators being crucial in accurately determining what isotopes are present and their activities irrespective of the software or analysis rotines employed. False positives were an evident problem for many of the participants and this can probably be explained by a number of factors. Participants noted repeatedly that the isotope assemblage present for some of the scenarios was not that which would be expected for releases from certain types of facilities. It was also possible that some analysis routines would, upon finding a number of specific isotopes, attempt to find other isotopes if the routines had been set up in a certain way (i.e upon finding 3 isotopes of iodine, the software automatically searches for other isotopes which tend to be found in the presence of radio-iodines). Some of the false positives reported were logical (xe isotopes for example) and some were not, the former being entirely reasonable and indicative of operator experience, the latter being indicative perhaps of non-experienced operators working with generic or manufacturer provided nuclear libraries. Many participants, in attempting to describe potential sources based on isotope signatures, questioned the non-presence of a number of isotopes (Cs-137 primarily for some scenarios). It had been clearly stated in the material provided to participants in advance of the exercise that not all isotopes that could be expected from any particular release situation were being included (a practical consideration in both the spectra simulation and dispersion calculations) so the lack of any particular isotope in any particular scenario should not have been a cause for uncertainty in analyzing the data. The spectra did not include aspects which would be pertinent in an actual situation such as true coincidence summation, random summing etc. so the effects of such factors on the participants abilities to correctly quantify the isotopes.

After analyzing the spectra data, the next step in the process was estimating the location of a possible release. For two of the scenarios, this, in principle, should have been relatively simple. Scenario 2 involved a straight line of measurement stations along the predominant wind direction in effect that day and Scenario 4 was of a similar character. Scenario 1 was more complex given the nature of meteorological conditions for the day of the release. The location for Scenario 3 was provided for the participants. The majority of the participants were able to correctly estimate the general area from which the release came – no participant was clearly wrong with respect to that estimation. In

more accurately pinpointing the source or the potential area within which the source was located, results were less definite. Scenario 1 was intrinsically difficult in that the source was not one which is always at a fixed position, in contrast to, for example, a land based facility. In addition, the weather patterns at the time resulted in a complex dispersion from the release point complicating matters further for the participants. While all participants were correct in their general positioning, all participants chose to estimate the source as being a land based facility even though in some instances, the location of the candidate facilities fell outside the bounds of what was indicated by the trajectory analyses they had performed. In fairness to the participants, there was nothing qualitative in the spectra for Scenario 1 that would have indicated a marine reactor as opposed to a land based one so no assistance could be found within the spectra in making the decision. One participant was willing to ascribe the release as potentially coming from a naval facility but this was as close as any participant came to correctly assigning the source. It was apparent in this instance that complex meteorology was not a hindrance to the participants in estimating location but that the assumption of a more conventional type of release with respect to the source was the predominant factor in the participants deciding where the release was coming from. This is not entirely unreasonable in itself but could perhaps be indicative of a need for a more open assessment of possibilities in determining potential release locations in the future.

Scenario 2 was straightforward with respect to meteorology, the released isotopes having been carried directly towards a series of measurement stations placed linearly along its route. The scenario was complex however as a number of facilities ly along or near to the dispersion plume making it potentially more difficult to ascribe the release to any specific facility. The actual release point is also in a general area with a number of possible candidate sites. These aspects were clearly reflected in the responses from participants – sites in the Netherlands, Great Britain and France being proposed as candidates. Some participants were quite specific in assigning the locations as being the Sizewell facility and it is not quite clear what differentiates those who were confident in the Sizewell assignation from those who were apparently more hesitant. It is possible that operator experience played a role in this regard or that there are subtle differences in how the analysis systems operated. Figure 13 appears to show some differences in the results provided by different systems with respect to where the release point could

possibly be and it is probable that further analysis of the differences would yield more information.

Scenario 4 was intended as a relatively simple scenario with respect to location identification, the release point being quite close to the measurement stations and a fairly simple meteorology prevailing over the time of the release. What seemed to have a large impact on the participants decisions in this scenario was the nature of the release as it was obviously not a typical release for a reactor facility. This assessment of the type of release then played a role in the participants attempting to ascribe the release to certain facility types – predominantly either a nuclear facility or a site where industrial processes (such as metal smelting) could feasibly result in a release of this type. Nonetheless, the correct location was either decided upon or featured within the candidate locations proposed by most participants.

Once a candidate release point is determined, a complete analysis involves estimating the nature of the release with respect start time, duration and magnitude. In estimating the start time of a release a number of paremeters are of use: meteorlogical information and information yielded by the results of the measurement data with respect to dose rates and isotopes. For EPHSOGAM, one of these information sources was not present to the degree that would be expected in a real situation – the mother-daughter relationships between released isotopes. The participants could however utilize the dose rate information provided for each station as well as any meteorological parameters.

For Scenario 1, the majority of the participants correctly ascribed the release as having taken place in the early hours of the 25th of March. The correct determination of the release point is of course dependent to a large extent on a correct estimate of the location of the relase. Where a participant assigned the release point to the wrong location, the estimates of the release time was concomitantly erroneous. The estimates of the duration of the release were, where made, overestimated by significant margins. This is potentially a result of the relatively complex meteorology in effect at the time. Estimates of the time and duration of the Scenario 2 release varied substantially between the participants ranging from 36 hours to a more accurate 3 hours. The release time was quite accurately estimated by all participants where the location had been assigned to the actual facility or one close by. Where an estimate of the location was in

error, the estimated timing was also erroneous. It was hoped that Scenario 3, for which the release point was known, would have allowed for a more precise assessment of time and duration and in this respect there is evidence that this was the case, participants being relatively close to the actual release time. While the actual length of the release was not estimated accurately, the majority of responses indicated a release of longer duration than just a couple of hours. The complex nature of the release was hinted at by one participant but there was little evidence that the participants felt able to, or that it was necessary, to attempt to describe the progression of the release beyond its start time and duration. In Scenario 4, where the actual location was estimated, evaluations of time and duration were quite close. Participants who selected a possible release location other than Rivne seemed to end up with a more inaccurate assessment of the temporal nature of the release.

Assessments of the released inventory were markedly less in terms of the number of participants willing to estimate how much activity had been released. While all participants had been willing to attempt estimates of location and time, approximately half were willing to tackle the problem of coming up with an estimate of released amounts. One participant provided a rough estimate for Scenario 1 that was a few orders of magnitude higher than actuality. Another participant produced a useful estimate for one of their candidate locations which was nearest the actual location and was, for some isotopes at least, not inaccurate when viewed with the degree of latitude inherent in such estimates. Three participants provided fairly comprehensive overviews of released activity in this scenario. One of the estimates was an order of magnitude above, one was below by a greater amount and a third was relatively close for many isotopes. There was a notable improvement with respect to Scenario 4 where, it can be presumed, the certainty in relation to location contributed to a more accurate assessements of activity, almost all estimates being within an order of magnitude of the true value. For Scenario 4, the estimates were fairly evenly scattered about the true values by an order of magnitude.

The results of EPHSOGAM provide some indications of the difficulties in analyzing data with respect to identifying sources and quantifiying releases. Irrespective of the software used, the results indicated that the general areas indicated by such analyses as potentially being the location of a release were similar – there were no major deviations

between participants in relation to where the release may have originated. Scenario 1 seemed to indicate that in making a firm estimate of the location, analysts were willing to select facilities somewhat outside the area indicated by the software. This of course may be an artefact of the fact that there is a natural prejudice towards assigning a release to an established land based facility as opposed to hazarding a guess that the release may be coming from a less "traditional" source. Despite this, some participants displayed a willingness to focus on facilities that were not permanently sited facilities such as nuclear power plants but could rather be the site of a nuclear powered vessel of some kind (such as naval installations). The problem of identifying any individual release point within a large area when there are a number of candidates was exemplified by Sceanrio 2 where the region of the release, and the path along wheich the contamination traversed, feature a number of possible candidates. Some participants were however more confident than others in assigning the release to the correct candidate. In the absence of more detailed insight into the actual mechanics of how these assignations were made, it can only be hypothesized that less-tangible factors, such as operator experience, played some role. Scenario 4 displayed a willingness on the part of the participants to consider non-nuclear power facilities in being responsible for a release.

Analysis of quantitative data of the type used in addressing the problems of an unidentified is not an apparent problem for any participant. Only one participant was displaying any consistent problem in quantifiying the data. All participants were in a position to exhibit an awareness of what the isotope assemblages may mean in thinking about where a release may have arisen. On some level it was thought that the participants may have attempted to have made more use of the dose rate data but there is no real evidence from the reports that the dose rate data was utilized or considered in any real way. Participants were all reasonably confident in estimating the time and duration of a release and estimates were within what could be expected. An obvious weakness in this regard was the absence of information that may have been of use inmaking such estimates (primarily mother daughter relationships) and it is difficult to appraise the extent that inclusion of such information would have made to the ability of participants to improve their estimates. Estimates of released activity were probably the least confident of all aspects of the activity. The inability or unwillingness of participants to estimate the activity is difficult to analyse from the results to hand.

Where estimates of activity were made they varied to large extent in quality. Despite accurate determinations of airborne activity and information as to the possible location of a release there were disparate estimates of released activity. Where the location was known with certainty, estimate quality seemed to improve. There was no evidence that an accurate measure of airborne activity contributed to a more accurate estimate of released activity.

Appendix 1. – Scenario Specific Informational Materials as Sent to Participants.

Scenario 1

Scenario 1 stations

Station 1

Location: 04º 46'25" E 43º 19' 50" N
Sampling start: 3/25/2017 22:00
Sampling stop: 3/27/2017 15:00
Sampling duration: 41 hours
Sampling rate: 400 m^3/hour

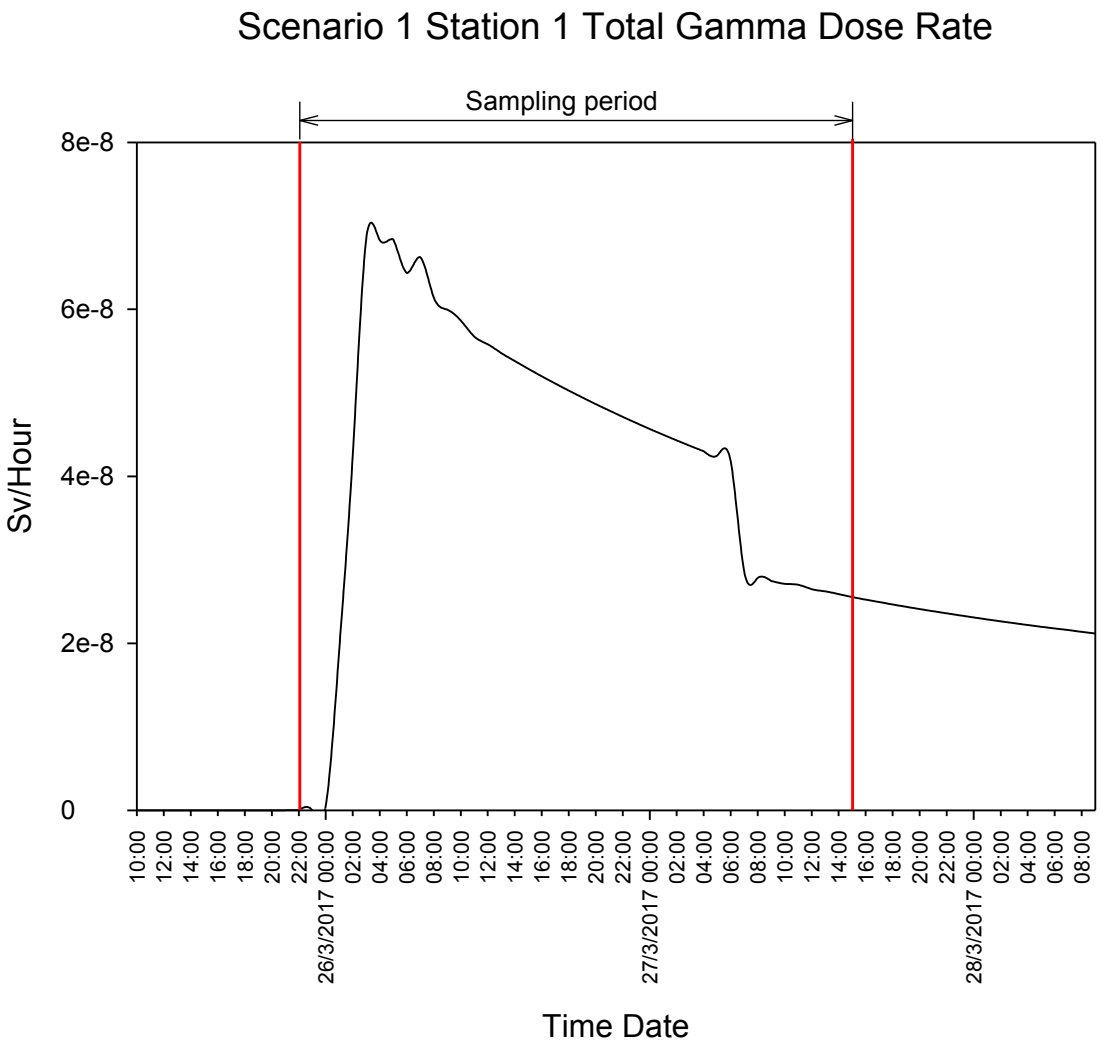
Station 2

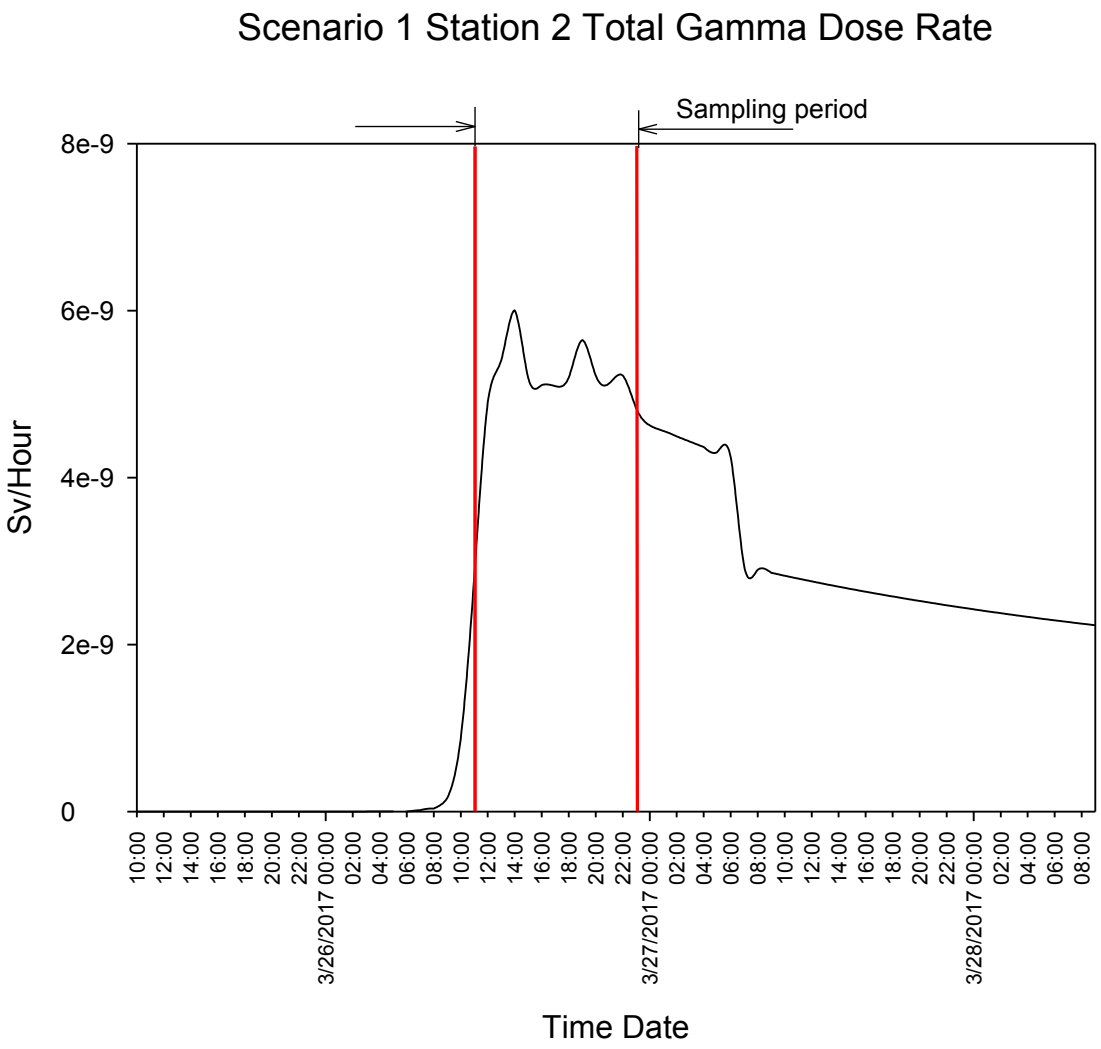
Location: 09º 41' 07" E 44º 23' 57" N
Sampling start: 3/26/2017 11:00
Sampling stop: 3/26/2017 23:00
Sampling duration:12 hours
Sampling rate: 500 m^3/hour

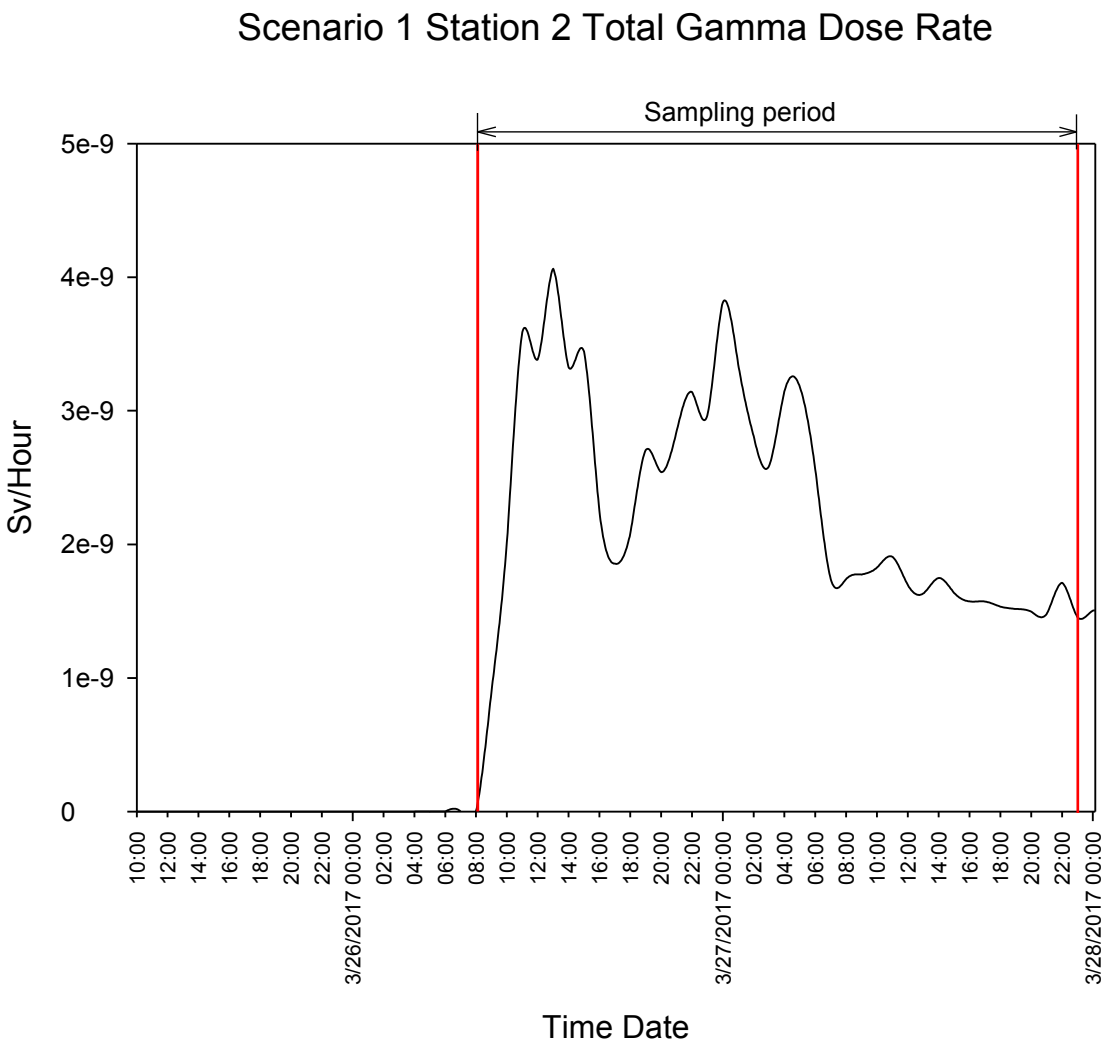
Station 3

Location: 03º 31' 23" E 45º 06' 56" N
Sampling start: 3/26/2017 8:00
Sampling stop: 3/27/2017 23:00
Sampling duration: 39 hours
Sampling rate: 300 m^3/hour

Scenario 1 stations: Total Gamma Dose Rates (Plume plus Deposition)




Scenario 1 Station 2 Total Gamma Dose Rate
Sampling period
8e-9
6e-9
4e-9
2e-9
0
Sv/Hour
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/26/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/27/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/28/2017 00:00
02:00
04:00
06:00
08:00
Time Date


Scenario 1 Station 2 Total Gamma Dose Rate
Sampling period
5e-9
4e-9
3e-9
2e-9
1e-9
0
Sv/Hour
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/26/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/27/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/28/2017 00:00
Time Date

Scenario 2

Scenario 2 stations

Station 1

Location: 08 24’ 46" E 55 22’ 26" N
Sampling start: 3/20/2017 19:00
Sampling stop: 3/20/2017 21:00
Sampling duration: 2 hours
Sampling rate: 600 m^3/hour

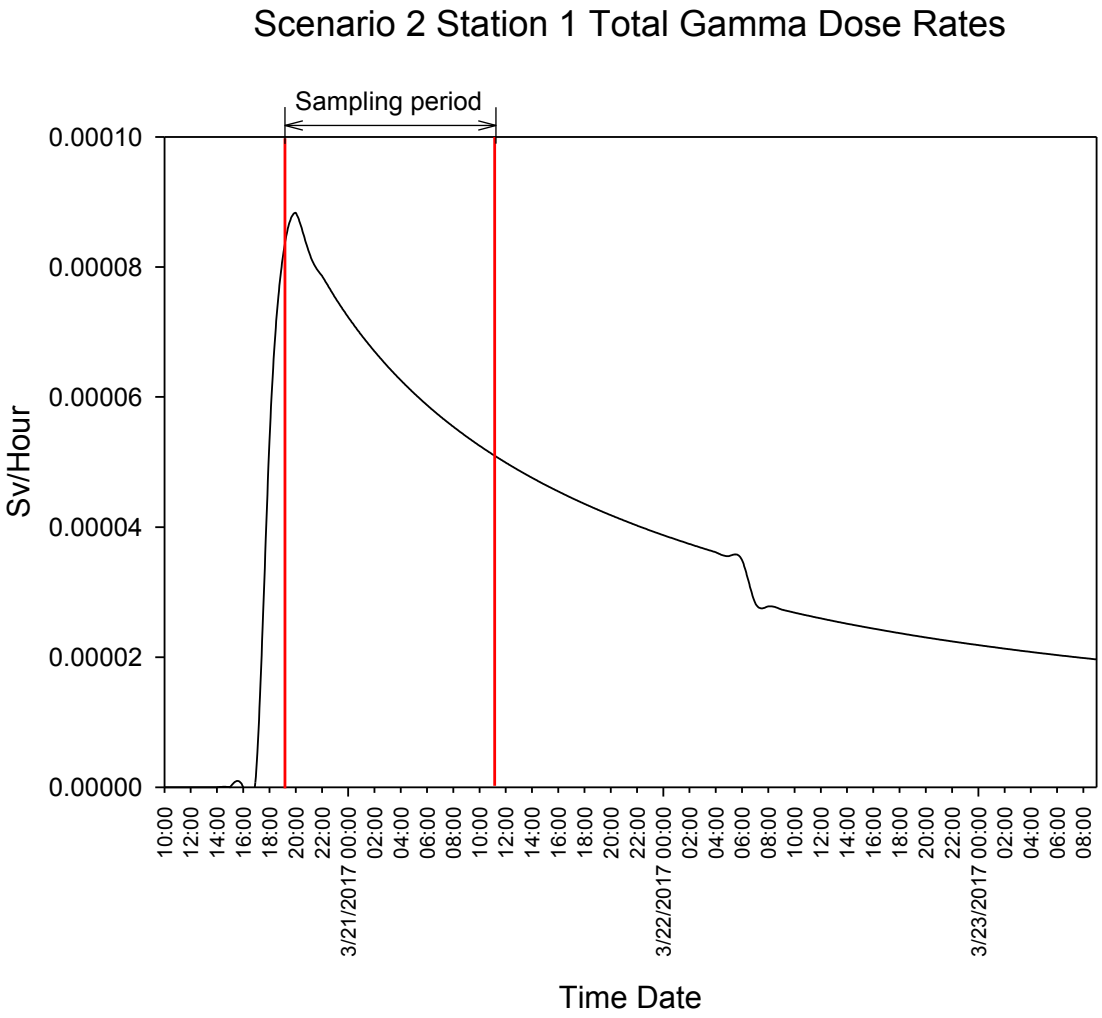
Station 2

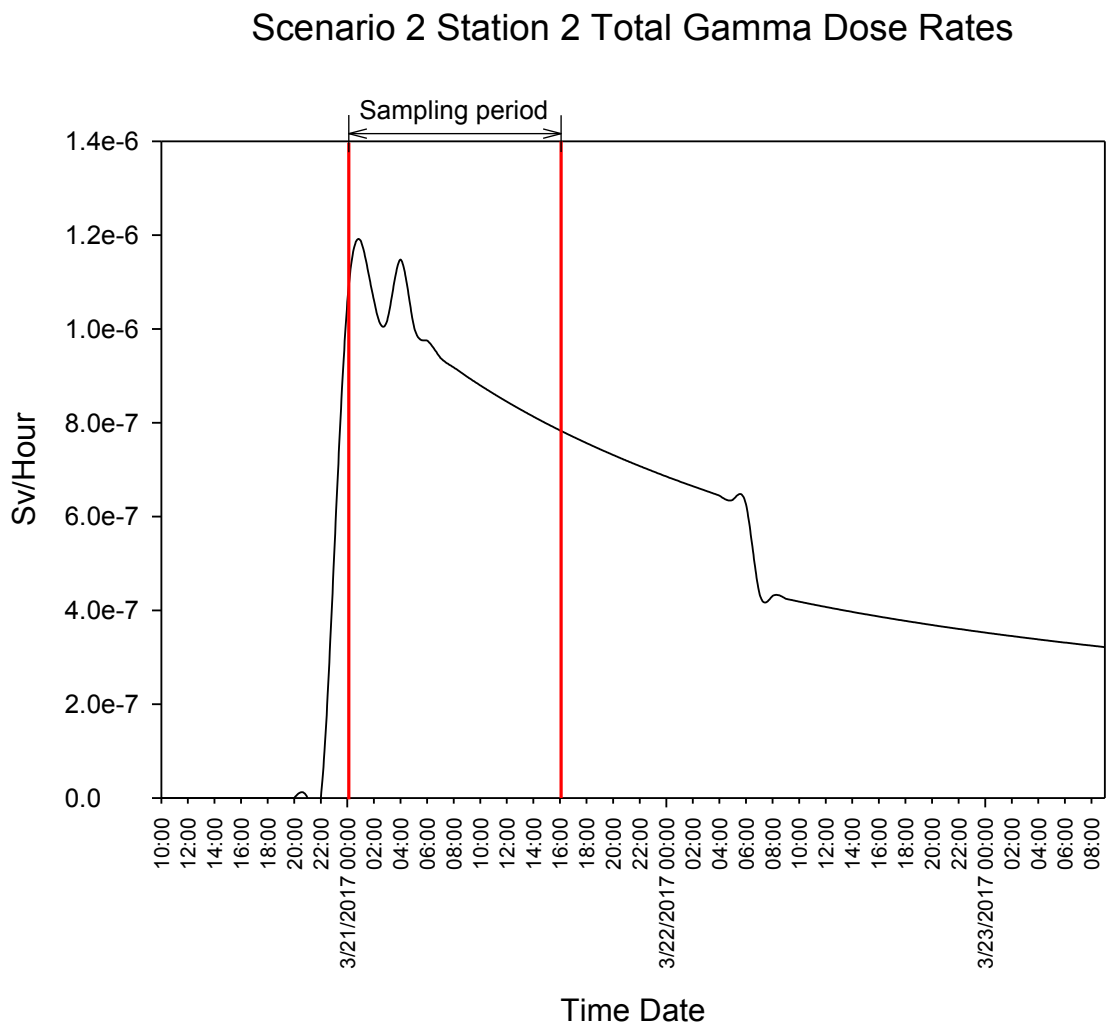
Location: 12 59’ 38" E 55 48’ 25" N
Sampling start: 3/21/2017 0:00
Sampling stop: 3/21/2017 6:00
Sampling duration: 6 hours
Sampling rate: 1000 m^3/hour

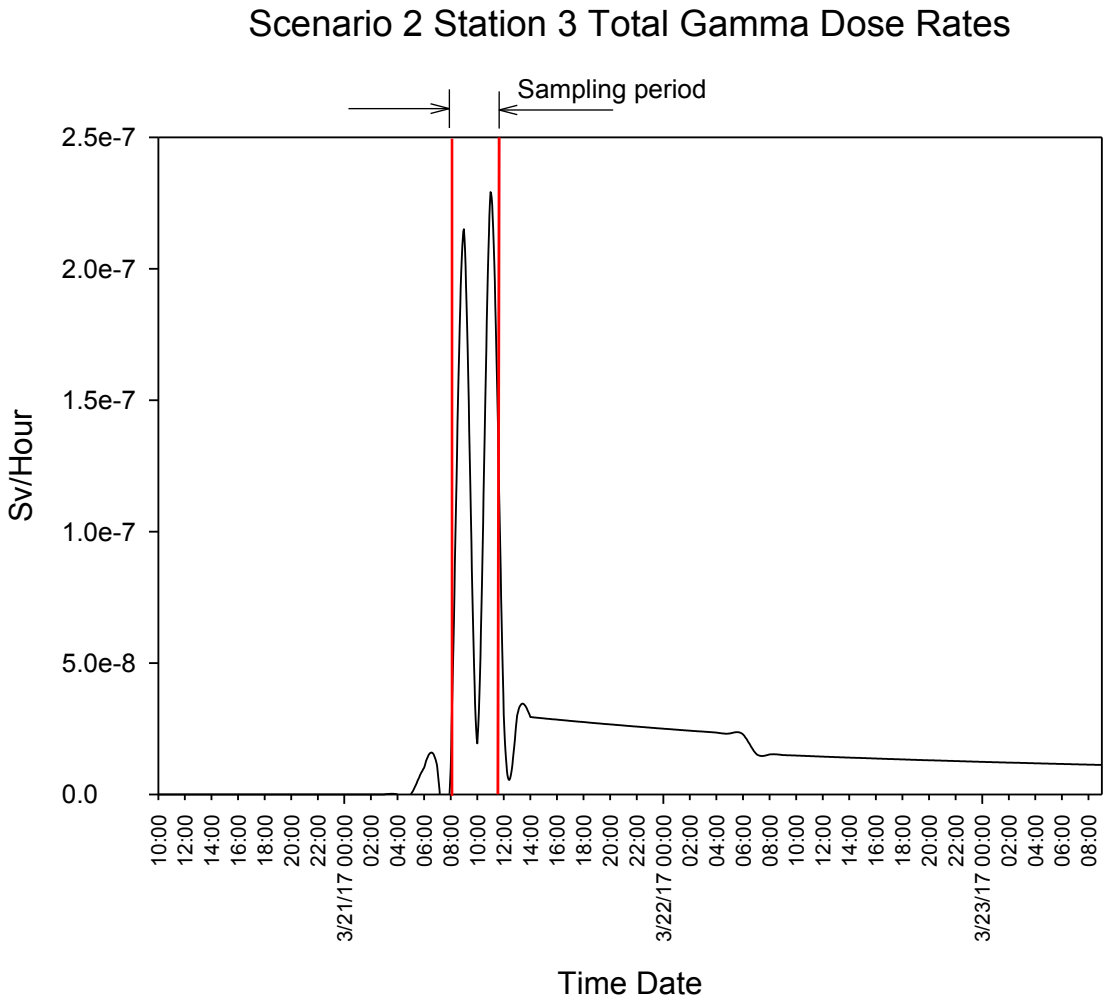
Station 3

Location: 21 07’ 38" E 55 42’ 06" N
Sampling start: 3/21/2017 8:00
Sampling stop: 3/21/2017 11:00
Sampling duration: 3 hours
Sampling rate: 500 m^3/hour

Scenario 2 stations: Total Gamma Dose Rates (Plume plus Deposition)




Scenario 2 Station 2 Total Gamma Dose Rates
Sampling period
1.4e-6
1.2e-6
1.0e-6
8.0e-7
6.0e-7
4.0e-7
2.0e-7
0.0
Sv/Hour
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/21/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/22/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/23/2017 00:00
02:00
04:00
06:00
08:00
Time Date


Scenario 2 Station 3 Total Gamma Dose Rates
Sampling period
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
0.0
Sv/Hour
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/21/17 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/22/17 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/23/17 00:00
02:00
04:00
06:00
08:00
Time Date

Scenario 3

Scenario 3 stations

Station 1

Location: 08 41’ 16" E 50 11’ 44" N
Sampling start: 3/22/2017 12:00
Sampling stop: 3/22/2017 18:00
Sampling duration: 6 hours
Sampling rate: 100 m^3/hour

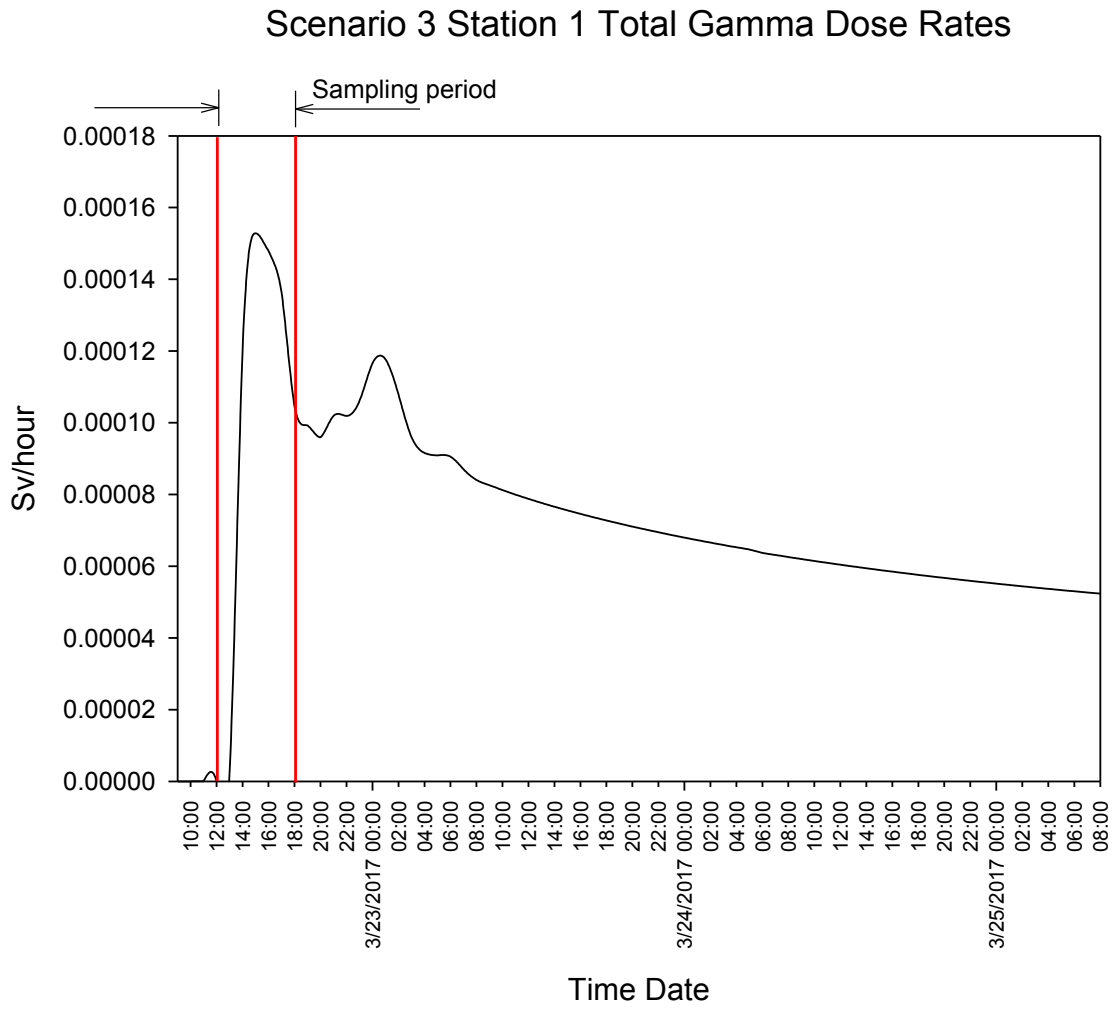
Station 2

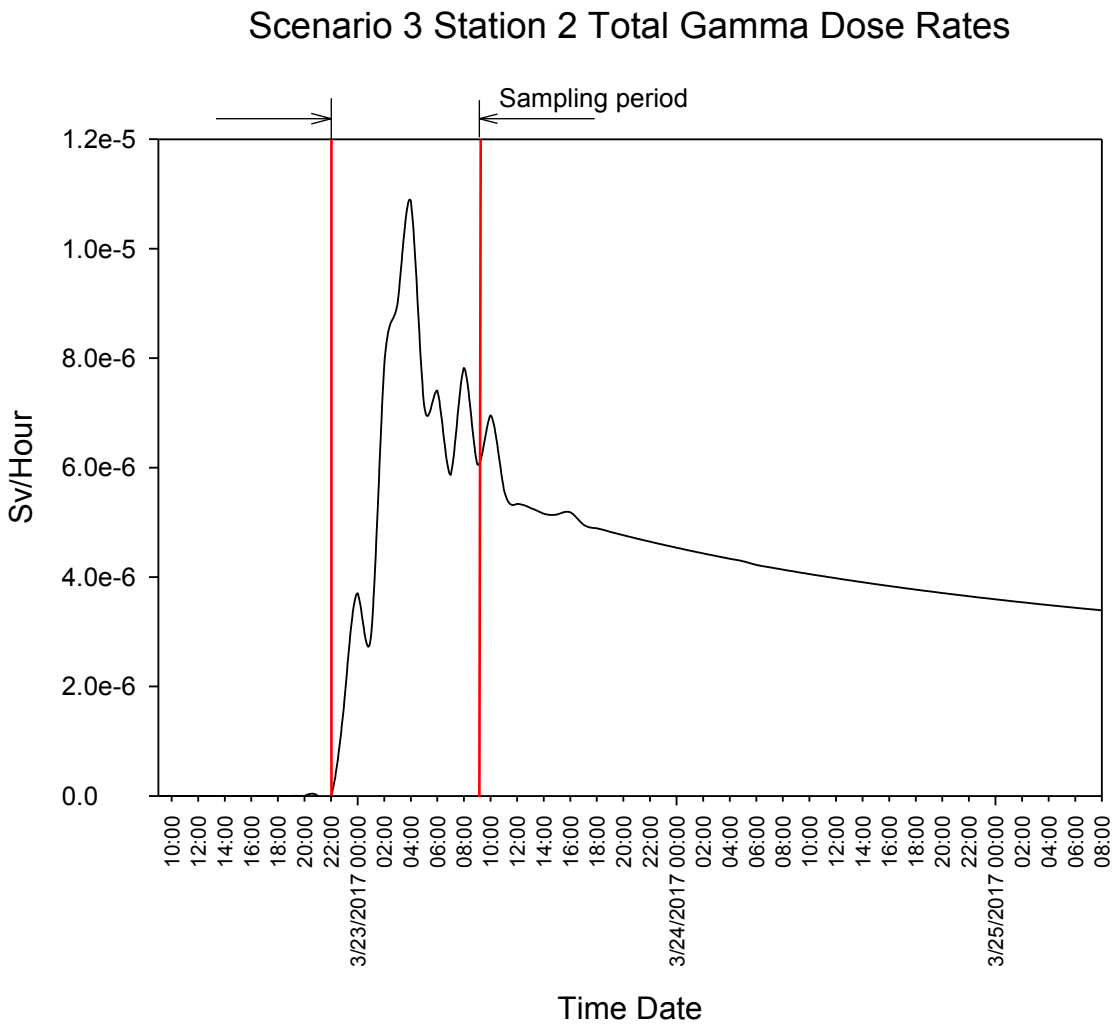
Location: 05 59’ 29" E 51 08’ 05" N
Sampling start: 3/22/2017 22:00
Sampling stop: 3/23/2017 9:00
Sampling duration:11 hours
Sampling rate: 150 m^3/hour

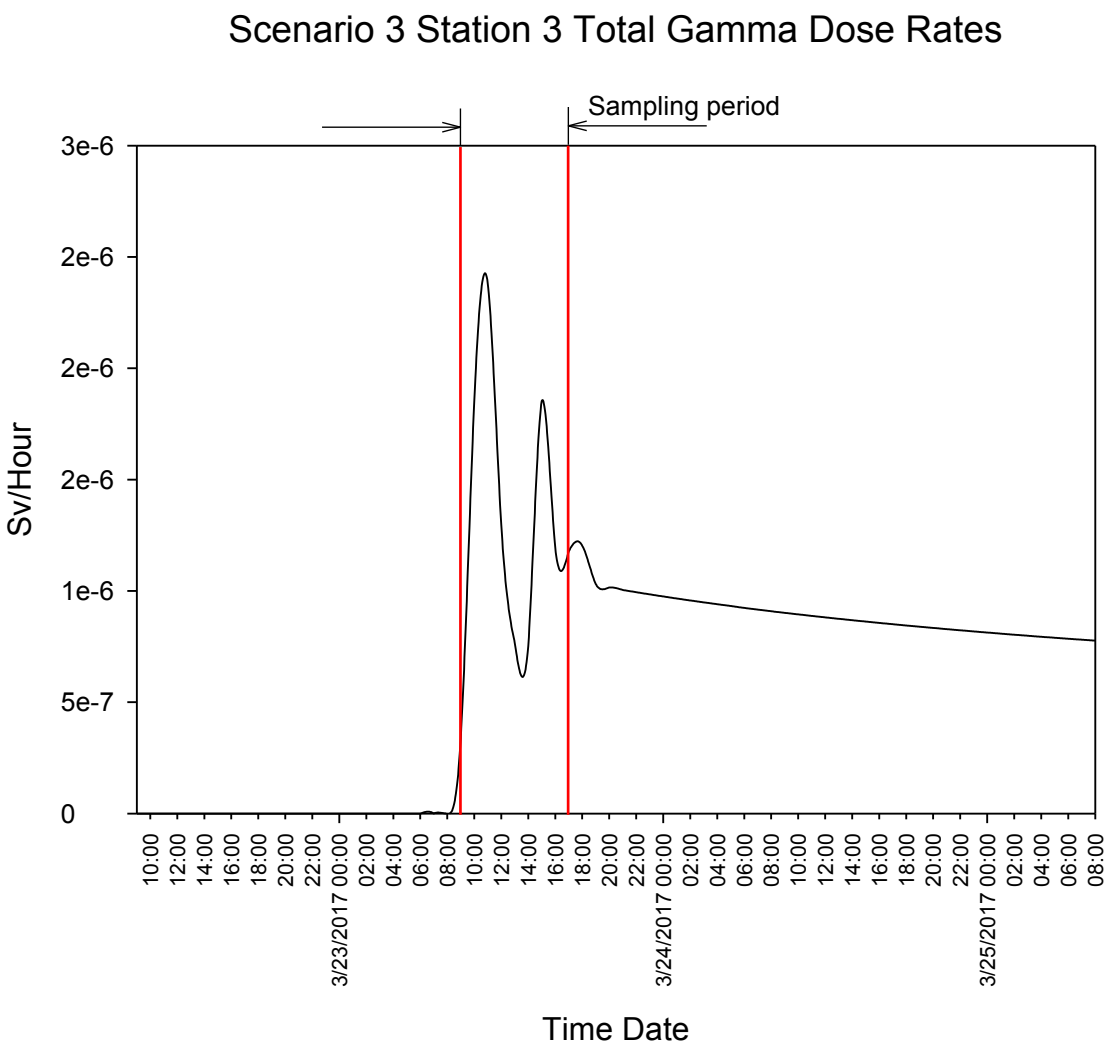
Station 3

Location: 03 18’ 30" E 51 06’ 31" N
Sampling start: 3/23/2017 9:00
Sampling stop: 3/23/2017 17:00
Sampling duration:8 hours
Sampling rate: 200 m^3/hour

Scenario 3 stations: Total Gamma Dose Rates (Plume plus Deposition)




Scenario 3 Station 2 Total Gamma Dose Rates
Sampling period
1.2e-5
1.0e-5
8.0e-6
6.0e-6
4.0e-6
2.0e-6
0.0
Sv/Hour
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/23/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/24/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/25/2017 00:00
02:00
04:00
06:00
08:00
Time Date


Scenario 3 Station 3 Total Gamma Dose Rates
Sampling period
3e-6
2e-6
2e-6
2e-6
1e-6
5e-7
0
Sv/Hour
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/23/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/24/2017 00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
3/25/2017 00:00
02:00
04:00
06:00
08:00
Time Date

Scenario 4

Scenario 4 stations

Station 1

Location: 27 07’11" E 52 06’ 00" N
Sampling start: 3/21/2017 11:00
Sampling stop: 3/21/2017 14:00
Sampling duration: 3 hours
Sampling rate: 800 m^3/hour

Station 2

Location: 29 50’ 37" E 53 28’ 22" N
Sampling start: 2/21/2017 14:00
Sampling stop: 3/22/2017 9:00
Sampling duration: 19 hours
Sampling rate: 500 m^3/hour

Station 3

Location: 32 41’ 42" E 56 19’ 52" N
Sampling start: 3/22/2017 6:00
Sampling stop: 3/22/2017 15:00
Sampling duration: 9 hours
Sampling rate: 600 m^3/hour

No total dose rate data for Scenario 4

Appendix 2. General Instructions Sent to Participants.

NKS EPHSOGAM – INSTRUCTIONS AND DETAILS

Dear Participant

Many thanks for your participation in this NKS activity. The text below is intended to provide useful information, details and instructions and should be read prior to responding to the activity.

Background.
The EPHSOGAM activity simulates 4 scenarios whereby radioactivity is detected on air filter samples at a number of locations. The operators of the stations request assistance and send gamma spectral data for the stations. The goal of the activity is, for each of the 4 scenarios, to provide an estimate of the location of the release, the time of the release, the nature of the release with respect to qualitative and quantitative information and any other information the participants would like to provide. In particular and in addition to the above, the organizers are interested in how participants approach the problem of identifying release locations and details.

Data Provided.

Each scenario will involve 3 monitoring stations. Information as to the locations of these stations will be provided (please note – we have not tried to ensure that the stations are in logical or real positions so if you find one in a lake or something, that's not a mistake, it's just the way it is). The stations were "sampling" for different periods of time and will have "sampled" different volumes of air. This information will be provided in the relevant information file for each scenario. The time periods during which each station was sampling will also be provided. Total Gamma Dose Rate data will be provided for three of the scenarios. Gamma spectra will be provided for each of the stations in each of the scenarios. Technical detail as to these spectra is provided in this text.

For Scenario 3, we are providing you with the location (just the location) of the release – the Grafenrheinfeld nuclear power plant in Germany. We are doing this to allow participants to fine tune their systems, test themselves. We would be grateful however if you would also report how you performed in this scenario for a situation where we had not provided this information. This will provide valuable input.

The Sources.

In developing the release "sources" we have tried to ensure that the release locations correspond with actual facilities or whatever from which a release may occur. We have not paid any attention to whether or not those facilities were actually operating during the EPHSOGAM time period. Please do not assume a release could not have occurred

from any particular site or facility because the facility was offline during the period for which EPHSOGAM is being conducted.

We have attempted to utilize realistic source terms with respect to amounts released and what was released. For practicality, the entire suite of possible isotopes from a source term has not been utilized. The most significant nuclides from a gamma spectrometry/dose point of view have been chosen (so for example, an isotope with insignificant gamma emissions relative to other isotopes will not have been included). Isotopes with half-lives less than an hour or so have, generally, not been included.

No attempt was made to ensure correctness with respect to various mother/daughter relationships.

Air sampling.

It can be assumed that the monitoring stations were using a super type of filter paper with 100% retention of particulate isotopes. For isotopes with gaseous and particulate forms, please just assume that all the isotope was present in particulate form. There was no reduction of sampling rate with time. The sampling times and rates of air sampling were not intended to be realistic. The times during which the samplers were active were “simplified” to some extent and tend to be a bit “ideal” with respect to plume passage etc.

Decay between emission and sampling has been included.

Gamma Data.

The gamma data was simulated as having been drawn from a very standard HPGe detector. The “detector” and its electronics are the same for all scenarios and all monitoring stations in order to keep things simple. The same calibration applies for all scenarios and stations.

Some details as to the spectra:

There was no decay of gamma isotopes over the period of gamma counting. Please switch off any type of decay corrections in your analysis routines.

No accounting was made of mother-daughter ingrowth relationships. Please switch off any related routines in your analysis software.

Gamma counting took place immediately after the sample was removed from the air sampler.

The samples were counted at a distance of 10 cm from the detector so true coincidence summation does not have to be accounted for. It can be assumed that no natural nuclides ended up on the air filters.

The detectors (all of them, for all scenarios) were calibrated with a mixed standard isotope solution presented to the detector in exactly the same geometry and sample matrix as for the samples). There is no need for any density corrections or whatever.

Nuclear data – the nuclear data used in EPHSOGAM was taken from the Table of Isotopes hosted at Lund University Sweden and which can be accessed at http://nucleardata.nuclear.lu.se/toi/ and was correct as of June 2017. Please ensure that your libraries and routines are at least up to date to 2017 or so!

The relevant reference time for each spectrum can be the time the count was started.

Detector.

The detector was a very standard coaxial HPGe detector, crystal size was 5.4 cm diameter and 5.1 cm in length. Endcap was aluminium, 3 mm from the crystal face. Nominal rel. efficiency was 22% and the resolution was 2.1 keV at 1332 keV. The MCA system was 4096 channels, zero was 0 keV, the gain was 0.75 keV/channel and the full scale energy was 3072 keV.

Calibration.

Calibration of the detector was conducted using a mixed isotope source present in the exact same configuration (matrix and geometry) as the samples. The source consisted of (at the time of counting) 10000 Bq of each of the following:

^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{85}Sr, ^{88}Y, ^{60}Co and ^{137}Cs.

Dead Time.

For some reason the dead time is excessive for some of the more active spectra. Please just ignore as it should have no influence on anything.

File formats.

We have tried to include the common gamma spectrum file formats. For various reasons, only the crucial information is included – channels, counts, live time, dead time, start time. Any other information is probably wrong!

Please note: Canberras proprietary .cnf file format shares the same extension as a system file on some versions of MS Windows. This can mean that the file will not be downloaded or virus checkers stop it or whatever. **We have renamed the .cnf files to .cnx. Please just rename them back!!**

The file naming format for the spectra is as follows: Scenario_X_Station_X.ext where X is the scenario and station number and .ext is the relevant extension. The calibration files are just called calibration. Please use the same file format for both calibration and the sample spectra – there have been problems before with how different formats

treat the first channel (is it 0 or 1) and we do not know if that is still an issue. Using the same format for calibration and analysis will remove any potential problems for safety.

The formats included are:
Ortec .chn and .spe, Canberra .cnf (**renamed to .cnx**), an Excel type .csv, the CTBTO .phd format and the XML .n42 format. At least one of these should work with most systems. If not please contact me.

Dose Rates.

Time development of total dose rate for each scenario and station will be provided for the relevant time periods. This will be in .csv format and can be opened in Excel or Notepad or whatever. This data will not be relevant for Scenario 4.

Reporting.

We are not going to be super fussy as to how reporting is done. If participants can send us the following information in whatever format you like, we will be happy.

For each Scenario.

1. Where you think the release occurred – a GPS coordinate, a circle drawn in Google Earth, a facility name, etc.

2. When you think the release occurred.

3. What isotopes do you think were released and how much of each.

4. Any other observation or conclusion you would like to draw – how the release developed over time, etc etc.

5. We would be grateful if you could provide information as to how you approached the problem – software used, how you estimated the release point etc.

For each Scenario and Station

1. What isotopes were in the sample

2. the concentrations of those isotopes in the sample in Bq/m^3

Appendix 3 – Spectral Information for the EPHSOGAM Scenarios.

Nuclide	Channel	Energy	Counts
Am-241	43	32.2	7.1
Am-241	44	33.2	67.3
Am-241	57	42.7	12.8
Am-241	58	43.4	181.1
Am-241	74	55.6	86.6
Am-241	77	57.9	26.7
Am-241	79	59.5	192486.2
Am-241	90	67.5	2.8
Am-241	93	69.8	18.8
Cd-109	117	88	27382.6
Am-241	132	99	162.9
Am-241	137	103	159.1
Co-57	163	122.1	736068.9
Am-241	164	123	8.6
Am-241	167	125.3	34.5
Co-57	182	136.5	93534.8
Am-241	195	146.6	4
Ce-139	221	165.9	701592.1
Am-241	277	208	6.5
Co-57	307	230.3	3
Sn-113	340	255.1	12489.1
Am-241	447	335.4	2.6
Co-57	453	339.5	72
Co-60	463	346.9	38.5
Co-57	470	352.4	65.8
Co-57	489	366.8	6.2
Sn-113	522	391.7	286687.3
Sr-85	685	514	327191.6
Co-57	760	569.9	52.4
Sn-113	851	638	2.6
Cs-137	882	661.7	226820.7
Co-57	923	692	400.9
Co-57	942	706.4	63.4
Co-60	1101	826.1	16.4
Y-88	1134	850.6	136.7
Sr-85	1158	868.5	24.8
Y-88	1197	898	187450.8
Co-60	1564	1173.2	156108.1
Co-60	1777	1332.5	138587.4
Y-88	1843	1382.4	28.1
Y-88	2448	1836.1	100675.3
Y-88	3645	2734.1	470.3
Y-88	4291	3218.5	3.9

Table I. Spectral information for the EPHSOGAM calibration spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Ru-103	53	39.8	68.5	I-132	828	621.2	33.1
Te-132	66	49.7	54332.1	I-132	840	630.2	274.8
Ru-103	71	53.3	945.1	I-131	849	637	5942.5
La-140	86	64.1	25.7	I-131	857	642.7	178.2
La-140	92	68.9	146.6	I-133	865	648.8	80.4
I-131	107	80.2	5663.3	I-135	866	649.9	23.5
La-140	146	109.4	555.1	I-132	867	650.5	51.5
Zr-97	149	111.6	53.2	Ru-103	869	651.8	10.5
Te-132	149	111.8	14040	I-135	875	656.1	3.8
Ru-103	151	113.3	16.8	Nb-97	877	658.1	19.9
Ru-103	153	115	35.7	I-132	890	667.7	1935.7
Te-132	155	116.3	15998.5	I-132	893	669.8	89.7
La-140	175	131.1	1235.9	I-133	893	670.1	58.8
I-132	182	136.7	5.1	I-132	895	671.4	68.1
I-132	197	147.4	15.4	I-133	905	678.7	29.7
I-133	201	150.4	134.2	I-135	906	679.2	2.7
I-135	221	165.7	5.3	I-133	907	680.2	875.9
La-140	231	173.5	340.6	I-135	920	690.1	6.3
I-133	236	177	352.2	Zr-97	921	690.5	45.6
I-131	236	177.2	703.9	Zr-97	932	699.2	24.9
Zr-97	244	182.9	27	Zr-97	938	703.8	247.3
I-132	245	183.6	8.8	I-133	942	706.6	1963.5
I-135	246	184.5	3.9	Zr-97	943	707.4	7.8
I-135	263	197.2	5.3	I-135	944	707.9	31.1
Zr-97	270	202.5	23.7	I-131	964	722.9	1302.5
I-133	272	203.7	19.1	Zr-95	966	724.2	18859.5
Zr-97	292	218.9	128.8	I-132	969	726.8	39.2
I-135	294	220.5	259.6	I-132	970	727.2	57.7
Te-132	304	228.2	641952.8	I-132	971	728.4	28.8
I-135	306	229.7	34.6	Zr-97	991	743.4	21622.5
I-131	310	232.2	7.2	La-140	1002	751.6	3106.3
Zr-95	314	235.7	379	Zr-95	1009	756.7	22121.8
Ru-103	323	241.9	73.9	I-133	1025	768.4	552.5
La-140	323	241.9	906.2	Zr-97	1029	772	53.9
I-133	328	246	129	I-132	1030	772.6	1287.2
I-135	330	247.5	3.9	Zr-97	1033	775	42.5
Zr-97	339	254.2	764.6	I-132	1040	780	19.9
I-135	340	254.7	3	I-132	1046	784.4	6.4
I-132	340	255.1	12	I-135	1047	785.5	6.5
I-133	350	262.7	1243.6	I-133	1053	789.6	58.6
I-132	351	262.9	63.1	I-135	1064	797.7	7.2
I-135	352	264.3	23.2	Zr-97	1073	804.5	131.7
La-140	355	266.5	931.5	Zr-97	1074	805.6	60.4
I-133	356	267.2	398.7	I-132	1079	809.5	42.7
Zr-97	363	272.4	144.4	I-132	1083	812	89.4
I-131	363	272.5	111.6	La-140	1088	815.8	15474.1
I-131	379	284.3	11381.1	I-133	1094	820.5	175.1
I-132	380	284.9	32.4	Zr-97	1106	829.8	50.1
I-135	385	288.5	358.7	I-135	1116	836.8	271.2
I-135	387	290.3	35	Zr-97	1140	854.9	72.6
Ru-103	390	292.7	19.5	I-133	1142	856.3	1346.2

Zr-97	393	294.8	47	I-132	1151	863	8.6
Ru-103	393	295	1029.6	La-140	1157	867.8	3450.7
I-131	394	295.8	3.2	I-133	1167	875.3	4797.5
Zr-97	396	297.2	38.1	I-132	1169	876.6	15.7
I-131	403	302.4	8.2	I-133	1213	909.7	219.7
I-135	407	304.9	3.5	I-132	1213	910.1	13.6
Zr-97	407	305.1	15.7	I-133	1215	911.5	47.1
I-135	408	305.8	10.4	La-140	1226	919.6	1581.8
I-132	409	306.7	4.2	La-140	1234	925.2	4078.7
La-140	409	306.9	43.5	I-132	1237	927.4	5.9
I-132	413	310.1	3.7	La-140	1268	951	299.2
I-132	414	310.4	3.7	I-132	1273	954.6	246.2
I-132	422	316.7	5.3	I-135	1282	961.4	5.3
Ru-103	424	317.8	60	Zr-97	1295	971.3	50.4
I-131	424	318.1	128.7	I-135	1296	972	31.1
I-131	433	324.7	34.4	I-135	1297	972.6	42.4
I-131	434	325.8	443.5	I-132	1312	984.2	8
La-140	438	328.8	32998.7	La-140	1324	992.9	7.2
Zr-97	441	330.4	74.2	I-135	1327	995.1	5.5
I-135	445	333.6	3.8	I-133	1357	1018.1	5.5
I-132	458	343.7	3.4	Zr-97	1357	1018.1	64.2
I-133	461	345.4	274.8	Zr-97	1362	1021.2	174.7
I-132	469	351.8	2.9	Zr-97	1369	1026.7	48.2
Zr-97	474	355.4	1006.9	I-132	1380	1035	6.6
Ru-103	477	357.5	26.3	I-133	1381	1035.6	7.9
I-131	478	358.4	23.5	I-135	1385	1038.8	264.1
I-133	481	361.1	277.8	La-140	1393	1045.1	13.2
I-135	482	361.9	17.2	I-133	1403	1052.3	498.6
I-132	484	363.3	17.5	I-133	1413	1060.1	122.9
I-131	486	364.5	118064.3	I-133	1450	1087.7	10.6
I-133	497	372.5	24.5	I-135	1462	1096.9	2.8
I-133	509	381.6	107.5	La-140	1463	1097.2	11.6
I-133	516	386.9	139	I-135	1469	1101.6	50.6
I-132	517	387.9	10	Zr-97	1481	1110.4	14.9
La-140	530	397.5	97.9	I-135	1499	1124	111.5
Zr-97	534	400.4	104.6	I-135	1509	1131.5	692.7
I-135	537	403	19.2	I-132	1515	1136	35.8
I-131	540	404.8	71	I-132	1524	1143.3	16
Zr-97	547	410	29.2	I-132	1530	1147.8	3.2
I-135	553	414.8	24.2	Zr-97	1531	1148	405.3
I-132	556	416.8	14.6	I-135	1547	1159.9	3.1
I-133	557	417.6	335.8	I-135	1559	1169	26
I-135	557	417.7	278.8	I-132	1564	1172.9	12.6
I-133	564	422.9	669.2	I-133	1649	1236.4	1166.1
I-135	573	429.9	23.5	I-135	1654	1240.5	25.4
I-132	576	431.8	14.1	I-135	1681	1260.4	796.2
La-140	577	432.5	3568.6	Zr-97	1701	1276.1	132.3
I-135	578	433.7	42.5	I-132	1721	1290.8	11.9
La-140	585	438.5	47.3	I-132	1727	1295.1	19.8
I-133	585	438.9	82.9	I-132	1731	1297.9	9.4
Ru-103	592	443.8	7356.4	I-133	1731	1298.2	1732.8
La-140	594	445.5	3.5	La-140	1738	1303.5	18.1

I-132	595	446.2	17.4	I-135	1792	1343.7	2
I-135	602	451.6	23.3	I-133	1801	1350.4	106.6
Zr-97	631	473.5	25.2	Zr-97	1815	1361	92.7
I-132	631	473.6	4.7	Zr-97	1817	1362.7	134.8
I-132	638	478.2	4.6	I-135	1824	1367.9	15.6
La-140	649	487	49711.3	I-132	1829	1372.1	24.6
I-132	651	488	10.9	I-133	1848	1386.2	6.2
Ru-103	663	497.1	182530.1	I-132	1865	1398.6	68.7
I-131	671	503	375.9	La-140	1874	1405.2	23.6
I-132	674	505.8	126.6	I-132	1923	1442.6	13.3
Zr-97	677	507.6	1691.3	I-135	1931	1448.4	7.7
I-133	681	510.5	3259	I-135	1943	1457.6	209.7
Zr-97	685	513.4	182.9	I-135	2004	1502.8	25.2
Ru-103	686	514.6	21.6	I-135	2089	1566.4	29.1
I-132	697	522.7	396.9	La-140	2128	1596.2	33790.3
I-133	706	529.9	149381.6	I-135	2237	1678	201.5
I-132	714	535.3	12.7	I-135	2275	1706.5	85
I-133	717	537.7	60.9	Zr-97	2334	1750.2	113.1
I-135	729	546.6	435.7	I-132	2343	1757.4	2.4
I-132	730	547.2	27	I-135	2388	1791.2	152.5
I-133	742	556.2	32.8	I-135	2441	1830.7	11.2
Ru-103	743	557	1556.1	Zr-97	2469	1851.6	30.4
Zr-97	744	558	8.6	La-140	2503	1877.3	12.4
I-132	746	559.7	2.1	I-132	2562	1921.8	8.8
I-133	756	567.1	4.8	La-140	2566	1924.6	3.9
Ru-103	757	567.9	5	I-135	2570	1927.3	5.4
I-135	768	576	7.5	I-132	2670	2002.2	7.8
I-135	784	588.3	2.9	I-135	2728	2045.9	15.1
I-132	800	600.1	2.8	La-140	2778	2083.2	3
Zr-97	803	602.4	392.3	I-135	3007	2255.5	9.6
Ru-103	814	610.3	9438.4	La-140	3131	2347.9	202.6
Ru-103	816	612	175.1	I-135	3212	2408.7	13.7
I-135	823	616.9	2	La-140	3285	2464.1	2.6
I-133	824	618	803.8	La-140	3362	2521.4	762.7
La-140	824	618.1	32	La-140	3396	2547.3	22
I-132	828	620.9	8.2	La-140	3866	2899.6	12.6
				La-140	4158	3118.5	4.3

Table II. Spectral information for the EPHSOGAM Scenario 1 Locations 1 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Ru-103	53	39.8	51.9	Zr-97	803	602.4	280.4
Te-132	66	49.7	35761.4	Ru-103	814	610.3	7143.2
Ru-103	71	53.3	715.3	Ru-103	816	612	132.6
La-140	86	64.1	16.3	I-133	824	618	224.2
La-140	92	68.9	92.9	La-140	824	618.1	20.3
I-131	107	80.2	3347	I-132	840	630.2	4.3
La-140	146	109.4	352	I-131	849	637	3512.8
Zr-97	149	111.6	38	I-131	857	642.7	105.4
Te-132	149	111.8	9242.4	I-133	865	648.8	22.4
Ru-103	151	113.3	12.7	I-135	866	649.9	3.7
Ru-103	153	115	27	Ru-103	869	651.8	7.9
Te-132	155	116.3	10533.1	I-132	890	667.7	30.6
La-140	175	131.1	784.2	I-133	893	670.1	16.4
I-133	201	150.4	37.4	I-133	905	678.7	8.3
La-140	231	173.5	216	I-133	907	680.2	244.2
I-133	236	177	98.2	Zr-97	921	690.5	32.6
I-131	236	177.2	416.2	Zr-97	932	699.2	17.8
Zr-97	244	182.9	19.3	Zr-97	938	703.8	176.9
Zr-97	270	202.5	16.9	I-133	942	706.6	547.4
I-133	272	203.7	5.3	Zr-97	943	707.4	5.6
Zr-97	292	218.9	92.1	I-135	944	707.9	4.9
I-135	294	220.5	41	I-131	964	722.9	769.9
Te-132	304	228.2	422577.2	Zr-95	966	724.2	12939
I-135	306	229.7	5.5	Zr-97	991	743.4	15465.1
I-131	310	232.2	4.2	La-140	1002	751.6	1969.8
Zr-95	314	235.7	260	Zr-95	1009	756.7	15179.7
Ru-103	323	241.9	56	I-133	1025	768.4	154.1
La-140	323	241.9	574.6	Zr-97	1029	772	38.5
I-133	328	246	36	I-132	1030	772.6	20.4
Zr-97	339	254.2	546.9	Zr-97	1033	775	30.4
I-133	350	262.7	346.9	I-133	1053	789.6	16.3
I-135	352	264.3	3.7	Zr-97	1073	804.5	94.2
La-140	355	266.5	590.7	Zr-97	1074	805.6	43.2
I-133	356	267.2	111.2	La-140	1088	815.8	9810.8
Zr-97	363	272.4	103.3	I-133	1094	820.5	48.8
I-131	363	272.5	66	Zr-97	1106	829.8	35.8
I-131	379	284.3	6729.3	I-135	1116	836.8	42.9
I-135	385	288.5	56.7	Zr-97	1140	854.9	51.9
I-135	387	290.3	5.5	I-133	1142	856.3	375.4
Ru-103	390	292.7	14.8	La-140	1157	867.8	2188.1
Zr-97	393	294.8	33.6	I-133	1167	875.3	1337.4
Ru-103	393	295	779.2	I-133	1213	909.7	61.3
Zr-97	396	297.2	27.2	I-133	1215	911.5	13.1

I-131	403	302.4	4.8	La-140	1226	919.6	1003
Zr-97	407	305.1	11.2	La-140	1234	925.2	2587.6
La-140	409	306.9	27.6	La-140	1268	951	189.8
Ru-103	424	317.8	45.4	I-132	1273	954.6	3.9
I-131	424	318.1	76.1	Zr-97	1295	971.3	36
I-131	433	324.7	20.4	I-135	1296	972	4.9
I-131	434	325.8	262.2	I-135	1297	972.6	6.7
La-140	438	328.8	20922.7	La-140	1324	992.9	4.6
Zr-97	441	330.4	53	Zr-97	1357	1018.1	45.9
I-133	461	345.4	76.6	Zr-97	1362	1021.2	125
Zr-97	474	355.4	719.7	Zr-97	1369	1026.7	34.5
Ru-103	477	357.5	19.9	I-133	1381	1035.6	2.2
I-131	478	358.4	13.9	I-135	1385	1038.8	41.7
I-133	481	361.1	77.5	La-140	1393	1045.1	8.4
I-135	482	361.9	2.7	I-133	1403	1052.3	139.1
I-131	486	364.5	69774.5	I-133	1413	1060.1	34.3
I-133	497	372.5	6.8	I-133	1450	1087.7	3
I-133	509	381.6	30	La-140	1463	1097.2	7.4
I-133	516	386.9	38.8	I-135	1469	1101.6	8
La-140	530	397.5	62.1	Zr-97	1481	1110.4	10.6
Zr-97	534	400.4	74.7	I-135	1499	1124	17.6
I-135	537	403	3	I-135	1509	1131.5	109.5
I-131	540	404.8	42	Zr-97	1531	1148	289.7
Zr-97	547	410	20.9	I-135	1559	1169	4.1
I-135	553	414.8	3.8	I-133	1649	1236.4	325.1
I-133	557	417.6	93.6	I-135	1654	1240.5	4
I-135	557	417.7	44.1	I-135	1681	1260.4	125.8
I-133	564	422.9	186.6	Zr-97	1701	1276.1	94.5
I-135	573	429.9	3.7	I-133	1731	1298.2	483.4
La-140	577	432.5	2263.7	La-140	1738	1303.5	11.5
I-135	578	433.7	6.7	I-133	1801	1350.4	29.7
La-140	585	438.5	30	Zr-97	1815	1361	66.3
I-133	585	438.9	23.1	Zr-97	1817	1362.7	96.4
Ru-103	592	443.8	5565.9	I-135	1824	1367.9	2.5
La-140	594	445.5	2.2	La-140	1874	1405.2	15
I-135	602	451.6	3.7	I-135	1943	1457.6	33.1
Zr-97	631	473.5	18	I-135	2004	1502.8	4
La-140	649	487	31522.7	I-135	2089	1566.4	4.6
Ru-103	663	497.1	138134.3	La-140	2128	1596.2	21428.5
I-131	671	503	222.1	I-135	2237	1678	31.8
I-132	674	505.8	2	I-135	2275	1706.5	13.4
Zr-97	677	507.6	1209.1	Zr-97	2334	1750.2	80.8
I-133	681	510.5	909.1	I-135	2388	1791.2	24.1
Zr-97	685	513.4	130.7	Zr-97	2469	1851.6	21.7
Ru-103	686	514.6	16.4	La-140	2503	1877.3	7.8
I-132	697	522.7	6.3	La-140	2566	1924.6	2.5

I-133	706	529.9	41651.4	I-135	2728	2045.9	2.4
I-133	717	537.7	17	La-140	3131	2347.9	128.5
I-135	729	546.6	68.9	I-135	3212	2408.7	2.2
I-133	742	556.2	9.1	La-140	3362	2521.4	483.7
Ru-103	743	557	1177.5	La-140	3396	2547.3	14
Zr-97	744	558	6.1	La-140	3866	2899.6	8
Ru-103	757	567.9	3.8	La-140	4158	3118.5	2.7

Table III. Spectral information for the EPHSOGAM Scenario 1 Locations 2 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Ru-103	53	39.8	83.6	Ru-103	816	612	213.7
Te-132	66	49.7	44786.6	I-133	824	618	333.8
Ru-103	71	53.3	1153	La-140	824	618.1	18.6
La-140	86	64.1	14.9	I-132	840	630.2	4.2
La-140	92	68.9	85.1	I-131	849	637	3688.6
I-131	107	80.2	3516.2	I-131	857	642.7	110.7
La-140	146	109.4	322.1	I-133	865	648.8	33.4
Zr-97	149	111.6	25.3	I-135	866	649.9	2.6
Te-132	149	111.8	11574	Ru-103	869	651.8	12.8
Ru-103	151	113.3	20.5	I-132	890	667.7	29.3
Ru-103	153	115	43.6	I-133	893	670.1	24.4
Te-132	155	116.3	13191	I-133	905	678.7	12.3
La-140	175	131.1	717.6	I-133	907	680.2	363.8
I-133	201	150.4	55.7	Zr-97	921	690.5	21.8
La-140	231	173.5	197.7	Zr-97	932	699.2	11.9
I-133	236	177	146.3	Zr-97	938	703.8	117.9
I-131	236	177.2	436.9	I-133	942	706.6	815.1
Zr-97	244	182.9	12.9	Zr-97	943	707.4	3.7
Zr-97	270	202.5	11.3	I-135	944	707.9	3.4
I-133	272	203.7	7.9	I-131	964	722.9	808.6
Zr-97	292	218.9	61.4	Zr-95	966	724.2	18296.9
I-135	294	220.5	28.5	Zr-97	991	743.4	10310.1
Te-132	304	228.2	529113.7	La-140	1002	751.6	1803.5
I-135	306	229.7	3.8	Zr-95	1009	756.7	21460
I-131	310	232.2	4.5	I-133	1025	768.4	229.4
Zr-95	314	235.7	367.7	Zr-97	1029	772	25.7
Ru-103	323	241.9	90.2	I-132	1030	772.6	19.5
La-140	323	241.9	526	Zr-97	1033	775	20.3
I-133	328	246	53.5	I-133	1053	789.6	24.3
Zr-97	339	254.2	364.6	Zr-97	1073	804.5	62.8
I-133	350	262.7	516.5	Zr-97	1074	805.6	28.8
I-135	352	264.3	2.5	La-140	1088	815.8	8977.4
La-140	355	266.5	540.7	I-133	1094	820.5	72.7
I-133	356	267.2	165.6	Zr-97	1106	829.8	23.9
Zr-97	363	272.4	68.8	I-135	1116	836.8	29.7
I-131	363	272.5	69.3	Zr-97	1140	854.9	34.6
I-131	379	284.3	7065.6	I-133	1142	856.3	559
I-135	385	288.5	39.3	La-140	1157	867.8	2002.3
I-135	387	290.3	3.8	I-133	1167	875.3	1992.1
Ru-103	390	292.7	23.8	I-133	1213	909.7	91.2
Zr-97	393	294.8	22.4	I-133	1215	911.5	19.6
Ru-103	393	295	1255.9	La-140	1226	919.6	918.3
Zr-97	396	297.2	18.1	La-140	1234	925.2	2368

I-131	403	302.4	5.1	La-140	1268	951	173.6
Zr-97	407	305.1	7.5	I-132	1273	954.6	3.7
La-140	409	306.9	25.3	Zr-97	1295	971.3	24
Ru-103	424	317.8	73.1	I-135	1296	972	3.4
I-131	424	318.1	79.9	I-135	1297	972.6	4.7
I-131	433	324.7	21.4	La-140	1324	992.9	4.2
I-131	434	325.8	275.4	I-133	1357	1018.1	2.3
La-140	438	328.8	19148.7	Zr-97	1357	1018.1	30.6
Zr-97	441	330.4	35.3	Zr-97	1362	1021.2	83.3
I-133	461	345.4	114.1	Zr-97	1369	1026.7	23
Zr-97	474	355.4	479.8	I-133	1381	1035.6	3.3
Ru-103	477	357.5	32.1	I-135	1385	1038.8	29
I-131	478	358.4	14.6	La-140	1393	1045.1	7.7
I-133	481	361.1	115.4	I-133	1403	1052.3	207.1
I-131	486	364.5	73292.6	I-133	1413	1060.1	51
I-133	497	372.5	10.2	La-140	1447	1085.2	-163.4
I-133	509	381.6	44.6	I-133	1450	1087.7	4.4
I-133	516	386.9	57.7	La-140	1463	1097.2	6.7
La-140	530	397.5	56.8	I-135	1469	1101.6	5.5
Zr-97	534	400.4	49.8	Zr-97	1481	1110.4	7.1
I-135	537	403	2.1	I-135	1499	1124	12.2
I-131	540	404.8	44.1	I-135	1509	1131.5	76
Zr-97	547	410	13.9	Zr-97	1531	1148	193.1
I-135	553	414.8	2.6	I-135	1559	1169	2.9
I-133	557	417.6	139.4	I-133	1649	1236.4	484.1
I-135	557	417.7	30.6	I-135	1654	1240.5	2.8
I-133	564	422.9	277.8	I-135	1681	1260.4	87.3
I-135	573	429.9	2.6	Zr-97	1701	1276.1	63
La-140	577	432.5	2071.2	I-133	1731	1298.2	720
I-135	578	433.7	4.7	La-140	1738	1303.5	10.5
La-140	585	438.5	27.5	La-140	1768	1325.9	-10.6
I-133	585	438.9	34.4	I-133	1801	1350.4	44.3
Ru-103	592	443.8	8973.3	Zr-97	1815	1361	44.2
La-140	594	445.5	2	Zr-97	1817	1362.7	64.3
I-135	602	451.6	2.6	I-133	1848	1386.2	2.6
Zr-97	631	473.5	12	La-140	1874	1405.2	13.7
La-140	649	487	28854.4	I-135	1943	1457.6	23
Ru-103	663	497.1	222683.7	La-140	1999	1499.4	-51.6
I-131	671	503	233.3	I-135	2004	1502.8	2.8
Zr-97	677	507.6	806.1	I-135	2089	1566.4	3.2
I-133	681	510.5	1353.8	La-140	2128	1596.2	19611.9
Zr-97	685	513.4	87.1	I-135	2237	1678	22.1
Ru-103	686	514.6	26.4	I-135	2275	1706.5	9.3
I-132	697	522.7	6	Zr-97	2334	1750.2	53.9
I-133	706	529.9	62030.7	I-135	2388	1791.2	16.7
I-133	717	537.7	25.3	La-140	2449	1836.9	-11.4

I-135	729	546.6	47.8	Zr-97	2469	1851.6	14.5
I-133	742	556.2	13.6	La-140	2503	1877.3	7.2
Ru-103	743	557	1897.9	La-140	2566	1924.6	2.3
Zr-97	744	558	4.1	La-140	3131	2347.9	117.6
I-133	756	567.1	2	La-140	3362	2521.4	442.6
Ru-103	757	567.9	6.1	La-140	3396	2547.3	12.8
La-140	766	574.2	-304.6	La-140	3866	2899.6	7.3
Zr-97	803	602.4	186.9	La-140	4158	3118.5	2.5
Ru-103	814	610.3	11515.2				

Table IV. Spectral information for the EPHSOGAM Scenario 1 Location 3 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
La-140	33	24.6	21.6	I-132	970	727.2	3152
Te-131m	49	36.8	34.7	I-132	971	728.4	1573.5
Te-132	66	49.7	1546270	I-134	974	730.7	30.8
Te-131m	68	51	64.1	Te-131m	985	738.8	407.3
Te-131m	70	52.6	60.1	I-134	986	739.2	11.5
Te-131m	72	54.1	13.5	Zr-97	991	743.4	376317.4
Te-131m	74	55.8	33.3	Te-131m	992	744.2	9735.5
Te-131m	81	60.8	82.9	Te-131m	999	749	93.5
Te-131m	83	62.4	541.5	La-140	1002	751.6	43122.5
Te-131m	84	63.2	64.2	Zr-95	1009	756.7	383998.9
La-140	86	64.1	357	I-134	1022	766.7	66.9
Te-131m	87	65.1	125.9	I-133	1025	768.4	10044.1
Te-131m	89	67	367.7	I-132	1029	771.7	18.6
La-140	92	68.9	2033.6	Zr-97	1029	772	937.2
Te-131m	98	73.3	466.8	I-132	1030	772.6	70332.2
Te-131m	105	78.6	280.6	Te-131m	1032	773.7	226321.4
Te-131m	106	79.2	2355	Te-131m	1032	774.1	3217.3
I-131	107	80.2	50148.6	Zr-97	1033	775	739.3
Te-131m	108	81.1	76034.8	I-132	1040	780	1088.1
Te-131m	115	86.4	2847.1	Te-131m	1043	782.5	45591
Te-131m	127	95	79.3	I-132	1046	784.4	348.5
Te-131m	129	96.4	125.1	I-135	1047	785.5	1871
Te-131m	131	98.3	284.1	I-133	1053	789.6	1065.4
Te-131m	133	100	1526.5	I-132	1055	791.2	90.1
Te-131m	135	101.6	3570	Te-131m	1058	793.8	80128.1
Te-131m	137	102.6	166694.4	I-135	1061	795.5	277.9
Te-131m	138	103.3	983.3	I-135	1064	797.7	2049.2
Te-131m	140	105	567.7	Te-131m	1069	801.6	109.7
Te-131m	146	109.4	756.7	Zr-97	1073	804.5	2292.2
La-140	146	109.4	7703	Zr-97	1074	805.6	1050.8
Te-131m	148	111	661.3	I-135	1076	807.2	548.4
Zr-97	149	111.6	925.3	I-132	1079	809.5	2333.3
Te-132	149	111.8	399579.6	I-132	1083	812	4883.8
Te-131m	151	113.5	249.7	La-140	1088	815.8	214721.5
Te-132	155	116.3	455380.6	I-134	1089	816.4	9.4
Te-131m	165	123.7	86.8	I-133	1094	820.5	3182.6
Te-131m	167	125.2	187.6	Te-131m	1097	822.8	34204.8
Te-131m	168	126.1	136.6	Zr-97	1106	829.8	872.5
Te-131m	170	127.4	513.3	I-132	1108	831.3	21.7
Te-131m	174	130.5	1563.1	I-135	1116	836.8	77568.9
La-140	175	131.1	17158.3	Te-131m	1127	844.9	835.3
Te-131m	176	132.2	103.3	I-134	1129	847	1405.4

Te-131m	180	134.9	16047.5	I-132	1131	847.9	14.5
I-134	181	135.4	262.5	Te-131m	1132	848.9	212.1
I-132	182	136.7	279.7	Te-131m	1136	852.2	2113.2
Te-131m	183	137.6	1729.2	Te-131m	1136	852.2	111874.1
I-134	185	139	45.9	Zr-97	1140	854.9	1264
I-132	197	147.4	843.6	Te-131m	1141	856.1	3341.6
Te-131m	199	149.3	1754.7	I-133	1142	856.3	24476.6
Te-131m	200	149.7	105305.8	I-134	1143	857.3	97.3
I-133	201	150.4	2439.6	I-132	1151	863	471.5
Te-131m	202	151.2	1737.4	I-134	1152	864	2.7
I-134	203	152	6.5	Te-131m	1153	865.1	1021.5
Te-131m	208	155.9	868.3	I-132	1155	866	30.1
Te-131m	213	159.7	2897.4	La-140	1157	867.8	47888.3
I-134	217	162.5	17.8	Te-131m	1163	872.3	531.1
I-135	217	162.7	474	I-133	1167	875.3	87198.5
I-135	221	165.7	1514.5	I-132	1169	876.6	860
Te-131m	226	169.7	690.3	Te-131m	1175	881.6	184.6
Te-131m	229	172	258.5	I-134	1179	884.1	918.4
La-140	231	173.5	4726.7	I-132	1181	886.1	20.5
I-133	236	177	6403.9	I-132	1185	888.7	28.6
Te-131m	236	177.2	1475.7	I-132	1206	904.4	10.4
I-131	236	177.2	6235.5	I-133	1213	909.7	3992.4
Te-131m	243	182.3	15364.4	Te-131m	1213	910	16765.9
Te-131m	243	182.3	16387.3	I-132	1213	910.1	742.8
Zr-97	244	182.9	469.2	I-133	1215	911.5	856.7
Te-131m	244	183.1	3445.7	La-140	1226	919.6	21947.6
I-132	245	183.6	482.1	Te-131m	1227	920.6	6055.2
I-135	246	184.5	1103.9	Te-131m	1231	923.4	576.9
Te-131m	251	188.1	4727.4	La-140	1234	925.2	56620.2
I-134	251	188.5	45.5	I-132	1237	927.4	321.8
Te-131m	253	189.8	11172.4	Te-131m	1240	930	95.5
Te-131m	254	190.5	2570.9	Te-131m	1255	941.3	3854.4
I-135	263	197.2	1513.5	I-132	1263	947.2	33.9
Te-131m	268	200.6	164274.2	I-134	1264	947.9	53.1
Zr-97	270	202.5	412.3	La-140	1268	951	4151.5
Te-131m	271	203.4	412.1	I-132	1273	954.6	13454
I-133	272	203.7	346.6	I-135	1280	960.3	304.4
Te-131m	277	207.5	827.5	I-135	1282	961.4	1520.2
Te-131m	280	210.3	321	I-132	1288	965.9	26.5
Te-131m	283	211.9	239.3	I-134	1289	966.9	5.1
Te-131m	285	214	8797	Zr-97	1295	971.3	876.9
I-134	289	217	12.7	I-135	1296	972	8903.6
Zr-97	292	218.9	2241.8	I-135	1297	972.6	12130.1
I-135	294	220.5	74281.7	I-134	1300	974.7	61.7
Te-131m	304	227.7	300.1	I-132	1312	984.2	438.4
Te-132	304	228.2	18269910	Te-131m	1317	987.8	730

I-135	306	229.7	9891.1	La-140	1324	992.9	99.9
Te-131m	308	230.7	3754.2	I-135	1327	995.1	1570.8
I-131	310	232.2	63.6	Te-131m	1327	995.1	416.3
Te-131m	310	232.3	1783.9	I-132	1328	995.8	22
I-132	312	234.3	89.9	Te-131m	1332	999.3	797.3
Te-131m	313	235	291.9	Te-131m	1338	1003.6	124.6
I-134	314	235.5	109.7	Te-131m	1341	1005.8	341
Zr-95	314	235.7	6578.5	I-132	1345	1009	33.4
Te-131m	321	240.9	141391.5	Zr-97	1357	1018.1	1117.7
La-140	323	241.9	12576.9	I-133	1357	1018.1	100.8
I-133	328	246	2344.4	Zr-97	1362	1021.2	3041
I-135	330	247.5	1104.3	Te-131m	1365	1023.6	286
I-132	334	250.8	50.7	Zr-97	1369	1026.7	839
Te-131m	338	253.2	11587.8	Te-131m	1370	1027.8	34.8
Zr-97	339	254.2	13309	I-132	1380	1035	361.6
I-135	340	254.7	852.4	Te-131m	1381	1035.4	473.9
I-132	340	255.1	657.4	I-133	1381	1035.6	144
Te-131m	341	255.4	5476.4	I-135	1385	1038.8	75548.4
Te-131m	349	261.4	264.5	I-134	1387	1040.3	24.6
I-133	350	262.7	22609.9	La-140	1393	1045.1	183.3
I-132	351	262.9	3450.1	I-132	1399	1049.6	32.2
I-135	352	264.3	6625	I-133	1403	1052.3	9064
La-140	355	266.5	12932.3	Te-131m	1413	1059.7	6839.1
I-133	356	267.2	7249.4	I-133	1413	1060.1	2234.7
Te-131m	356	267.2	259.1	Te-131m	1430	1072.3	100.5
Zr-97	363	272.4	2513.7	I-134	1430	1072.6	176.3
I-131	363	272.5	989.3	I-132	1442	1081.8	24.2
I-132	371	278.4	99.5	I-132	1448	1086.2	53.6
Te-131m	371	278.6	28991.3	I-133	1450	1087.7	192.9
I-134	372	278.8	6.3	I-135	1462	1096.9	807.2
Te-131m	375	281.4	566.6	I-132	1463	1096.9	29.6
Te-131m	378	283.2	6244.8	La-140	1463	1097.2	161.1
I-131	379	284.3	100827.7	I-134	1467	1100.1	8
I-132	380	284.9	1770.7	I-135	1469	1101.6	14473.4
I-135	385	288.5	102624.2	I-134	1471	1103.2	9.2
I-135	387	290.3	10002.9	Te-131m	1478	1108.3	97.4
Te-131m	387	290.3	1207	Zr-97	1481	1110.4	259.1
Zr-97	393	294.8	817.2	I-132	1483	1112.4	43.1
I-131	394	295.8	28.4	Te-131m	1485	1114.1	48.5
Te-131m	396	297.1	770.9	I-135	1499	1124	31911.4
Zr-97	396	297.2	662.3	Te-131m	1501	1125.5	47707.2
I-131	403	302.4	72.6	I-132	1502	1126.5	32.1
Te-131m	404	302.7	584.8	Te-131m	1503	1127	4029.2
Te-131m	405	303.9	582.5	I-135	1509	1131.5	198157
I-135	407	304.9	996.3	Te-131m	1512	1134.2	31.8
Zr-97	407	305.1	273.8	I-132	1515	1136	1957.9

I-135	408	305.8	2979.6	I-134	1515	1136.2	102
I-132	409	306.7	229.6	I-132	1524	1143.3	872.9
La-140	409	306.9	604.3	I-132	1530	1147.8	175.8
Te-131m	413	309.5	5495	Zr-97	1531	1148	7052.1
I-132	413	310.1	204.1	Te-131m	1532	1148.9	942.4
I-132	414	310.4	203.9	Te-131m	1532	1148.9	6282.5
I-132	422	316.7	287.4	Te-131m	1535	1150.9	2697.4
I-131	424	318.1	1139.9	I-135	1536	1151.9	8.9
I-134	426	319.8	17.6	I-134	1545	1159.1	3.7
Te-131m	432	323.7	214.4	I-135	1547	1159.9	885.7
I-131	433	324.7	305.1	Te-131m	1550	1162.7	108.7
I-131	434	325.8	3929.5	Te-131m	1554	1165.5	564.1
I-135	435	326	66.9	I-135	1559	1169	7448.1
La-140	438	328.8	457744.3	I-132	1564	1172.9	688.2
Zr-97	441	330.4	1290.6	I-135	1574	1180.5	536.2
Te-131m	442	331.2	419	Te-131m	1575	1181.4	45.9
I-135	445	333.6	1080.8	I-134	1587	1190	3.8
Te-131m	446	334.3	129642.1	Te-131m	1609	1206.6	38236.5
Te-131m	447	335.4	1861.5	Te-131m	1615	1211	242.3
I-135	457	342.5	24.9	I-132	1616	1212.3	7.3
Te-131m	457	342.9	5158.6	I-135	1634	1225.6	347.9
I-132	458	343.7	184	Te-131m	1636	1227.2	11.4
I-133	461	345.4	4995.5	I-133	1649	1236.4	21189.8
Te-131m	461	345.9	1303.3	Te-131m	1650	1237.3	2521.5
I-134	468	351.1	14.7	I-134	1652	1239	2.2
Te-131m	468	351.3	2694.4	I-135	1654	1240.5	7279.6
I-132	469	351.8	159.5	I-132	1672	1254.1	35
Te-131m	471	353.5	980.7	Te-131m	1672	1254.2	101.3
Te-131m	473	354.7	2912.5	I-135	1673	1254.8	47.5
Zr-97	474	355.4	17521	I-135	1681	1260.4	227755.6
Te-131m	477	357.4	242.5	I-132	1685	1263.6	15.9
I-131	478	358.4	208.3	I-134	1693	1269.5	5.7
I-133	481	361.1	5050.2	I-132	1697	1272.8	98.3
I-135	482	361.9	4925.8	Zr-97	1701	1276.1	2300.7
Te-131m	483	362.3	956.6	I-135	1704	1277.8	451.2
I-132	484	363.3	957.6	I-132	1721	1290.8	652.4
I-131	486	364.5	1045894	I-132	1727	1295.1	1082.4
Te-131m	487	365	14905.8	I-132	1731	1297.9	511.2
I-133	497	372.5	444.9	I-133	1731	1298.2	31511.4
Te-131m	501	375.8	138.3	La-140	1738	1303.5	250.6
Te-131m	506	379.3	228.3	I-135	1745	1308.7	261.4
I-133	509	381.6	1953.5	I-132	1752	1314	33.5
Te-131m	512	383.9	2345.1	Te-131m	1754	1315.6	2518.5
I-133	516	386.9	2526.1	I-135	1754	1315.8	499.5
I-132	517	387.9	548.6	Te-131m	1755	1316.2	359.6
La-140	530	397.5	1358.3	I-132	1757	1317.9	66.8

Zr-97	534	400.4	1819.8	Te-131m	1758	1318.3	140.9
I-135	537	403	5493.4	Te-131m	1778	1333.8	193.9
Te-131m	538	403.3	343.1	I-135	1780	1334.8	239
I-131	540	404.8	629.6	Te-131m	1787	1340.6	356.2
I-134	541	405.5	221.7	I-135	1792	1343.7	578.9
Te-131m	544	408.2	677.9	I-133	1801	1350.4	1938.2
Zr-97	547	410	507.5	I-134	1803	1352.6	3.9
I-134	548	411	17	Zr-97	1815	1361	1612.5
I-135	553	414.8	6909.7	Zr-97	1817	1362.7	2347.6
I-132	556	416.8	799	I-135	1824	1367.9	4472.9
Te-131m	557	417.4	3016.3	I-132	1829	1372.1	1346.2
I-133	557	417.6	6100.7	Te-131m	1836	1376.8	148.5
I-135	557	417.7	79752.2	I-133	1848	1386.2	113.5
I-133	564	422.9	12164.6	Te-131m	1853	1389.6	52.6
I-135	573	429.9	6730.2	I-132	1854	1390.7	8.1
I-132	576	431.8	770.9	Te-131m	1860	1394.8	371.9
Te-131m	577	432.4	6876.2	I-132	1865	1398.6	3752.2
La-140	577	432.5	49542.4	Te-131m	1871	1403.6	39
I-134	578	433.4	116.7	La-140	1874	1405.2	327.9
I-135	578	433.7	12163	I-132	1881	1410.6	22.8
La-140	585	438.5	657.1	I-134	1886	1414.3	2
I-133	585	438.9	1507.1	I-135	1888	1416.3	225.9
La-140	594	445.5	48.1	I-135	1922	1441.8	118
I-132	595	446.2	952.1	I-132	1923	1442.6	727.5
I-135	602	451.6	6655.5	I-135	1931	1448.4	2211.5
Te-131m	603	452.3	15279.4	I-134	1940	1455.2	20.4
I-134	612	458.9	34.9	I-132	1942	1456.5	25.2
Te-131m	617	462.9	17763.2	I-135	1943	1457.6	59962.8
I-134	621	465.5	9.4	I-134	1960	1470	6.6
Te-131m	624	468.2	3025.7	I-132	1969	1476.7	66.1
Zr-97	631	473.5	439	Te-131m	1995	1496.5	186.1
I-132	631	473.6	254	I-135	2004	1502.8	7203.2
I-132	638	478.2	251.6	I-132	2026	1519.6	39.1
La-140	649	487	689787.2	I-135	2029	1522	250.4
I-132	651	488	594.7	I-134	2055	1541.5	4.3
I-134	652	488.8	36.2	I-132	2056	1542.3	7.7
Te-131m	657	492.7	701.3	I-135	2058	1543.7	169
I-131	671	503	3330.4	Te-131m	2064	1547.8	215.7
I-132	674	505.8	6915.2	I-135	2089	1566.4	8329.6
Te-131m	676	506.8	790.9	I-133	2120	1589.9	33.1
Zr-97	677	507.6	29419.8	I-132	2124	1592.9	22.2
I-133	681	510.5	59270.8	La-140	2128	1596.2	469007
Zr-97	685	513.4	3181.5	I-135	2152	1613.8	161.8
I-134	686	514.4	52.9	I-134	2152	1613.8	34.5
I-132	697	522.7	21683.3	I-132	2157	1617.9	4.7
Te-131m	700	524.8	1165.9	I-132	2159	1618.9	3.3

I-133	706	529.9	2716571	I-132	2182	1636.5	5.5
Te-131m	708	530.7	892.6	I-132	2192	1644	6
I-135	708	530.8	570.1	I-134	2192	1644.3	3.2
I-132	714	535.3	692.3	Te-131m	2195	1646	3616.4
I-133	717	537.7	1107.5	I-132	2215	1661.4	7.3
I-134	721	540.8	172.4	I-132	2228	1671.3	9.9
Te-131m	722	541.4	958.1	I-135	2237	1678	57626.8
I-135	729	546.6	124622.2	Te-131m	2262	1696.8	43.3
Te-131m	729	546.7	322.7	I-135	2275	1706.5	24332.6
I-132	730	547.2	1476.4	I-132	2287	1715.4	24.1
I-133	742	556.2	595.2	I-132	2294	1720.6	23.6
Zr-97	744	558	149.2	I-132	2303	1727.2	29.2
Te-131m	744	558.1	186	I-134	2322	1741.5	19.1
I-132	746	559.7	112.7	Zr-97	2334	1750.2	1967.7
I-134	754	565.5	20.3	I-132	2336	1752.3	10.7
I-133	756	567.1	87.6	I-132	2343	1757.4	128.6
I-134	761	570.8	6.6	I-132	2347	1760.4	25.2
I-132	763	572.5	73.1	I-132	2358	1768.5	10.6
Te-131m	764	572.7	362.7	I-132	2371	1778.5	33.5
I-135	768	576	2137.4	I-132	2382	1786.5	4.6
Te-131m	773	579.8	597.3	I-135	2388	1791.2	43624
Te-131m	782	586.3	15243.9	I-134	2409	1806.8	39.8
I-135	784	588.3	837.5	I-132	2419	1814	6.6
I-132	788	591.1	84.1	I-132	2440	1830.1	11.5
I-134	794	595.4	228.4	Te-131m	2441	1830.6	40.2
Te-131m	796	597	383.2	I-135	2441	1830.7	3207.5
I-132	800	600.1	153.9	I-135	2460	1845.3	32.7
Te-131m	803	602	2303	Zr-97	2469	1851.6	529
Zr-97	803	602.4	6826.7	La-140	2503	1877.3	171.5
Te-131m	813	609.4	1035.8	I-132	2506	1879.2	5.6
I-132	813	609.8	45.4	Te-131m	2507	1880.1	158.3
I-135	823	616.9	584.5	Te-131m	2517	1887.7	3445.7
I-133	824	618	14612.5	I-132	2552	1913.7	11.8
La-140	824	618.1	443.9	I-132	2562	1921.8	481.8
I-132	828	620.9	446.6	Te-131m	2565	1924.1	9.7
I-132	828	621.2	1807.8	La-140	2566	1924.6	54.7
I-134	829	621.8	209.1	I-135	2570	1927.3	1553.4
I-134	837	628	43.2	Te-131m	2582	1936.2	182.1
I-132	840	630.2	15014.6	I-135	2598	1948.5	329.9
I-131	849	637	52641.7	Te-131m	2640	1980.3	74.1
I-131	857	642.7	1579.7	I-132	2648	1985.6	4.2
I-133	865	648.8	1461.1	Te-131m	2668	2000.9	4822.5
I-135	866	649.9	6730.9	I-132	2670	2002.2	428
I-132	867	650.5	2813.7	I-135	2728	2045.9	4313.2
I-135	875	656.1	1087.4	La-140	2778	2083.2	41.9
Te-131m	876	657.2	211.7	I-132	2782	2086.8	92.4

Te-131m	887	665.1	29616.1	I-135	2817	2112.4	331.8
I-132	890	667.7	105741.7	I-135	2869	2151.5	103.8
I-132	893	669.8	4898.4	Te-131m	2891	2168.5	767
I-133	893	670.1	1068.7	I-132	2897	2172.7	71.4
I-132	895	671.4	3718.6	I-135	2906	2179.7	18.4
I-134	903	677.3	143.6	I-132	2916	2187	2.4
I-133	905	678.7	540.3	I-135	2919	2189.4	58.8
I-135	906	679.2	771.4	I-132	2964	2223.2	39.7
I-133	907	680.2	15917.4	I-134	2982	2236.7	3.1
Te-131m	909	681.9	204.3	I-132	2999	2249.1	11.2
I-132	913	684.4	83.5	I-135	3007	2255.5	2732.6
I-135	913	684.6	310.4	Te-131m	3028	2270.7	803.9
Te-131m	915	685.9	1026.4	Te-131m	3110	2332.7	5.5
I-132	917	687.8	40.5	La-140	3131	2347.9	2812
I-135	920	690.1	1795.9	I-132	3187	2390.5	58.5
Zr-97	921	690.5	794.1	I-132	3211	2408.6	2.9
Te-131m	927	695.6	2607.3	I-135	3212	2408.7	3925.6
Zr-97	932	699.2	433	La-140	3285	2464.1	35.8
Te-131m	937	702.5	2537.7	I-135	3288	2466.1	287.2
Zr-97	938	703.8	4303.8	I-135	3303	2477.1	5.7
I-133	942	706.6	35679.2	La-140	3362	2521.4	10582.9
I-134	942	706.7	14.5	I-132	3367	2525.1	11.4
Zr-97	943	707.4	135.7	La-140	3377	2533.1	11.8
I-135	944	707.9	8900	La-140	3396	2547.3	305.5
Te-131m	951	713.1	9157.5	La-140	3866	2899.6	174.4
I-131	964	722.9	11539.1	La-140	4158	3118.5	59.4
Zr-95	966	724.2	327436.8	La-140	4427	3320.4	8.4
I-132	969	726.8	2140				

Table V. Spectral information for the EPHSOGAM Scenario 2 Location 1 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Te-131m	49	36.8	16.4	I-132	917	687.8	6.7
Te-132	66	49.7	5711426	I-135	920	690.1	651.7
Te-131m	68	51	30.3	Zr-97	921	690.5	1973
Te-131m	70	52.6	28.4	Te-131m	927	695.6	1232.1
Te-131m	72	54.1	6.4	Zr-97	932	699.2	1075.8
Te-131m	74	55.8	15.7	Te-131m	937	702.5	1199.5
Te-131m	81	60.8	39.2	Zr-97	938	703.8	10691.6
Te-131m	83	62.4	256	I-133	942	706.6	25764.1
Te-131m	84	63.2	30.4	Zr-97	943	707.4	337
La-140	86	64.1	966.2	I-135	944	707.9	3230.1
Te-131m	87	65.1	59.5	Te-131m	951	713.1	4327.8
Te-131m	89	67	173.8	I-131	964	722.9	34504.2
La-140	92	68.9	5504.4	Zr-95	966	724.2	1479410
Te-131m	98	73.3	220.6	I-132	969	726.8	354.4
Te-131m	105	78.6	132.6	I-132	970	727.2	522.1
Te-131m	106	79.2	1113	I-132	971	728.4	260.7
I-131	107	80.2	150013.4	Te-131m	985	738.8	192.4
Te-131m	108	81.1	35935.8	Zr-97	991	743.4	934922.6
I-131	115	85.9	5.4	Te-131m	992	744.2	4601.7
Te-131m	115	86.4	1345.8	Te-131m	999	749	44.2
Te-131m	127	95	37.5	La-140	1002	751.6	116712.8
Te-131m	129	96.4	59.1	Zr-95	1009	756.7	1736233
Te-131m	131	98.3	134.3	I-133	1025	768.4	7254.1
Te-131m	133	100	721.7	I-132	1029	771.7	3.1
Te-131m	135	101.6	1687.1	Zr-97	1029	772	2328.6
Te-131m	137	102.6	78752.1	I-132	1030	772.6	11651.2
Te-131m	138	103.3	464.6	Te-131m	1032	773.7	106940.7
Te-131m	140	105	268.3	Te-131m	1032	774.1	1520.4
Te-131m	146	109.4	357.7	Zr-97	1033	775	1836.8
La-140	146	109.4	20846.6	I-132	1040	780	180.3
Te-131m	148	111	312.6	Te-131m	1043	782.5	21546.9
Zr-97	149	111.6	2298.4	I-132	1046	784.4	57.7
Te-132	149	111.8	1475557	I-135	1047	785.5	678.8
Te-131m	151	113.5	118	I-133	1053	789.6	769.5
Te-132	155	116.3	1681931	I-132	1055	791.2	14.9
Te-131m	165	123.7	41	Te-131m	1058	793.8	37876.1
Te-131m	167	125.2	88.6	I-135	1061	795.5	100.8
Te-131m	168	126.1	64.6	I-135	1064	797.7	743.4
Te-131m	170	127.4	242.6	Te-131m	1069	801.6	51.8
Te-131m	174	130.5	738.7	Zr-97	1073	804.5	5693.4
La-140	175	131.1	46435.2	Zr-97	1074	805.6	2610.7
Te-131m	176	132.2	48.8	I-135	1076	807.2	199

Te-131m	180	134.9	7582.9	I-132	1079	809.5	386.5
I-132	182	136.7	46.3	I-132	1083	812	809.1
Te-131m	183	137.6	817.3	La-140	1088	815.8	581165.4
I-132	197	147.4	139.7	I-133	1094	820.5	2298.8
Te-131m	199	149.3	829.5	Te-131m	1097	822.8	16171.5
Te-131m	200	149.7	49757.4	Zr-97	1106	829.8	2167.6
I-133	201	150.4	1761.7	I-132	1108	831.3	3.6
Te-131m	202	151.2	821.2	I-135	1116	836.8	28146.3
Te-131m	208	155.9	410.4	Te-131m	1127	844.9	394.8
Te-131m	213	159.7	1369.3	I-132	1131	847.9	2.4
I-135	217	162.7	172	Te-131m	1132	848.9	100.2
I-135	221	165.7	549.4	Te-131m	1136	852.2	998.7
Te-131m	226	169.7	326.3	Te-131m	1136	852.2	52874.9
Te-131m	229	172	122.2	Zr-97	1140	854.9	3139.9
La-140	231	173.5	12792.9	Te-131m	1141	856.1	1579.8
I-133	236	177	4624.7	I-133	1142	856.3	17676.9
Te-131m	236	177.2	697.1	I-132	1151	863	78.1
I-131	236	177.2	18654.2	Te-131m	1153	865.1	482.8
Te-131m	243	182.3	7264.2	I-132	1155	866	5
Te-131m	243	182.3	7747.1	La-140	1157	867.8	129601.9
Zr-97	244	182.9	1165.4	Te-131m	1163	872.3	251.1
Te-131m	244	183.1	1628.4	I-133	1167	875.3	62971.2
I-132	245	183.6	79.8	I-132	1169	876.6	142.5
I-135	246	184.5	400.6	Te-131m	1175	881.6	87.3
Te-131m	251	188.1	2234.2	I-132	1181	886.1	3.4
Te-131m	253	189.8	5282.4	I-132	1185	888.7	4.7
Te-131m	254	190.5	1215	I-133	1213	909.7	2883.4
I-135	263	197.2	549.2	Te-131m	1213	910	7922.9
Te-131m	268	200.6	77627.4	I-132	1213	910.1	123.1
Zr-97	270	202.5	1024.3	I-133	1215	911.5	618.7
Te-131m	271	203.4	194.8	La-140	1226	919.6	59407.6
I-133	272	203.7	250.3	Te-131m	1227	920.6	2862.2
Te-131m	277	207.5	391.1	Te-131m	1231	923.4	272.7
Te-131m	280	210.3	151.7	La-140	1234	925.2	153198.1
Te-131m	283	211.9	113.1	I-132	1237	927.4	53.3
Te-131m	285	214	4157.9	Te-131m	1240	930	45.1
Zr-97	292	218.9	5566.7	Te-131m	1255	941.3	1821.5
I-135	294	220.5	26948.8	I-132	1263	947.2	5.6
Te-131m	304	227.7	141.9	La-140	1268	951	11236.5
Te-132	304	228.2	67475660	I-132	1273	954.6	2228
I-135	306	229.7	3588.3	I-135	1280	960.3	110.4
Te-131m	308	230.7	1774.4	I-135	1282	961.4	551.6
I-131	310	232.2	190.1	I-132	1288	965.9	4.4
Te-131m	310	232.3	843.1	Zr-97	1295	971.3	2178.9
I-132	312	234.3	14.9	I-135	1296	972	3230.8
Te-131m	313	235	137.9	I-135	1297	972.6	4401.6

Zr-95	314	235.7	29745.1	I-132	1312	984.2	72.6
Te-131m	321	240.9	66833.3	Te-131m	1317	987.8	345
La-140	323	241.9	34042.8	La-140	1324	992.9	270.5
I-133	328	246	1693.3	I-135	1327	995.1	569.9
I-135	330	247.5	400.7	Te-131m	1327	995.1	196.8
I-132	334	250.8	8.4	I-132	1328	995.8	3.7
Te-131m	338	253.2	5476.8	Te-131m	1332	999.3	376.8
Zr-97	339	254.2	33057.6	Te-131m	1338	1003.6	58.9
I-135	340	254.7	309.4	Te-131m	1341	1005.8	161.2
I-132	340	255.1	108.9	I-132	1345	1009	5.5
Te-131m	341	255.4	2587.7	Zr-97	1357	1018.1	2774.9
Te-131m	349	261.4	125	I-133	1357	1018.1	72.8
I-133	350	262.7	16327.8	Zr-97	1362	1021.2	7554.5
I-132	351	262.9	571.3	Te-131m	1365	1023.6	135.1
I-135	352	264.3	2403.6	Zr-97	1369	1026.7	2084.4
La-140	355	266.5	34998.2	Te-131m	1370	1027.8	16.5
I-133	356	267.2	5236.1	I-132	1380	1035	59.9
Te-131m	356	267.2	122.4	Te-131m	1381	1035.4	224
Zr-97	363	272.4	6245.5	I-133	1381	1035.6	104
I-131	363	272.5	2958.6	I-135	1385	1038.8	27416.9
I-132	371	278.4	16.5	La-140	1393	1045.1	495.9
Te-131m	371	278.6	13702.9	I-132	1399	1049.6	5.3
Te-131m	375	281.4	267.8	I-133	1403	1052.3	6545.7
Te-131m	378	283.2	2951.1	Te-131m	1413	1059.7	3232.1
I-131	379	284.3	301555.7	I-133	1413	1060.1	1614
I-132	380	284.9	293.3	Te-131m	1430	1072.3	47.5
I-135	385	288.5	37231.4	I-132	1442	1081.8	4
I-135	387	290.3	3629.3	I-132	1448	1086.2	8.9
Te-131m	387	290.3	570.6	I-133	1450	1087.7	139.3
Zr-97	393	294.8	2030.4	I-135	1462	1096.9	292.9
I-131	394	295.8	85	I-132	1463	1096.9	4.9
Te-131m	396	297.1	364.5	La-140	1463	1097.2	436.2
Zr-97	396	297.2	1645.2	I-135	1469	1101.6	5250.9
I-131	403	302.4	217.2	Te-131m	1478	1108.3	46.1
Te-131m	404	302.7	276.3	Zr-97	1481	1110.4	643.8
Te-131m	405	303.9	275.3	I-132	1483	1112.4	7.1
I-135	407	304.9	361.4	Te-131m	1485	1114.1	22.9
Zr-97	407	305.1	680.2	I-135	1499	1124	11582.9
I-135	408	305.8	1081	Te-131m	1501	1125.5	22543.8
I-132	409	306.7	38	I-132	1502	1126.5	5.3
La-140	409	306.9	1635.5	Te-131m	1503	1127	1904.2
Te-131m	413	309.5	2597.4	I-135	1509	1131.5	71898.5
I-132	413	310.1	33.8	Te-131m	1512	1134.2	15
I-132	414	310.4	33.8	I-132	1515	1136	324.3
I-132	422	316.7	47.6	I-132	1524	1143.3	144.6
I-131	424	318.1	3408	I-132	1530	1147.8	29.1

Te-131m	432	323.7	101.3	Zr-97	1531	1148	17515.4
I-131	433	324.7	912.5	Te-131m	1532	1148.9	445.4
I-131	434	325.8	11752.9	Te-131m	1532	1148.9	2969.3
I-135	435	326	24.3	Te-131m	1535	1150.9	1274.3
La-140	438	328.8	1239376	I-135	1536	1151.9	3.2
Zr-97	441	330.4	3206.4	I-135	1547	1159.9	321.4
Te-131m	442	331.2	198.1	Te-131m	1550	1162.7	51.4
I-135	445	333.6	392.2	Te-131m	1554	1165.5	266.6
Te-131m	446	334.3	61269.8	I-135	1559	1169	2702.7
Te-131m	447	335.4	879.8	I-132	1564	1172.9	114
I-135	457	342.5	9	I-135	1574	1180.5	194.5
Te-131m	457	342.9	2437.8	Te-131m	1575	1181.4	21.7
I-132	458	343.7	30.5	Te-131m	1609	1206.6	18073.1
I-133	461	345.4	3606.1	Te-131m	1615	1211	114.5
Te-131m	461	345.9	616	I-135	1634	1225.6	126.2
Te-131m	468	351.3	1273.3	Te-131m	1636	1227.2	5.4
I-132	469	351.8	26.4	I-133	1649	1236.4	15301.3
Te-131m	471	353.5	463.5	Te-131m	1650	1237.3	1191.2
Te-131m	473	354.7	1376.6	I-135	1654	1240.5	2640.9
Zr-97	474	355.4	43520.6	I-132	1672	1254.1	5.8
Te-131m	477	357.4	114.6	Te-131m	1672	1254.2	47.9
I-131	478	358.4	623	I-135	1673	1254.8	17.2
I-133	481	361.1	3649	I-135	1681	1260.4	82637
I-135	482	361.9	1786.8	I-132	1685	1263.6	2.6
Te-131m	483	362.3	452.1	I-132	1697	1272.8	16.3
I-132	484	363.3	158.6	Zr-97	1701	1276.1	5716.3
I-131	486	364.5	3128719	I-135	1704	1277.8	163.8
Te-131m	487	365	7045.8	I-132	1721	1290.8	108.1
I-133	497	372.5	321.3	I-132	1727	1295.1	179.2
Te-131m	501	375.8	65.3	I-132	1731	1297.9	84.7
Te-131m	506	379.3	107.9	I-133	1731	1298.2	22757.8
I-133	509	381.6	1410.9	La-140	1738	1303.5	678.3
Te-131m	512	383.9	1108.2	I-135	1745	1308.7	94.8
I-133	516	386.9	1824.2	I-132	1752	1314	5.5
I-132	517	387.9	90.9	Te-131m	1754	1315.6	1190.2
La-140	530	397.5	3675	I-135	1754	1315.8	181.3
Zr-97	534	400.4	4520.5	Te-131m	1755	1316.2	170
I-135	537	403	1993.5	I-132	1757	1317.9	11.1
Te-131m	538	403.3	162.2	Te-131m	1758	1318.3	66.6
I-131	540	404.8	1882.4	Te-131m	1778	1333.8	91.7
Te-131m	544	408.2	320.4	I-135	1780	1334.8	86.7
Zr-97	547	410	1260.9	Te-131m	1787	1340.6	168.4
I-135	553	414.8	2507	I-135	1792	1343.7	210
I-132	556	416.8	132.4	I-133	1801	1350.4	1399.5
Te-131m	557	417.4	1425.5	Zr-97	1815	1361	4006
I-133	557	417.6	4405.5	Zr-97	1817	1362.7	5830.2

I-135	557	417.7	28934.4	I-135	1824	1367.9	1622.7
I-133	564	422.9	8785.3	I-132	1829	1372.1	223
I-135	573	429.9	2441.9	Te-131m	1836	1376.8	70.2
I-132	576	431.8	127.7	I-133	1848	1386.2	81.9
Te-131m	577	432.4	3248.4	Te-131m	1853	1389.6	24.8
La-140	577	432.5	134090.2	Te-131m	1860	1394.8	175.8
I-135	578	433.7	4413.9	I-132	1865	1398.6	621.5
La-140	585	438.5	1778.3	Te-131m	1871	1403.6	18.5
I-133	585	438.9	1088.4	La-140	1874	1405.2	887.4
La-140	594	445.5	130.1	I-132	1881	1410.6	3.8
I-132	595	446.2	157.7	I-135	1888	1416.3	82
I-135	602	451.6	2415.5	I-135	1922	1441.8	42.8
Te-131m	603	452.3	7221.4	I-132	1923	1442.6	120.5
Te-131m	617	462.9	8396.9	I-135	1931	1448.4	802.2
Te-131m	624	468.2	1430	I-132	1942	1456.5	4.2
Zr-97	631	473.5	1090.5	I-135	1943	1457.6	21759.5
I-132	631	473.6	42.1	I-132	1969	1476.7	10.9
I-132	638	478.2	41.7	Te-131m	1995	1496.5	87.9
La-140	649	487	1867194	I-135	2004	1502.8	2613.7
I-132	651	488	98.5	I-132	2026	1519.6	6.5
Te-131m	657	492.7	331.5	I-135	2029	1522	90.8
I-131	671	503	9957.7	I-135	2058	1543.7	61.3
I-132	674	505.8	1145.5	Te-131m	2064	1547.8	101.9
Te-131m	676	506.8	373.9	I-135	2089	1566.4	3022.6
Zr-97	677	507.6	73104.5	I-133	2120	1589.9	23.9
I-133	681	510.5	42801	I-132	2124	1592.9	3.7
Zr-97	685	513.4	7904.5	La-140	2128	1596.2	1269761
I-132	697	522.7	3592.4	I-135	2152	1613.8	58.7
Te-131m	700	524.8	551.1	Te-131m	2195	1646	1708.7
I-133	706	529.9	1961130	I-135	2237	1678	20909.8
Te-131m	708	530.7	421.8	Te-131m	2262	1696.8	20.5
I-135	708	530.8	206.8	I-135	2275	1706.5	8831.5
I-132	714	535.3	114.7	I-132	2287	1715.4	4
I-133	717	537.7	799.9	I-132	2294	1720.6	3.9
Te-131m	722	541.4	452.8	I-132	2303	1727.2	4.8
I-135	729	546.6	45210.4	Zr-97	2334	1750.2	4888.7
Te-131m	729	546.7	152.5	I-132	2343	1757.4	21.3
I-132	730	547.2	244.5	I-132	2347	1760.4	4.2
I-133	742	556.2	429.9	I-132	2371	1778.5	5.5
Zr-97	744	558	370.8	I-135	2388	1791.2	15825.2
Te-131m	744	558.1	87.9	Te-131m	2441	1830.6	19
I-132	746	559.7	18.7	I-135	2441	1830.7	1164
I-133	756	567.1	63.3	I-135	2460	1845.3	11.9
I-132	763	572.5	12.1	Zr-97	2469	1851.6	1313.8
Te-131m	764	572.7	171.4	La-140	2503	1877.3	464.3
I-135	768	576	775.6	Te-131m	2507	1880.1	74.8

Te-131m	773	579.8	282.3	Te-131m	2517	1887.7	1628.7
Te-131m	782	586.3	7204.1	I-132	2562	1921.8	79.8
I-135	784	588.3	304	Te-131m	2565	1924.1	4.6
I-132	788	591.1	13.9	La-140	2566	1924.6	148
Te-131m	796	597	181.2	I-135	2570	1927.3	563.6
I-132	800	600.1	25.5	Te-131m	2582	1936.2	86.1
Te-131m	803	602	1088.6	I-135	2598	1948.5	119.7
Zr-97	803	602.4	16958.1	Te-131m	2640	1980.3	35
Te-131m	813	609.4	489.5	Te-131m	2668	2000.9	2279.4
I-132	813	609.8	7.5	I-132	2670	2002.2	70.9
I-135	823	616.9	212.1	I-135	2728	2045.9	1564.7
I-133	824	618	10553.3	La-140	2778	2083.2	113.4
La-140	824	618.1	1201.4	I-132	2782	2086.8	15.3
I-132	828	620.9	74	I-135	2817	2112.4	120.4
I-132	828	621.2	299.6	I-135	2869	2151.5	37.7
I-132	840	630.2	2486.8	Te-131m	2891	2168.5	362.5
I-131	849	637	157444	I-132	2897	2172.7	11.8
I-131	857	642.7	4724.1	I-135	2906	2179.7	6.7
I-133	865	648.8	1055.2	I-135	2919	2189.4	21.3
I-135	866	649.9	2442.1	I-132	2964	2223.2	6.6
I-132	867	650.5	466.2	I-135	3007	2255.5	991.7
I-135	875	656.1	394.5	Te-131m	3028	2270.7	380
Te-131m	876	657.2	100.1	Te-131m	3110	2332.7	2.6
Te-131m	887	665.1	13998	La-140	3131	2347.9	7612.7
I-132	890	667.7	17517.9	I-132	3187	2390.5	9.7
I-132	893	669.8	811.5	I-135	3212	2408.7	1424.4
I-133	893	670.1	771.8	La-140	3285	2464.1	96.8
I-132	895	671.4	616	I-135	3288	2466.1	104.2
I-133	905	678.7	390.1	I-135	3303	2477.1	2.1
I-135	906	679.2	280	La-140	3362	2521.4	28649.2
I-133	907	680.2	11500.4	La-140	3377	2533.1	31.8
Te-131m	909	681.9	96.6	La-140	3396	2547.3	826.8
I-132	913	684.4	13.8	La-140	3866	2899.6	472.1
I-135	913	684.6	112.6	La-140	4158	3118.5	160.9
Te-131m	915	685.9	485.1	La-140	4427	3320.4	22.9

Table VI. Spectral information for the EPHSOGAM Scenario 2 Location 2 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
La-140	33	24.6	6.1	Te-131m	803	602	171.2
Te-131m	49	36.8	2.6	Zr-97	803	602.4	854.4
Te-132	66	49.7	415068	Te-131m	813	609.4	77
Te-131m	68	51	4.8	I-135	823	616.9	3.5
Te-131m	70	52.6	4.5	I-133	824	618	658
Te-131m	74	55.8	2.5	La-140	824	618.1	126.3
Te-131m	81	60.8	6.2	I-132	840	630.2	10.4
Te-131m	83	62.4	40.3	I-131	849	637	3628.9
Te-131m	84	63.2	4.8	I-131	857	642.7	108.9
La-140	86	64.1	101.6	I-133	865	648.8	65.8
Te-131m	87	65.1	9.4	I-135	866	649.9	40
Te-131m	89	67	27.3	I-135	875	656.1	6.5
La-140	92	68.9	578.8	Te-131m	876	657.2	15.7
Te-131m	98	73.3	34.7	Te-131m	887	665.1	2200.9
Te-131m	105	78.6	20.9	I-132	890	667.7	73.6
Te-131m	106	79.2	175	I-132	893	669.8	3.4
I-131	107	80.2	3458.1	I-133	893	670.1	48.1
Te-131m	108	81.1	5652.5	I-132	895	671.4	2.6
Te-131m	115	86.4	211.6	I-133	905	678.7	24.3
Te-131m	127	95	5.9	I-135	906	679.2	4.6
Te-131m	129	96.4	9.3	I-133	907	680.2	717.1
Te-131m	131	98.3	21.1	Te-131m	909	681.9	15.2
Te-131m	133	100	113.5	Te-131m	915	685.9	76.3
Te-131m	135	101.6	265.4	I-135	920	690.1	10.7
Te-131m	137	102.6	12387.2	Zr-97	921	690.5	99.4
Te-131m	138	103.3	73.1	Te-131m	927	695.6	193.8
Te-131m	140	105	42.2	Zr-97	932	699.2	54.2
Te-131m	146	109.4	56.3	Te-131m	937	702.5	188.7
La-140	146	109.4	2192.3	Zr-97	938	703.8	538.7
Te-131m	148	111	49.2	I-133	942	706.6	1607.4
Zr-97	149	111.6	115.8	Zr-97	943	707.4	17
Te-132	149	111.8	107239.9	I-135	944	707.9	52.9
Te-131m	151	113.5	18.6	Te-131m	951	713.1	680.6
Te-132	155	116.3	122206.4	I-131	964	722.9	795.5
Te-131m	165	123.7	6.4	Zr-95	966	724.2	62214.5
Te-131m	167	125.2	13.9	I-132	970	727.2	2.2
Te-131m	168	126.1	10.2	Te-131m	985	738.8	30.3
Te-131m	170	127.4	38.2	Zr-97	991	743.4	47097
Te-131m	174	130.5	116.2	Te-131m	992	744.2	723.7
La-140	175	131.1	4883	Te-131m	999	749	6.9
Te-131m	176	132.2	7.7	La-140	1002	751.6	12272.1

Te-131m	180	134.9	1192.8	Zr-95	1009	756.7	72969.7
Te-131m	183	137.6	128.5	I-133	1025	768.4	452.2
Te-131m	199	149.3	130.4	Zr-97	1029	772	117.3
Te-131m	200	149.7	7825.3	I-132	1030	772.6	48.9
I-133	201	150.4	109.9	Te-131m	1032	773.7	16825.9
Te-131m	202	151.2	129.1	Te-131m	1032	774.1	239.2
Te-131m	208	155.9	64.5	Zr-97	1033	775	92.5
Te-131m	213	159.7	215.3	Te-131m	1043	782.5	3388.3
I-135	217	162.7	2.8	I-135	1047	785.5	11.1
I-135	221	165.7	9	I-133	1053	789.6	48
Te-131m	226	169.7	51.3	Te-131m	1058	793.8	5956.8
Te-131m	229	172	19.2	I-135	1064	797.7	12.2
La-140	231	173.5	1345.2	Te-131m	1069	801.6	8.2
I-133	236	177	288.4	Zr-97	1073	804.5	286.9
Te-131m	236	177.2	109.7	Zr-97	1074	805.6	131.5
I-131	236	177.2	430	I-135	1076	807.2	3.3
Te-131m	243	182.3	1142.3	I-132	1083	812	3.4
Te-131m	243	182.3	1218.1	La-140	1088	815.8	61109
Zr-97	244	182.9	58.7	I-133	1094	820.5	143.3
Te-131m	244	183.1	256.1	Te-131m	1097	822.8	2542.9
I-135	246	184.5	6.6	Zr-97	1106	829.8	109.2
Te-131m	251	188.1	351.4	I-135	1116	836.8	461.2
Te-131m	253	189.8	830.5	Te-131m	1127	844.9	62.1
Te-131m	254	190.5	191.1	Te-131m	1132	848.9	15.8
I-135	263	197.2	9	Te-131m	1136	852.2	157
Te-131m	268	200.6	12211.6	Te-131m	1136	852.2	8315.6
Zr-97	270	202.5	51.6	Zr-97	1140	854.9	158.2
Te-131m	271	203.4	30.6	Te-131m	1141	856.1	248.5
I-133	272	203.7	15.6	I-133	1142	856.3	1101.9
Te-131m	277	207.5	61.5	Te-131m	1153	865.1	75.9
Te-131m	280	210.3	23.9	La-140	1157	867.8	13629.3
Te-131m	283	211.9	17.8	Te-131m	1163	872.3	39.5
Te-131m	285	214	654	I-133	1167	875.3	3926
Zr-97	292	218.9	280.6	Te-131m	1175	881.6	13.7
I-135	294	220.5	441.5	I-133	1213	909.7	179.8
Te-131m	304	227.7	22.3	Te-131m	1213	910	1246.2
Te-132	304	228.2	4902351	I-133	1215	911.5	38.6
I-135	306	229.7	58.8	La-140	1226	919.6	6247.3
Te-131m	308	230.7	279	Te-131m	1227	920.6	450.1
I-131	310	232.2	4.4	Te-131m	1231	923.4	42.9
Te-131m	310	232.3	132.6	La-140	1234	925.2	16113.8
Te-131m	313	235	21.7	Te-131m	1240	930	7.1
Zr-95	314	235.7	1250.2	Te-131m	1255	941.3	286.5
Te-131m	321	240.9	10511.1	La-140	1268	951	1181.6
La-140	323	241.9	3579.8	I-132	1273	954.6	9.4
I-133	328	246	105.6	I-135	1282	961.4	9

I-135	330	247.5	6.6	Zr-97	1295	971.3	109.8
Te-131m	338	253.2	861.1	I-135	1296	972	52.9
Zr-97	339	254.2	1665.5	I-135	1297	972.6	72.1
I-135	340	254.7	5.1	Te-131m	1317	987.8	54.3
Te-131m	341	255.4	406.9	La-140	1324	992.9	28.4
Te-131m	349	261.4	19.7	I-135	1327	995.1	9.3
I-133	350	262.7	1018.2	Te-131m	1327	995.1	30.9
I-132	351	262.9	2.4	Te-131m	1332	999.3	59.3
I-135	352	264.3	39.4	Te-131m	1338	1003.6	9.3
La-140	355	266.5	3680.3	Te-131m	1341	1005.8	25.4
I-133	356	267.2	326.5	Zr-97	1357	1018.1	139.9
Te-131m	356	267.2	19.3	I-133	1357	1018.1	4.5
Zr-97	363	272.4	314.6	Zr-97	1362	1021.2	380.6
I-131	363	272.5	68.2	Te-131m	1365	1023.6	21.3
Te-131m	371	278.6	2155.1	Zr-97	1369	1026.7	105
Te-131m	375	281.4	42.1	Te-131m	1370	1027.8	2.6
Te-131m	378	283.2	464	Te-131m	1381	1035.4	35.2
I-131	379	284.3	6951.8	I-133	1381	1035.6	6.5
I-135	385	288.5	610	I-135	1385	1038.8	449.1
I-135	387	290.3	59.5	La-140	1393	1045.1	52.2
Te-131m	387	290.3	89.7	I-133	1403	1052.3	408.1
Zr-97	393	294.8	102.3	Te-131m	1413	1059.7	508.3
Te-131m	396	297.1	57.3	I-133	1413	1060.1	100.6
Zr-97	396	297.2	82.9	Te-131m	1430	1072.3	7.5
I-131	403	302.4	5	I-133	1450	1087.7	8.7
Te-131m	404	302.7	43.4	I-135	1462	1096.9	4.8
Te-131m	405	303.9	43.3	La-140	1463	1097.2	45.9
I-135	407	304.9	5.9	I-135	1469	1101.6	86
Zr-97	407	305.1	34.3	Te-131m	1478	1108.3	7.2
I-135	408	305.8	17.7	Zr-97	1481	1110.4	32.4
La-140	409	306.9	172	Te-131m	1485	1114.1	3.6
Te-131m	413	309.5	408.6	I-135	1499	1124	189.7
I-131	424	318.1	78.6	Te-131m	1501	1125.5	3546.6
Te-131m	432	323.7	15.9	Te-131m	1503	1127	299.4
I-131	433	324.7	21	I-135	1509	1131.5	1178.3
I-131	434	325.8	270.9	Te-131m	1512	1134.2	2.4
La-140	438	328.8	130325.5	Zr-97	1531	1148	882.7
Zr-97	441	330.4	161.5	Te-131m	1532	1148.9	70
Te-131m	442	331.2	31.1	Te-131m	1532	1148.9	467
I-135	445	333.6	6.4	Te-131m	1535	1150.9	200.5
Te-131m	446	334.3	9637.1	I-135	1547	1159.9	5.3
Te-131m	447	335.4	138.4	Te-131m	1550	1162.7	8.1
Te-131m	457	342.9	383.3	Te-131m	1554	1165.5	41.9
I-133	461	345.4	224.9	I-135	1559	1169	44.3
Te-131m	461	345.9	96.9	I-135	1574	1180.5	3.2
Te-131m	468	351.3	200.3	Te-131m	1575	1181.4	3.4

Te-131m	471	353.5	72.9	Te-131m	1609	1206.6	2842.4
Te-131m	473	354.7	216.5	Te-131m	1615	1211	18
Zr-97	474	355.4	2192.9	I-135	1634	1225.6	2.1
Te-131m	477	357.4	18	I-133	1649	1236.4	954.7
I-131	478	358.4	14.4	Te-131m	1650	1237.3	187.4
I-133	481	361.1	227.4	I-135	1654	1240.5	43.3
I-135	482	361.9	29.3	Te-131m	1672	1254.2	7.5
Te-131m	483	362.3	71.1	I-135	1681	1260.4	1353.9
I-131	486	364.5	72087.8	Zr-97	1701	1276.1	288
Te-131m	487	365	1108	I-135	1704	1277.8	2.7
I-133	497	372.5	20	I-133	1731	1298.2	1419.2
Te-131m	501	375.8	10.3	La-140	1738	1303.5	71.3
Te-131m	506	379.3	17	Te-131m	1754	1315.6	187.2
I-133	509	381.6	88	I-135	1754	1315.8	3
Te-131m	512	383.9	174.3	Te-131m	1755	1316.2	26.7
I-133	516	386.9	113.7	Te-131m	1758	1318.3	10.5
La-140	530	397.5	386.6	Te-131m	1778	1333.8	14.4
Zr-97	534	400.4	227.8	Te-131m	1787	1340.6	26.5
I-135	537	403	32.7	I-135	1792	1343.7	3.4
Te-131m	538	403.3	25.5	I-133	1801	1350.4	87.2
I-131	540	404.8	43.4	Zr-97	1815	1361	201.9
Te-131m	544	408.2	50.4	Zr-97	1817	1362.7	293.8
Zr-97	547	410	63.5	I-135	1824	1367.9	26.6
I-135	553	414.8	41.1	Te-131m	1836	1376.8	11
Te-131m	557	417.4	224.2	I-133	1848	1386.2	5.1
I-133	557	417.6	274.8	Te-131m	1853	1389.6	3.9
I-135	557	417.7	474.2	Te-131m	1860	1394.8	27.6
I-133	564	422.9	547.8	I-132	1865	1398.6	2.6
I-135	573	429.9	40	Te-131m	1871	1403.6	2.9
Te-131m	577	432.4	511.1	La-140	1874	1405.2	93.3
La-140	577	432.5	14099.4	I-135	1931	1448.4	13.1
I-135	578	433.7	72.3	I-135	1943	1457.6	356.4
La-140	585	438.5	187	Te-131m	1995	1496.5	13.8
I-133	585	438.9	67.9	I-135	2004	1502.8	42.8
La-140	594	445.5	13.7	Te-131m	2064	1547.8	16
I-135	602	451.6	39.6	I-135	2089	1566.4	49.5
Te-131m	603	452.3	1135.7	La-140	2128	1596.2	133482.3
Te-131m	617	462.9	1320.5	Te-131m	2195	1646	268.8
Te-131m	624	468.2	224.9	I-135	2237	1678	342.6
Zr-97	631	473.5	54.9	Te-131m	2262	1696.8	3.2
La-140	649	487	196342.3	I-135	2275	1706.5	144.7
Te-131m	657	492.7	52.1	Zr-97	2334	1750.2	246.3
I-131	671	503	229.6	I-135	2388	1791.2	259.3
I-132	674	505.8	4.8	Te-131m	2441	1830.6	3
Te-131m	676	506.8	58.8	I-135	2441	1830.7	19.1
Zr-97	677	507.6	3683.2	Zr-97	2469	1851.6	66.2

I-133	681	510.5	2668.1	La-140	2503	1877.3	48.8
Zr-97	685	513.4	398.2	Te-131m	2507	1880.1	11.8
I-132	697	522.7	15.1	Te-131m	2517	1887.7	256.1
Te-131m	700	524.8	86.7	La-140	2566	1924.6	15.6
I-133	706	529.9	122275.5	I-135	2570	1927.3	9.2
Te-131m	708	530.7	66.3	Te-131m	2582	1936.2	13.5
I-135	708	530.8	3.4	Te-131m	2640	1980.3	5.5
I-133	717	537.7	49.9	Te-131m	2668	2000.9	358.5
Te-131m	722	541.4	71.2	I-135	2728	2045.9	25.6
I-135	729	546.6	740.8	La-140	2778	2083.2	11.9
Te-131m	729	546.7	24	Te-131m	2891	2168.5	57
I-133	742	556.2	26.8	I-135	3007	2255.5	16.2
Zr-97	744	558	18.7	Te-131m	3028	2270.7	59.7
Te-131m	744	558.1	13.8	La-140	3131	2347.9	800.3
I-133	756	567.1	3.9	I-135	3212	2408.7	23.3
Te-131m	764	572.7	27	La-140	3285	2464.1	10.2
I-135	768	576	12.7	La-140	3362	2521.4	3012.5
Te-131m	773	579.8	44.4	La-140	3377	2533.1	3.3
Te-131m	782	586.3	1133.2	La-140	3396	2547.3	86.9
I-135	784	588.3	5	La-140	3866	2899.6	49.6
Te-131m	796	597	28.5	La-140	4158	3118.5	16.9
				La-140	4427	3320.4	2.4

Table VII. Spectral information for the EPHSOGAM Scenario 2 Location 3 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Ba-140	40	30	176170.2	I-134	1129	847	2255.8
Te-132	66	49.7	19706120	I-132	1131	847.9	1404.1
I-131	107	80.2	3305051	I-133	1142	856.3	443866
I-131	115	85.9	119	I-134	1143	857.3	156.1
Te-132	149	111.8	5094904	I-132	1151	863	45647
Ba-140	151	113.5	8552	I-134	1152	864	4.4
Te-132	155	116.3	5801872	I-132	1155	866	2915
Ba-140	158	118.8	32925.5	I-133	1167	875.3	1581963
Ba-140	177	132.7	110968.9	I-132	1169	876.6	83263.5
I-134	181	135.4	421.5	I-134	1179	884.1	1474.9
I-132	182	136.7	27077.3	I-132	1181	886.1	1982.2
I-134	185	139	73.6	I-132	1185	888.7	2767
I-132	197	147.4	81661.8	I-132	1206	904.4	1011.1
I-133	201	150.4	44248.4	I-133	1213	909.7	72411.5
I-134	203	152	10.5	I-132	1213	910.1	71905.6
I-134	217	162.5	28.5	I-133	1215	911.5	15532.9
I-135	217	162.7	2235.7	I-134	1230	922.6	3.1
Ba-140	217	162.7	3438974	I-132	1237	927.4	31154.5
I-135	221	165.7	7140.9	I-132	1263	947.2	3279.1
I-133	236	177	116125.3	I-134	1264	947.9	85.2
I-131	236	177.2	410967	I-132	1273	954.6	1302292
I-132	245	183.6	46665.4	I-135	1280	960.3	1436.1
I-135	246	184.5	5205.9	I-135	1282	961.4	7170.4
I-134	251	188.5	73.1	I-132	1288	965.9	2561.8
I-135	263	197.2	7139	I-134	1289	966.9	8.2
I-133	272	203.7	6284.4	I-135	1296	972	42002.3
I-134	289	217	20.4	I-135	1297	972.6	57227.9
I-135	294	220.5	350339.3	I-134	1300	974.7	99
Te-132	304	228.2	2.33E+08	I-132	1312	984.2	42434.6
I-135	306	229.7	46647.8	I-135	1327	995.1	7408.8
I-131	310	232.2	4187.7	I-132	1328	995.8	2134.9
I-132	312	234.3	8709.3	I-132	1345	1009	3232.3
I-134	314	235.5	176.1	I-133	1357	1018.1	1829.3
Zr-95	314	235.7	9863.4	I-132	1380	1035	35001.8
Cs-134	324	242.7	6961.2	I-133	1381	1035.6	2610.6
I-133	328	246	42523.3	Cs-134	1385	1038.6	61984.6
I-135	330	247.5	5208	I-135	1385	1038.8	356398.1
I-132	334	250.8	4910.2	I-134	1387	1040.3	39.5
I-135	340	254.7	4021.8	I-132	1399	1049.6	3116.5
I-132	340	255.1	63641.5	I-133	1403	1052.3	164367
I-133	350	262.7	409996.5	I-133	1413	1060.1	40524.7

I-132	351	262.9	334003.8	I-134	1430	1072.6	283.1
I-135	352	264.3	31245.9	I-132	1442	1081.8	2345.6
I-133	356	267.2	131513.4	I-132	1448	1086.2	5184.9
I-131	363	272.5	65179.1	I-133	1450	1087.7	3498.7
I-132	371	278.4	9632.6	I-135	1462	1096.9	3807.8
I-134	372	278.8	10.1	I-132	1463	1096.9	2862.2
I-131	379	284.3	6643945	I-134	1467	1100.1	12.8
I-132	380	284.9	171441.5	I-135	1469	1101.6	68264.3
I-135	385	288.5	484228.2	I-134	1471	1103.2	14.8
I-135	387	290.3	47179.2	I-132	1483	1112.4	4172.9
I-131	394	295.8	1873.4	I-135	1499	1124	150538.2
I-132	403	302	11.3	I-132	1502	1126.5	3109.6
I-131	403	302.4	4785.4	I-135	1509	1131.5	934681.1
Ba-140	406	304.8	1558128	I-132	1515	1136	189513.8
I-135	407	304.9	4697.8	I-134	1515	1136.2	163.9
I-135	408	305.8	14054.3	I-132	1524	1143.3	84502.1
I-132	409	306.7	22222.9	I-132	1530	1147.8	17030.1
I-132	413	310.1	19760.2	I-135	1536	1151.9	42
I-132	414	310.4	19741.1	I-134	1545	1159.1	6
I-132	422	316.7	27823.6	I-135	1547	1159.9	4177.9
I-131	424	318.1	75128.9	I-134	1552	1164	2.3
I-134	426	319.8	28.3	Cs-134	1557	1168	100672
I-131	433	324.7	20103.8	I-135	1559	1169	35130
I-131	434	325.8	258933.8	I-132	1564	1172.9	66624.2
I-135	435	326	315.9	I-135	1574	1180.5	2529.3
Cs-134	435	326.6	3131	I-134	1587	1190	6
I-135	445	333.6	5098.8	I-132	1616	1212.3	711.2
I-135	457	342.5	117.6	I-135	1634	1225.6	1640.8
I-132	458	343.7	17815.7	I-133	1649	1236.4	384360.9
I-133	461	345.4	90596.3	I-134	1652	1239	3.5
I-134	468	351.1	23.5	I-135	1654	1240.5	34334.5
I-132	469	351.8	15442.8	I-132	1672	1254.1	3388
I-131	478	358.4	13727.3	I-135	1673	1254.8	224
I-133	481	361.1	91604.5	I-135	1681	1260.4	1074369
I-135	482	361.9	23231	I-132	1685	1263.6	1539.5
I-132	484	363.3	92711	I-134	1693	1269.5	9.1
I-131	486	364.5	68907000	I-132	1697	1272.8	9516.8
I-133	497	372.5	8069.4	I-135	1704	1277.8	2128.2
I-133	509	381.6	35438	I-132	1721	1290.8	63157.6
I-133	516	386.9	45808.7	I-132	1727	1295.1	104735
I-132	517	387.9	53120.1	I-132	1731	1297.9	49490.2
I-135	537	403	25916.3	I-133	1731	1298.2	571501.4
I-131	540	404.8	41485	I-135	1745	1308.7	1233.4
I-134	541	405.5	356.1	I-132	1752	1314	3242.8
I-134	548	411	27.2	I-135	1754	1315.8	2356.6
I-135	553	414.8	32583.4	I-132	1757	1317.9	6467.4

I-132	556	416.8	77346.2	I-132	1759	1319.1	-26.8
I-133	557	417.6	110679.6	I-135	1760	1319.7	-363.7
I-135	557	417.7	376223.1	I-135	1779	1334.3	-3.9
I-133	564	422.9	220638.5	I-135	1780	1334.8	1126.8
Ba-140	565	423.7	819989.1	I-134	1781	1336	2.2
I-135	573	429.9	31743.6	I-135	1792	1343.7	2730.5
I-132	576	431.8	74628.9	I-133	1801	1350.4	35151.2
I-134	578	433.4	187.4	I-134	1803	1352.6	6.3
I-135	578	433.7	57372.9	Cs-134	1820	1365.2	146559.5
Ba-140	583	437.6	486257	I-135	1824	1367.9	21094.9
I-133	585	438.9	27330.1	I-132	1829	1372.1	130330.1
I-132	595	446.2	92174.9	I-133	1848	1386.2	2057.5
I-135	602	451.6	31392.5	I-132	1854	1390.7	781.4
I-134	612	458.9	56	I-132	1865	1398.6	363222.6
I-134	621	465.5	15.2	I-132	1881	1410.6	2209.6
I-132	631	473.6	24605.7	I-134	1886	1414.3	3.2
Cs-134	634	475.4	196469	I-135	1888	1416.3	1065.2
I-132	638	478.2	24368.9	I-134	1904	1428.2	2.5
I-132	651	488	57578.9	I-134	1908	1431.4	2.5
I-134	652	488.8	58.2	I-135	1922	1441.8	556.5
I-131	671	503	219378.3	I-132	1923	1442.6	70432.1
I-132	674	505.8	669493.4	I-135	1931	1448.4	10427.3
I-133	681	510.5	1074863	I-134	1940	1455.2	32.7
I-134	686	514.4	85	I-132	1942	1456.5	2442.7
I-132	697	522.7	2099939	I-135	1943	1457.6	282820.2
I-133	706	529.9	49251490	I-134	1960	1470	10.6
I-135	708	530.8	2688.1	I-132	1969	1476.7	6395.5
I-132	714	535.3	67033.2	I-135	2004	1502.8	33976.4
Ba-140	716	537.3	5009067	I-132	2026	1519.6	3780.4
I-133	717	537.7	20085.5	I-135	2029	1522	1181
I-134	721	540.8	276.9	I-134	2055	1541.5	6.9
I-135	729	546.6	587793.3	I-132	2056	1542.3	745
I-132	730	547.2	142933.7	I-135	2058	1543.7	797.1
I-133	742	556.2	10795.8	I-135	2089	1566.4	39296.5
I-132	746	559.7	10915.2	I-133	2120	1589.9	601.1
Cs-134	751	563.2	933240.8	I-132	2124	1592.9	2148.6
I-134	754	565.5	32.6	I-135	2152	1613.8	763.5
I-133	756	567.1	1588.8	I-134	2152	1613.8	55.4
Cs-134	759	569.3	1701072	I-132	2157	1617.9	450.3
I-134	761	570.8	10.7	I-132	2159	1618.9	315
I-132	763	572.5	7077.2	I-134	2172	1629.2	2.4
I-135	768	576	10083.5	I-132	2182	1636.5	534.3
I-135	784	588.3	3951.2	I-132	2192	1644	576.3
I-132	788	591.1	8138.5	I-134	2192	1644.3	5.1
I-134	794	595.4	366.7	I-134	2207	1655.2	2.9
I-132	800	600.1	14896.3	I-132	2215	1661.4	702.3

Cs-134	806	604.7	10182250	I-132	2228	1671.3	959.7
I-132	813	609.8	4400.5	I-135	2237	1678	271847.1
I-135	823	616.9	2757.4	I-135	2275	1706.5	114783.7
I-133	824	618	265028.8	I-132	2287	1715.4	2337.9
I-132	828	620.9	43245.3	I-132	2294	1720.6	2288.7
I-132	828	621.2	175007.4	I-132	2303	1727.2	2828.9
I-134	829	621.8	335.8	I-134	2322	1741.5	30.7
I-134	837	628	69.3	I-132	2336	1752.3	1040.8
I-132	840	630.2	1453534	I-132	2343	1757.4	12452
I-131	849	637	3467981	I-132	2347	1760.4	2444.2
I-131	857	642.7	104085.5	I-132	2358	1768.5	1031.3
I-133	865	648.8	26497.8	I-132	2371	1778.5	3239.2
I-135	866	649.9	31743	I-132	2382	1786.5	445
I-132	867	650.5	272425.6	I-135	2388	1791.2	205759.3
I-135	875	656.1	5130	I-134	2409	1806.8	63.9
I-132	879	659	4.1	I-132	2419	1814	643.5
Cs-137	882	661.7	6638303	I-132	2440	1830.1	1115.6
I-132	890	667.7	10236490	I-135	2441	1830.7	15127.7
I-132	893	669.8	474188.4	I-135	2460	1845.3	154.2
I-133	893	670.1	19386	I-132	2506	1879.2	543.1
I-132	895	671.4	360036.7	I-132	2552	1913.7	1142.6
I-134	903	677.3	230.5	I-132	2562	1921.8	46635
I-133	905	678.7	9798.2	I-135	2570	1927.3	7326.7
I-135	906	679.2	3638.8	I-135	2598	1948.5	1556.2
I-133	907	680.2	288755.8	I-132	2648	1985.6	409.9
I-132	913	684.4	8079.9	I-132	2670	2002.2	41438.9
I-135	913	684.6	1464.5	I-135	2728	2045.9	20345.1
I-132	917	687.8	3920.8	I-132	2782	2086.8	8947.3
I-135	920	690.1	8472.3	I-135	2817	2112.4	1564.9
I-133	942	706.6	647182.3	I-135	2869	2151.5	489.7
I-134	942	706.7	23.3	I-134	2880	2159.9	2
I-135	944	707.9	41988.3	I-132	2897	2172.7	6907.2
I-131	964	722.9	760355.8	I-135	2906	2179.7	86.7
Zr-95	966	724.2	490641.5	I-132	2916	2187	231.9
I-132	969	726.8	207120.3	I-135	2919	2189.4	277.3
I-132	970	727.2	305108.2	I-132	2964	2223.2	3842.5
I-132	971	728.4	152389.8	I-134	2982	2236.7	4.9
I-134	974	730.7	49.4	I-132	2999	2249.1	1080.5
I-134	986	739.2	18.5	I-135	3007	2255.5	12891
Zr-95	1009	756.7	575505.5	I-132	3055	2291.5	124.5
I-134	1022	766.7	107.5	I-134	3083	2312.4	2.1
I-133	1025	768.4	182114.8	I-135	3143	2357	6.8
I-132	1029	771.7	1802.7	I-132	3187	2390.5	5660
I-132	1030	772.6	6809509	I-132	3211	2408.6	280.7
I-132	1040	780	105333.1	I-135	3212	2408.7	18515.6
I-132	1046	784.4	33737.5	I-132	3259	2444	164.6

I-135	1047	785.5	8824.6	I-132	3273	2454.8	61.4
I-133	1053	789.6	19322.3	I-135	3288	2466.1	1354.5
I-132	1055	791.2	8720.3	I-135	3303	2477.1	27
I-135	1061	795.5	1311	I-132	3317	2487.8	22.8
Cs-134	1061	795.9	6871376	I-132	3367	2525.1	1105.7
I-135	1064	797.7	9664.3	I-132	3395	2546.5	45
Cs-134	1069	802	693065.3	I-132	3426	2569.8	136.2
I-135	1076	807.2	2586	I-132	3458	2593.8	33
I-132	1079	809.5	225924.2	I-132	3471	2603.2	41.1
I-132	1083	812	472826.6	I-132	3476	2607.2	27.4
I-134	1089	816.4	15.2	I-132	3486	2614.5	98.2
I-133	1094	820.5	57725.4	I-132	3538	2653.8	26.8
I-132	1108	831.3	2103.4	I-132	3588	2690.8	26.4
I-135	1116	836.8	365927.1	I-132	3623	2717.5	91.4
Cs-134	1129	847	22.7	I-132	3677	2757.8	33.4

Table VIII. Spectral information for the EPHSOGAM Scenario 3 Location1 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Ba-140	40	30	60462.5	I-135	1061	795.5	101.9
Te-132	66	49.7	5598329	Cs-134	1061	795.9	2628476
I-131	107	80.2	1177195	I-135	1064	797.7	750.9
I-131	115	85.9	42.4	Cs-134	1069	802	265117.2
Te-132	149	111.8	1446832	I-135	1076	807.2	200.9
Ba-140	151	113.5	2934.7	I-132	1079	809.5	2914.9
Te-132	155	116.3	1648792	I-132	1083	812	6101.8
Ba-140	158	118.8	11299.9	I-133	1094	820.5	12688.6
Ba-140	177	132.7	38082.4	I-132	1108	831.3	27.1
I-132	182	136.7	349.5	I-135	1116	836.8	28428.2
I-132	197	147.4	1053.8	Cs-134	1129	847	8.7
I-133	201	150.4	9727.9	I-132	1131	847.9	18.1
I-135	217	162.7	173.7	I-133	1142	856.3	97555.2
Ba-140	217	162.7	1180056	I-132	1151	863	589.1
I-135	221	165.7	555.2	I-132	1155	866	37.6
I-133	236	177	25526.7	I-133	1167	875.3	347613.9
I-131	236	177.2	146364	I-132	1169	876.6	1074.6
I-132	245	183.6	602.5	I-132	1181	886.1	25.6
I-135	246	184.5	404.7	I-132	1185	888.7	35.7
I-135	263	197.2	554.8	I-132	1206	904.4	13
I-133	272	203.7	1381.6	I-133	1213	909.7	15917.5
I-135	294	220.5	27221	I-132	1213	910.1	928.1
Te-132	304	228.2	66154400	I-133	1215	911.5	3415.6
I-135	306	229.7	3624.5	I-132	1237	927.4	402.1
I-131	310	232.2	1491.8	I-132	1263	947.2	42.3
I-132	312	234.3	112.4	I-132	1273	954.6	16800.5
Zr-95	314	235.7	2725.7	I-135	1280	960.3	111.5
Cs-134	324	242.7	2662.9	I-135	1282	961.4	557.1
I-133	328	246	9347.9	I-132	1288	965.9	33.1
I-135	330	247.5	404.7	I-135	1296	972	3263.1
I-132	334	250.8	63.4	I-135	1297	972.6	4446.2
I-135	340	254.7	312.5	I-132	1312	984.2	547.6
I-132	340	255.1	821.2	I-135	1327	995.1	575.7
I-133	350	262.7	90127.2	I-132	1328	995.8	27.5
I-132	351	262.9	4309.1	I-132	1345	1009	41.7
I-135	352	264.3	2427.8	I-133	1357	1018.1	402.1
I-133	356	267.2	28906.9	I-132	1380	1035	451.8
I-131	363	272.5	23214.7	I-133	1381	1035.6	573.9
I-132	371	278.4	124.3	Cs-134	1385	1038.6	23717.6
I-131	379	284.3	2366372	I-135	1385	1038.8	27689.6
I-132	380	284.9	2212.3	I-132	1399	1049.6	40.2

I-135	385	288.5	37597.2	I-133	1403	1052.3	36138
I-135	387	290.3	3667.5	I-133	1413	1060.1	8907.8
I-131	394	295.8	667.2	I-132	1442	1081.8	30.3
I-131	403	302.4	1704.4	I-132	1448	1086.2	66.9
Ba-140	406	304.8	534610.9	I-133	1450	1087.7	769
I-135	407	304.9	365.2	I-135	1462	1096.9	295.8
I-135	408	305.8	1092	I-132	1463	1096.9	36.9
I-132	409	306.7	286.8	I-135	1469	1101.6	5304.6
I-132	413	310.1	255	I-132	1483	1112.4	53.9
I-132	414	310.4	254.7	I-135	1499	1124	11699.9
I-132	422	316.7	359	I-132	1502	1126.5	40.1
I-131	424	318.1	26756.4	I-135	1509	1131.5	72625.3
I-131	433	324.7	7161.8	I-132	1515	1136	2446.4
I-131	434	325.8	92228.8	I-132	1524	1143.3	1090.2
I-135	435	326	24.5	I-132	1530	1147.8	219.7
Cs-134	435	326.6	1197.9	I-135	1536	1151.9	3.3
I-135	445	333.6	396	I-135	1547	1159.9	324.6
I-135	457	342.5	9.1	Cs-134	1557	1168	38509.4
I-132	458	343.7	229.9	I-135	1559	1169	2729.9
I-133	461	345.4	19914.7	I-132	1564	1172.9	859.9
I-132	469	351.8	199.3	I-135	1574	1180.5	196.5
I-131	478	358.4	4888.5	I-132	1616	1212.3	9.2
I-133	481	361.1	20136.6	I-135	1634	1225.6	127.5
I-135	482	361.9	1804.9	I-133	1649	1236.4	84482.7
I-132	484	363.3	1196.3	I-135	1654	1240.5	2667.6
I-131	486	364.5	24546850	I-132	1672	1254.1	43.7
I-133	497	372.5	1773.7	I-135	1673	1254.8	17.4
I-133	509	381.6	7788.6	I-135	1681	1260.4	83469.5
I-133	516	386.9	10070.8	I-132	1685	1263.6	19.9
I-132	517	387.9	685.4	I-132	1697	1272.8	122.9
I-135	537	403	2013.8	I-135	1704	1277.8	165.4
I-131	540	404.8	14771.9	I-132	1721	1290.8	815.1
I-135	553	414.8	2532.4	I-132	1727	1295.1	1351.5
I-132	556	416.8	998.3	I-132	1731	1297.9	638.6
I-133	557	417.6	24324.8	I-133	1731	1298.2	125636.5
I-135	557	417.7	29236.6	I-135	1745	1308.7	95.8
I-133	564	422.9	48489.3	I-132	1752	1314	41.8
Ba-140	565	423.7	281436.9	I-135	1754	1315.8	183.1
I-135	573	429.9	2467.6	I-132	1757	1317.9	83.5
I-132	576	431.8	963.2	I-135	1780	1334.8	87.6
I-135	578	433.7	4457.5	I-135	1792	1343.7	212.2
Ba-140	583	437.6	166826.5	I-133	1801	1350.4	7725.9
I-133	585	438.9	6007.3	Cs-134	1820	1365.2	56055.1
I-132	595	446.2	1189.6	I-135	1824	1367.9	1638.9
I-135	602	451.6	2438.8	I-132	1829	1372.1	1681.9
I-132	631	473.6	317.5	I-133	1848	1386.2	452.2

Cs-134	634	475.4	75156.9	I-132	1854	1390.7	10.1
I-132	638	478.2	314.4	I-132	1865	1398.6	4687.3
I-132	651	488	743.1	I-132	1881	1410.6	28.5
I-131	671	503	78140.5	I-135	1888	1416.3	82.8
I-132	674	505.8	8639.8	I-135	1922	1441.8	43.2
I-133	681	510.5	236342.2	I-132	1923	1442.6	908.7
I-132	697	522.7	27094	I-135	1931	1448.4	810.7
I-133	706	529.9	10826600	I-132	1942	1456.5	31.5
I-135	708	530.8	209	I-135	1943	1457.6	21973.4
I-132	714	535.3	865	I-132	1969	1476.7	82.5
Ba-140	716	537.3	1718625	I-135	2004	1502.8	2640.4
I-133	717	537.7	4416.1	I-132	2026	1519.6	48.8
I-135	729	546.6	45672.4	I-135	2029	1522	91.7
I-132	730	547.2	1844.6	I-132	2056	1542.3	9.6
I-133	742	556.2	2372.6	I-135	2058	1543.7	61.9
I-132	746	559.7	140.9	I-135	2089	1566.4	3053.2
Cs-134	751	563.2	356926.3	I-133	2120	1589.9	132.1
I-133	756	567.1	349.2	I-132	2124	1592.9	27.7
Cs-134	759	569.3	650730.7	I-135	2152	1613.8	59.3
I-132	763	572.5	91.3	I-132	2157	1617.9	5.8
I-135	768	576	783.5	I-132	2159	1618.9	4.1
I-135	784	588.3	307	I-132	2182	1636.5	6.9
I-132	788	591.1	105	I-132	2192	1644	7.4
I-132	800	600.1	192.2	I-132	2215	1661.4	9.1
Cs-134	806	604.7	3895727	I-132	2228	1671.3	12.4
I-132	813	609.8	56.8	I-135	2237	1678	21122.9
I-135	823	616.9	214.2	I-135	2275	1706.5	8916.7
I-133	824	618	58248.3	I-132	2287	1715.4	30.2
I-132	828	620.9	558.1	I-132	2294	1720.6	29.5
I-132	828	621.2	2259.8	I-132	2303	1727.2	36.5
I-132	840	630.2	18751.5	I-132	2336	1752.3	13.4
I-131	849	637	1235603	I-132	2343	1757.4	160.7
I-131	857	642.7	37079.5	I-132	2347	1760.4	31.5
I-133	865	648.8	5824.3	I-132	2358	1768.5	13.3
I-135	866	649.9	2466.5	I-132	2371	1778.5	41.8
I-132	867	650.5	3515.9	I-132	2382	1786.5	5.7
I-135	875	656.1	398.5	I-135	2388	1791.2	15987.6
Cs-137	882	661.7	3062479	I-132	2419	1814	8.3
I-132	890	667.7	132105.8	I-132	2440	1830.1	14.4
I-132	893	669.8	6120.2	I-135	2441	1830.7	1175.6
I-133	893	670.1	4261.1	I-135	2460	1845.3	12
I-132	895	671.4	4645.9	I-132	2506	1879.2	7
I-133	905	678.7	2154.1	I-132	2552	1913.7	14.7
I-135	906	679.2	282.8	I-132	2562	1921.8	601.7
I-133	907	680.2	63482.7	I-135	2570	1927.3	569.3
I-132	913	684.4	104.3	I-135	2598	1948.5	120.9

I-135	913	684.6	113.8	I-132	2648	1985.6	5.3
I-132	917	687.8	50.6	I-132	2670	2002.2	534.8
I-135	920	690.1	658.3	I-135	2728	2045.9	1580.5
I-133	942	706.6	142250.9	I-132	2782	2086.8	115.5
I-135	944	707.9	3261.6	I-135	2817	2112.4	121.6
I-131	964	722.9	270799.6	I-135	2869	2151.5	38
Zr-95	966	724.2	135612.5	I-132	2897	2172.7	89.1
I-132	969	726.8	2672.4	I-135	2906	2179.7	6.7
I-132	970	727.2	3937	I-132	2916	2187	3
I-132	971	728.4	1966.2	I-135	2919	2189.4	21.5
Zr-95	1009	756.7	159119.5	I-132	2964	2223.2	49.6
I-133	1025	768.4	40045.8	I-132	2999	2249.1	13.9
I-132	1029	771.7	23.3	I-135	3007	2255.5	1001.5
I-132	1030	772.6	87870.4	I-132	3187	2390.5	73
I-132	1040	780	1359.4	I-132	3211	2408.6	3.6
I-132	1046	784.4	435.4	I-135	3212	2408.7	1438.6
I-135	1047	785.5	685.7	I-132	3259	2444	2.1
I-133	1053	789.6	4247.4	I-135	3288	2466.1	105.2
I-132	1055	791.2	112.5	I-135	3303	2477.1	2.1
				I-132	3367	2525.1	14.3

Table IX. Spectral information for the EPHSOGAM Scenario 3 Location 2 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts	Nuclide	Channel	Energy	Counts
Ba-140	40	30	13543.3	I-132	893	669.8	247.7
Te-132	66	49.7	1078724	I-133	893	670.1	612.5
I-131	107	80.2	339237.9	I-132	895	671.4	188
I-131	115	85.9	12.2	I-133	905	678.7	309.7
Te-132	149	111.8	278733.1	I-135	906	679.2	31.4
Ba-140	151	113.5	657.7	I-133	907	680.2	9128.4
Te-132	155	116.3	317675.4	I-132	913	684.4	4.2
Ba-140	158	118.8	2532.2	I-135	913	684.6	12.6
Ba-140	177	132.7	8536.1	I-132	917	687.8	2
I-132	182	136.7	14.1	I-135	920	690.1	73.1
I-132	197	147.4	42.6	I-133	942	706.6	20461.1
I-133	201	150.4	1398.2	I-135	944	707.9	362.4
I-135	217	162.7	19.3	I-131	964	722.9	78035
Ba-140	217	162.7	264471.6	Zr-95	966	724.2	35811.1
I-135	221	165.7	61.7	I-132	969	726.8	108.2
I-133	236	177	3670.6	I-132	970	727.2	159.4
I-131	236	177.2	42182	I-132	971	728.4	79.6
I-132	245	183.6	24.4	Zr-95	1009	756.7	41990.6
I-135	246	184.5	45	I-133	1025	768.4	5757.7
I-135	263	197.2	61.6	I-132	1030	772.6	3556
I-133	272	203.7	198.6	I-132	1040	780	55
I-135	294	220.5	3024.3	I-132	1046	784.4	17.6
Te-132	304	228.2	12747930	I-135	1047	785.5	76.2
I-135	306	229.7	402.7	I-133	1053	789.6	610.8
I-131	310	232.2	429.8	I-132	1055	791.2	4.6
I-132	312	234.3	4.5	I-135	1061	795.5	11.3
Zr-95	314	235.7	719.4	Cs-134	1061	795.9	802242.5
Cs-134	324	242.7	812.5	I-135	1064	797.7	83.4
I-133	328	246	1344.1	Cs-134	1069	802	80922.1
I-135	330	247.5	45	I-135	1076	807.2	22.3
I-132	334	250.8	2.6	I-132	1079	809.5	118
I-135	340	254.7	34.7	I-132	1083	812	246.9
I-132	340	255.1	33.2	I-133	1094	820.5	1825
I-133	350	262.7	12960.5	I-135	1116	836.8	3159.4
I-132	351	262.9	174.4	Cs-134	1129	847	2.7
I-135	352	264.3	269.7	I-133	1142	856.3	14026.1
I-133	356	267.2	4156.6	I-132	1151	863	23.8
I-131	363	272.5	6691.9	I-133	1167	875.3	49991
I-132	371	278.4	5	I-132	1169	876.6	43.5
I-131	379	284.3	681829.7	I-133	1213	909.7	2289.2

I-132	380	284.9	89.5	I-132	1213	910.1	37.6
I-135	385	288.5	4180.3	I-133	1215	911.5	491.1
I-135	387	290.3	407.5	I-132	1237	927.4	16.3
I-131	394	295.8	192.3	I-132	1273	954.6	680.1
I-131	403	302.4	491.1	I-135	1280	960.3	12.4
Ba-140	406	304.8	119837.3	I-135	1282	961.4	61.9
I-135	407	304.9	40.6	I-135	1296	972	362.6
I-135	408	305.8	121.4	I-135	1297	972.6	494
I-132	409	306.7	11.6	I-132	1312	984.2	22.2
I-132	413	310.1	10.3	I-135	1327	995.1	64
I-132	414	310.4	10.3	I-133	1357	1018.1	57.8
I-132	422	316.7	14.5	I-132	1380	1035	18.3
I-131	424	318.1	7708.7	I-133	1381	1035.6	82.5
I-131	433	324.7	2063.4	Cs-134	1385	1038.6	7237
I-131	434	325.8	26576.9	I-135	1385	1038.8	3076.3
I-135	435	326	2.7	I-133	1403	1052.3	5195.3
Cs-134	435	326.6	365.5	I-133	1413	1060.1	1280.5
I-135	445	333.6	44	I-132	1448	1086.2	2.7
I-132	458	343.7	9.3	I-133	1450	1087.7	110.6
I-133	461	345.4	2863.5	I-135	1462	1096.9	32.9
I-132	469	351.8	8.1	I-135	1469	1101.6	589.3
I-131	478	358.4	1408.9	I-132	1483	1112.4	2.2
I-133	481	361.1	2895.6	I-135	1499	1124	1299.7
I-135	482	361.9	200.6	I-135	1509	1131.5	8068.7
I-132	484	363.3	48.4	I-132	1515	1136	99
I-131	486	364.5	7072871	I-132	1524	1143.3	44.1
I-133	497	372.5	255	I-132	1530	1147.8	8.9
I-133	509	381.6	1120	I-135	1547	1159.9	36.1
I-133	516	386.9	1448	Cs-134	1557	1168	11751.3
I-132	517	387.9	27.7	I-135	1559	1169	303.3
I-135	537	403	223.7	I-132	1564	1172.9	34.8
I-131	540	404.8	4257.7	I-135	1574	1180.5	21.8
I-135	553	414.8	281.5	I-135	1634	1225.6	14.2
I-132	556	416.8	40.4	I-133	1649	1236.4	12151.8
I-133	557	417.6	3498.7	I-135	1654	1240.5	296.4
I-135	557	417.7	3248.5	I-135	1681	1260.4	9271.5
I-133	564	422.9	6972.5	I-132	1697	1272.8	5
Ba-140	565	423.7	63062.7	I-135	1704	1277.8	18.4
I-135	573	429.9	274.1	I-132	1721	1290.8	33
I-132	576	431.8	39	I-132	1727	1295.1	54.7
I-135	578	433.7	495.2	I-132	1731	1297.9	25.8
Ba-140	583	437.6	37382.2	I-133	1731	1298.2	18061.3
I-133	585	438.9	864	I-135	1745	1308.7	10.6
I-132	595	446.2	48.1	I-135	1754	1315.8	20.3
I-135	602	451.6	271.1	I-132	1757	1317.9	3.4
I-132	631	473.6	12.8	I-135	1780	1334.8	9.7

Cs-134	634	475.4	22945	I-135	1792	1343.7	23.6
I-132	638	478.2	12.7	I-133	1801	1350.4	1111.2
I-132	651	488	30.1	Cs-134	1820	1365.2	17110.8
I-131	671	503	22522.8	I-135	1824	1367.9	182.1
I-132	674	505.8	349.7	I-132	1829	1372.1	68.1
I-133	681	510.5	33969.1	I-133	1848	1386.2	65
I-132	697	522.7	1096.2	I-132	1865	1398.6	189.7
I-133	706	529.9	1556720	I-135	1888	1416.3	9.2
I-135	708	530.8	23.2	I-135	1922	1441.8	4.8
I-132	714	535.3	35	I-132	1923	1442.6	36.8
Ba-140	716	537.3	385222.5	I-135	1931	1448.4	90.1
I-133	717	537.7	634.8	I-135	1943	1457.6	2441.7
I-135	729	546.6	5075.3	I-132	1969	1476.7	3.3
I-132	730	547.2	74.6	I-135	2004	1502.8	293.3
I-133	742	556.2	341.1	I-135	2029	1522	10.2
I-132	746	559.7	5.7	I-135	2058	1543.7	6.9
Cs-134	751	563.2	108965.3	I-135	2089	1566.4	339.2
I-133	756	567.1	50.2	I-133	2120	1589.9	19
Cs-134	759	569.3	198603.2	I-135	2152	1613.8	6.6
I-132	763	572.5	3.7	I-135	2237	1678	2346.8
I-135	768	576	87	I-135	2275	1706.5	990.6
I-135	784	588.3	34.1	I-132	2343	1757.4	6.5
I-132	788	591.1	4.3	I-135	2388	1791.2	1776
I-132	800	600.1	7.8	I-135	2441	1830.7	130.6
Cs-134	806	604.7	1188772	I-132	2562	1921.8	24.4
I-132	813	609.8	2.3	I-135	2570	1927.3	63.2
I-135	823	616.9	23.8	I-135	2598	1948.5	13.4
I-133	824	618	8376.1	I-132	2670	2002.2	21.6
I-132	828	620.9	22.6	I-135	2728	2045.9	175.7
I-132	828	621.2	91.4	I-132	2782	2086.8	4.7
I-132	840	630.2	759.1	I-135	2817	2112.4	13.5
I-131	849	637	356085.8	I-135	2869	2151.5	4.2
I-131	857	642.7	10683.2	I-132	2897	2172.7	3.6
I-133	865	648.8	837.6	I-135	2919	2189.4	2.4
I-135	866	649.9	274.2	I-132	2964	2223.2	2
I-132	867	650.5	142.3	I-135	3007	2255.5	111.3
I-135	875	656.1	44.3	I-132	3187	2390.5	3
Cs-137	882	661.7	876364.8	I-135	3212	2408.7	159.8
I-132	890	667.7	5345.7	I-135	3288	2466.1	11.7

Table X. Spectral information for the EPHSOGAM Scenario 3 Location 3 spectrum. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Nuclide	Channel	Energy	Counts
Location 1			
Co-60	463	346.9	4
Co-58	1081	810.8	6708.4
Mn-54	1113	834.8	39639.7
Co-58	1152	864	43.6
Co-60	1564	1173.2	16263.2
Co-60	1777	1332.5	14438.2
Co-58	2233	1674.7	17.8
Location 2			
Co-58	1081	810.8	401.6
Mn-54	1113	834.8	2625.5
Co-58	1152	864	2.6
Co-60	1564	1173.2	1109.7
Co-60	1777	1332.5	985.2
Location 3			
Co-58	1081	810.8	202.6
Mn-54	1113	834.8	643.3
Co-60	1564	1173.2	1109.7
Co-60	1777	1332.5	985.2

Table XI. Spectral information for the locations of EPHSOGAM Scenario 4. Single and double escape peaks and x-rays not listed in Table but present in the spectrum.

Appendix 4 – Participant Reports for the EPHSOGAM Scenarios.

Note: All reports have been redacted as participation in EPHSOGAM was anonymous.

[redacted]

Spectrum analysis

Two different programs were used for the analyses: an in-house software and [redacted]. The in-house software is not built for air filter analysis, but was used because of the experience of the analyst. [redacted] has the advantage of automatically calculating the average activity concentration in the air by taking into account the decay of the nuclides during the sampling duration. Unfortunately, during the time frame of this project, it was only possible to get completely automatic analysis from [redacted] – nothing was done manually. The automatic analysis for Scenario 2 and 3 did not seem to perform well. Since the half-life of the nuclides in Scenario 4 are long compared to the sampling duration, we thus only present the [redacted] results for Scenario 1.

Nuclide identification

In scenario 1-3 it was clear that the filters contain fission products. We thus tried to explain the spectra with fission products. Almost all peaks were identified. Some of the air filters could contain Xe-133, however the 80 keV peak could be completely explained by other nuclides in the spectrum and Xe-133 would not accumulate in a normal air filter anyway.

In scenario 4 the presence of Co-60 was obvious. The rest of the peaks could be explained by impurities to be expected in a Co-60 sample. According to the abstract of, Mn-54 is a possible impurity in Co-60 samples. [1]

The identifications raised some questions we did not find answers to within the allocated time:

Why is there no cesium in scenario 1 and 2? What kind of release is this?

Why is the Mn-54 concentrations in Scenario 4 so high compared to the cobalt concentrations?

Air concentrations

[redacted] calculates the average activity concentrations during the sampling duration by taking the decay of the nuclides into account. The in-house software used is not made specifically for air sample analysis and does not have this feature. For the manual analysis, we did not calculate the average concentration, but simply calculated the activity concentrations in air by dividing the activity in the spectra with the sampled air volumes. The [redacted] concentrations should thus be equal to or higher than those resulting from the manual analysis. Plume non-uniformities during the sampling periods were not taken into account in either method.

[1] https://link.springer.com/article/10.1007/BF01224157

With the in-house software, the given uncertainties include uncertainties related to peak area, efficiency calibration and gamma line yield. For the [redacted] analysis we do not include uncertainties.

The dose rates were not used for the calculations. Given more time, one could try to use the dose rate data to estimate plume non-uniformities and estimate the maximum activity concentration in the air during the sampling period. However, there would be many uncertainties due to fallout, plume movement and the fact that in a real case not all isotopes contributing to the dose rate are visible in the air filter.

Scenario 1

Table 1: Calculated air concentrations from the manual analysis (Man.) and [redacted] automatic analysis (US).

Nuclide	Location 1		Location 2		Location 3	
	Man. [Bq/m3]	US [Bq/m3]	Man. [Bq/m3]	US [Bq/m3]	Man. [Bq/m3]	US [Bq/m3]
Y-93	-	0.36	-	0.042	-	0.059
Zr-95	1.71(1%)	1.74	0.33(1%)	0.35	0.35(1%)	0.35
Zr-97	0.98 (1%)	2.05	0.19(1%)	0.25	0.097(1%)	0.20
Ru-103	5.66(1%)	5.51	1.18(1%)	1.20	1.47(1%)	1.50
Te-131m	-	0.067	-	-	-	1.76
Te-132	9.97(4%)	-	1.79(4%)	-	1.72(4%)	-
I-124	-	-	-	-	-	0.003
I-131	2.95(1%)	3.08	0.48(1%)	0.49	0.39(1%)	0.33
I-132	0.074(4%)	0.072	-	-	-	-
I-133	5.23(2%)	9.48	0.39(1%)	0.50	0.46(1%)	0.84
I-135	0.16(5%)	0.89	0.005(29%)	0.014	0.003(27%)	0.016
Xe-133	-	0.17	-	0.027	-	0.004
Ba-133	-	0.039	-	0.007	-	0.003
Ba-142	-	1100	-	5.61	-	8.86
La-140	3.04(1%)	4.09	0.53(1%)	0.60	0.41(1%)	0.0009
Ce-145	-	-	-	-	-	2960
Nd-151	-	-	-	-	-	71.5
Dy-157*	-	0.062	-	-	-	-
Ho-167*	-	0.16	-	-	-	-
Yb-169*	-	-	-	-	-	0.11

*Not fission products

Scenario 2

	Activity concentration [Bq/m3] (not average!)		
Nuclide	Location 1	Location 2	Location 3
Zr-95	410(1%)	368(1%)	14.8(1%)
Zr-97	235(1%)	115(1%)	23.6(1%)
Se-81m	240(2%)	-	-
Te-131	25.6(1%)	-	1.6(6%)
Te-131m	371(2%)	35.0(2%)	22.1(2%)
Te-132	3870(4%)	2860(4%)	827(4%)
I-131	363(3%)	215(1%)	20.0(1%)
I-132	56.3(1%)	1.6(3%)	-
I-133	1300(3%)	187(3%)	46.4(3%)
I-135	752(3%)	54.8(3%)	-
Xe-133	59.2(2%)	15.4(2%)	3.2(6%)
La-140	572(1%)	310(1%)	1.3(1%)

Scenario 3

	Activity concentration [Bq/m3] (not average!)		
Nuclide	Location 1	Location 2	Location 3
Zr-95	1220(1%)	124(1%)	33.5(1%)
Te-132	98800(4%)	10200(4%)	2030(4%)
I-131	47300(1%)	6120(1%)	1810(1%)
I-132	10900(1%)	48.8(1%)	1.5(5%)
I-133	47100(3%)	3760(3%)	558(3%)
I-135	7070(3%)	202(3%)	22.6(3%)
Xe-133	3450(2%)	444(2%)	133(2%)
Cs-134	9730(1%)	1360(1%)	427(1%)
Cs-137	8080(1%)	1360(1%)	402(1%)
Ba-140	17100(1%)	2160(1%)	499(1%)

Scenario 4

	Activity concentration [Bq/m3] (not average!)		
Nuclide	Location 1	Location 2	Location 3
Mn-54	0.63(1%)	0.01(2%)	0.0044(4%)
Co-58	0.10(1%)	0.0016(5%)	0.0015(7%)
Co-60	0.36(1%)	0.0064(3%)	0.011(3%)

Dispersion calculations

All the dispersion calculations were carried out using [redacted] dispersion model. It is a model provided by [redacted] Meteorological Institute [redacted]. The source term location was determined using [redacted] inverse modelling capability. The inverse models were run for all the 3 stations for each scenario.

After the source location assumption a normal [redacted] dispersion model run was performed. The source term contained the nuclides identified in gamma spectrum analysis. Unfortunately we had not enough resources to adjust individual activity for each nuclide. Therefore only crude estimation of order of magnitude is given in results.

The detailed images of dispersion model output is are in the appendix. There is also location coordinates and the source term included.

Source terms and locations

Scenario 1:

- Location: Cofrentes Nuclear Power Plant, Spain
- Start of release: 2017-03-25 03:00:00 UTC
- Release duration: 30 hours
- Activity for each nuclide is about 1e17 Bq.

Scenario 2:

- Location: Sizewell Nuclear Power Plant, UK
- Start of release: 2017-03-19 20:00:00 UTC
- Release duration: 36 hours
- Activity for each nuclide is about 1e19 Bq

Scenario 3:

- Start of release: 2017-03-22 08:00:00 UTC
- Release interval #1
    - From 0 to 5 hours, about 1e17 Bq / nuclide
- Release interval #2:
    - From 9 to 15 hours, about 1e17 Bq / nuclide

Scenario 4:

- Location: Eastern Poland Ursus iron foundry (could be this case: http://www.nti.org/analysis/articles/poland-seven-co-60-sources-stolen-foundry-lublin/). If not, at least the location is a little west of southwest from Location 1.
- Release:
    - 1e+13 Bq of Co-60 + impurities

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1 Scenario 1: inverse calculation, Station 1

Selected time: 2017-03-24 06:00 UTC
Comment: additions: 2017-09-28T05:13Z metadata added to _QDz0Gu.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-26 00:00 UTC
Weather: ECMWF
Model: inverse

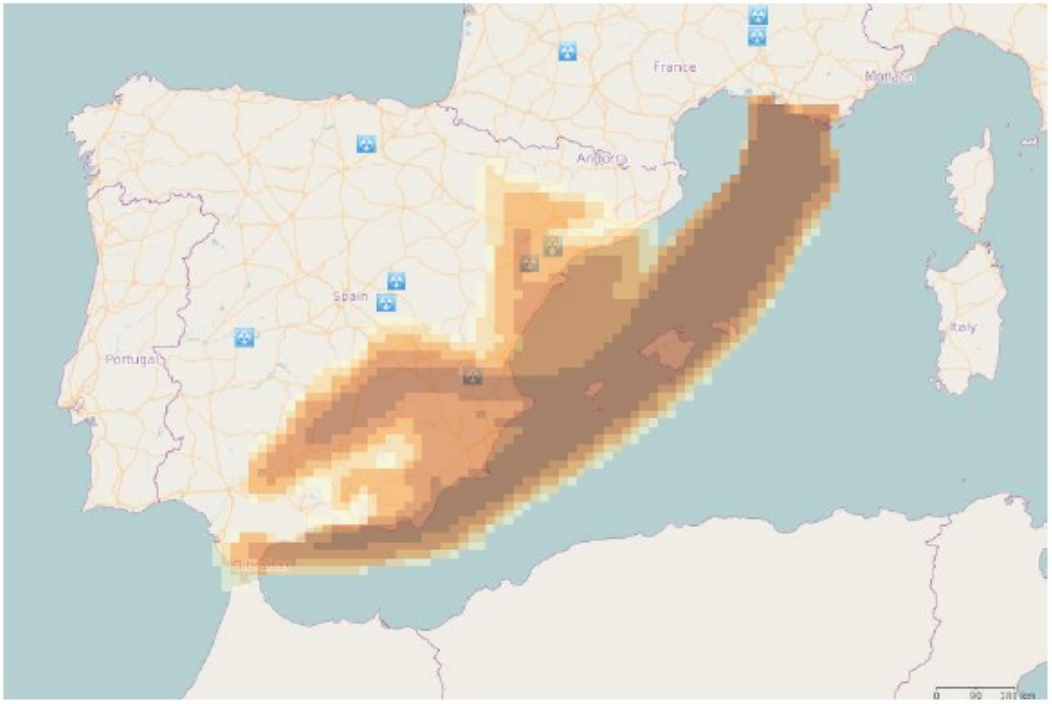


Figure 1: Scenario 1: inverse calculation, Station 1

2 Scenario 1: inverse calculation, Station 2

Selected time: 2017-03-25 05:00 UTC
Comment: additions: 2017-09-28T05:25Z metadata added to JSujoe.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-26 08:00 UTC
Weather: ECMWF
Model: inverse

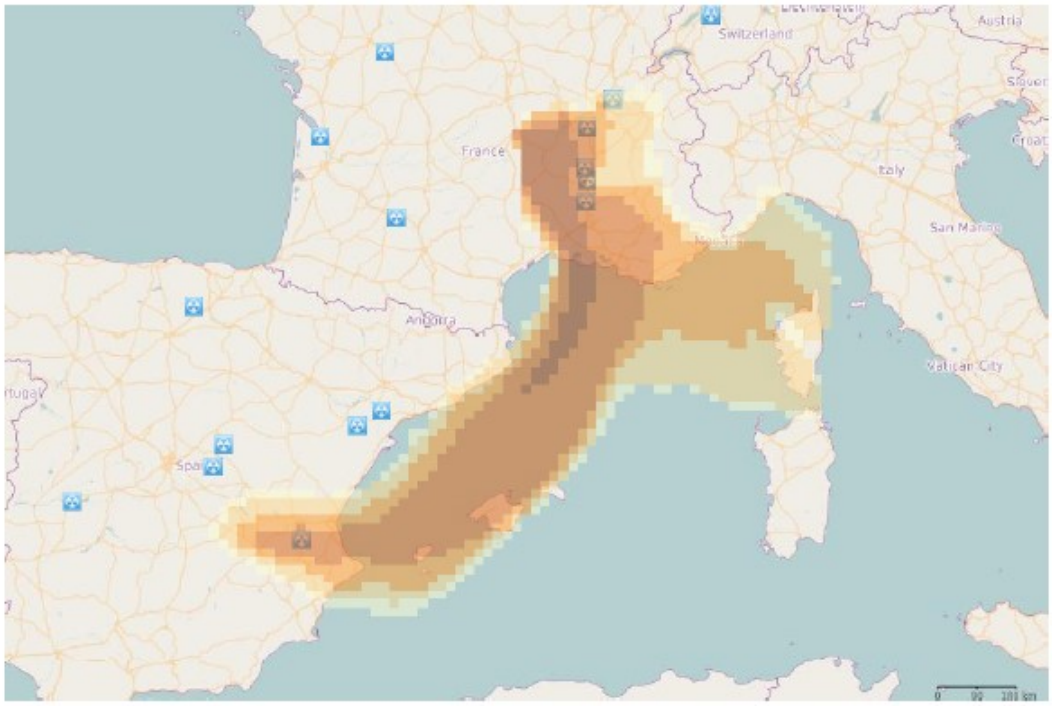


Figure 2: Scenario 1: inverse calculation, Station 2

3 Scenario 1: inverse calculation, Station 3

Selected time: 2017-03-25 05:00 UTC
Comment: additions: 2017-09-28T05:23Z netadata added to _bsVqZo.nc4
Source: _4 (r571581)
Calculation start: 2017-03-26 11:00 UTC
Weather: ECMWF
Model: inverse

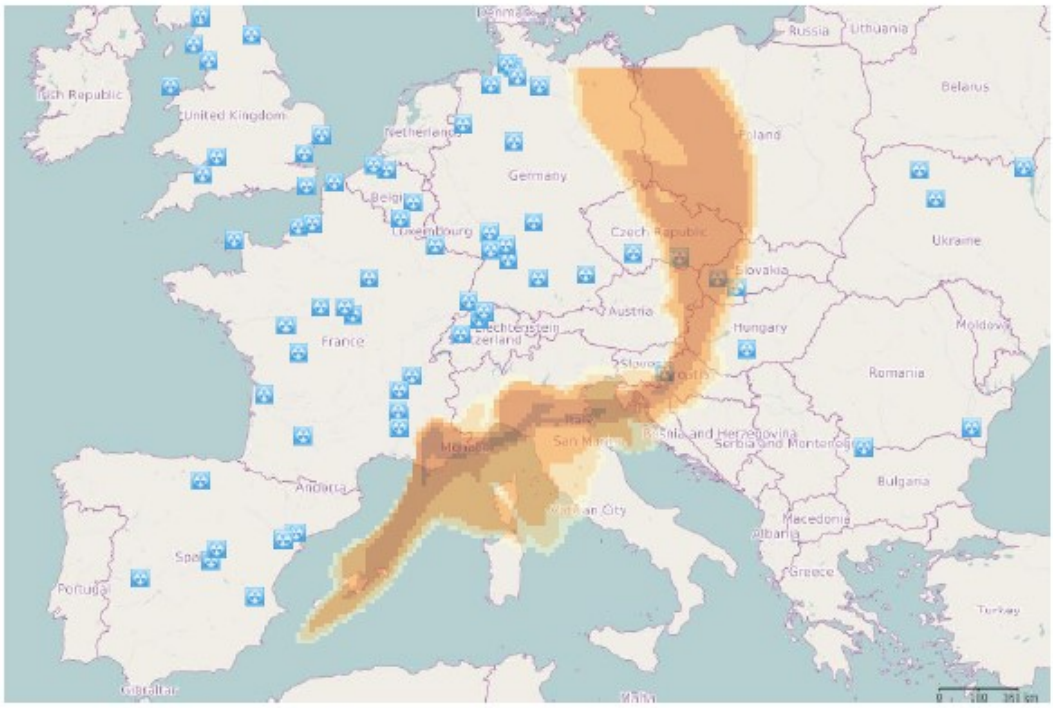


Figure 3: Scenario 1: inverse calculation, Station 3

6 Scenario 1: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-26 03:00 UTC
Comment: additions: 2017-09-28T10:10Z metadata added to kvrPMK.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-25 03:00 UTC

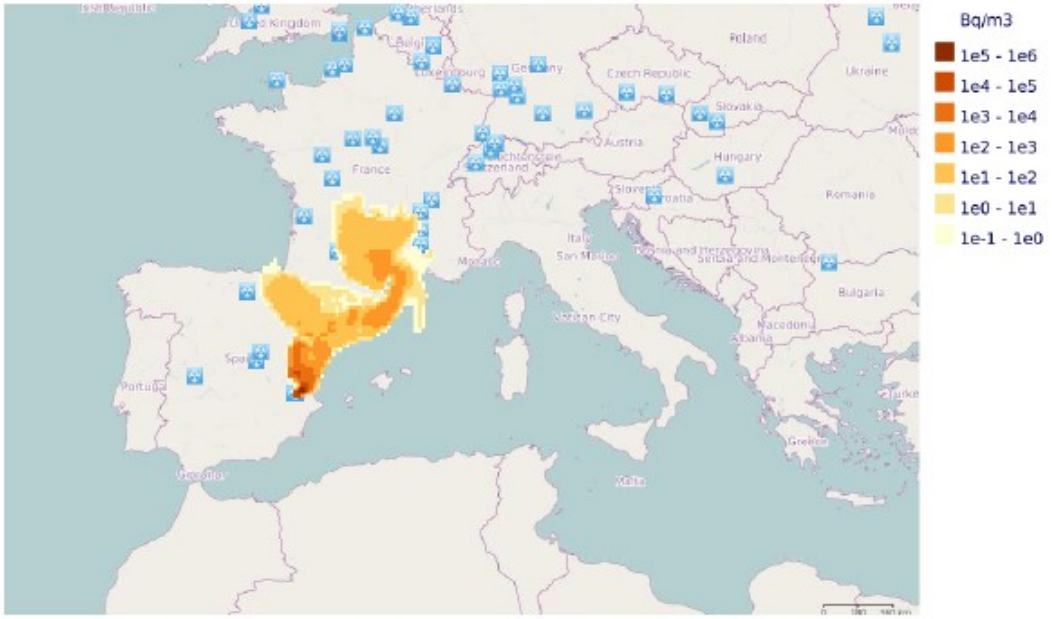


Figure 4: Scenario 1: Volume activity of i-131 in air - (dispersion)

7 Scenario 1: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-26 15:00 UTC
Comment: additions: 2017-09-28T10:10Z metadata added to kvrPMK.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-25 03:00 UTC

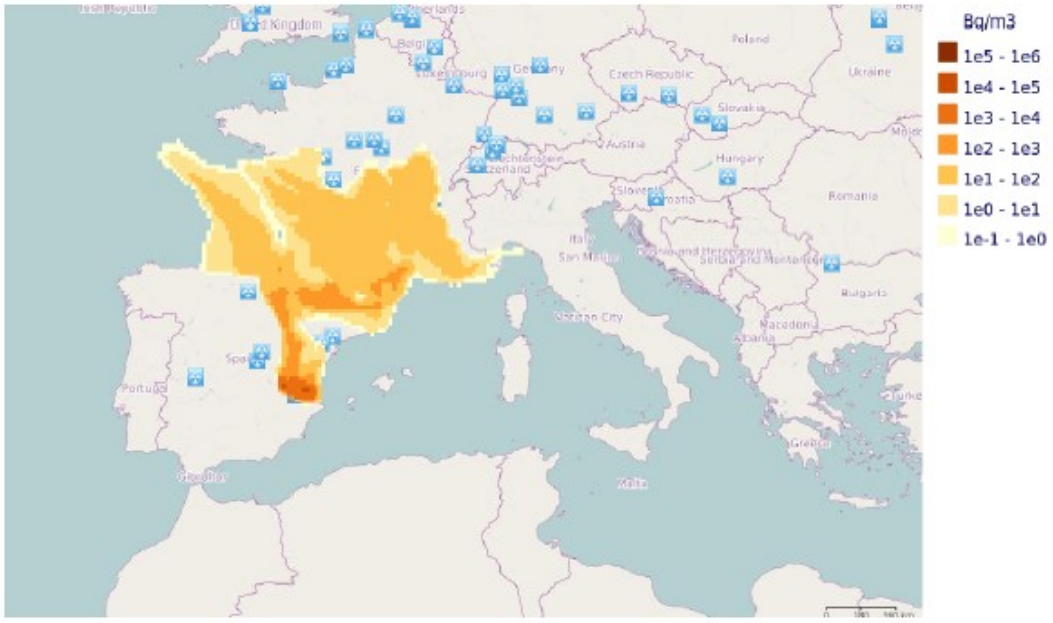


Figure 5: Scenario 1: Volume activity of i-131 in air - (dispersion)

8 Scenario 1: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-27 03:00 UTC
Comment: additions: 2017-09-28T10:10Z metadata added to kvrPMK.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-25 03:00 UTC

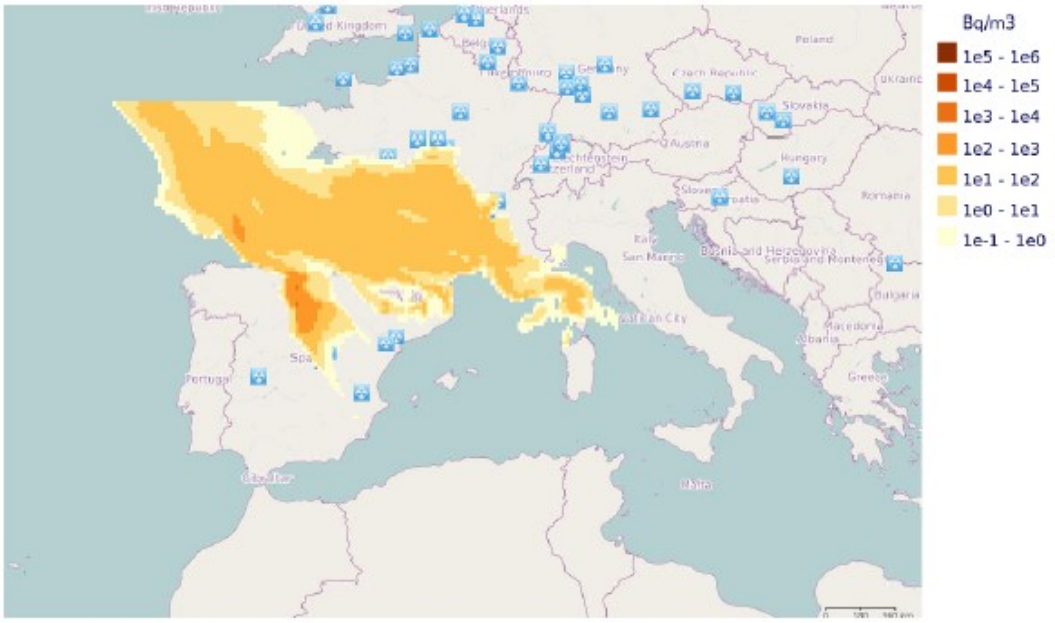


Figure 6: Scenario 1: Volume activity of i-131 in air - (dispersion)

9 Scenario 1: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-27 15:00 UTC
Comment: additions: 2017-09-28T10:10Z STUK metadata added to kvrPMK.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-25 03:00 UTC

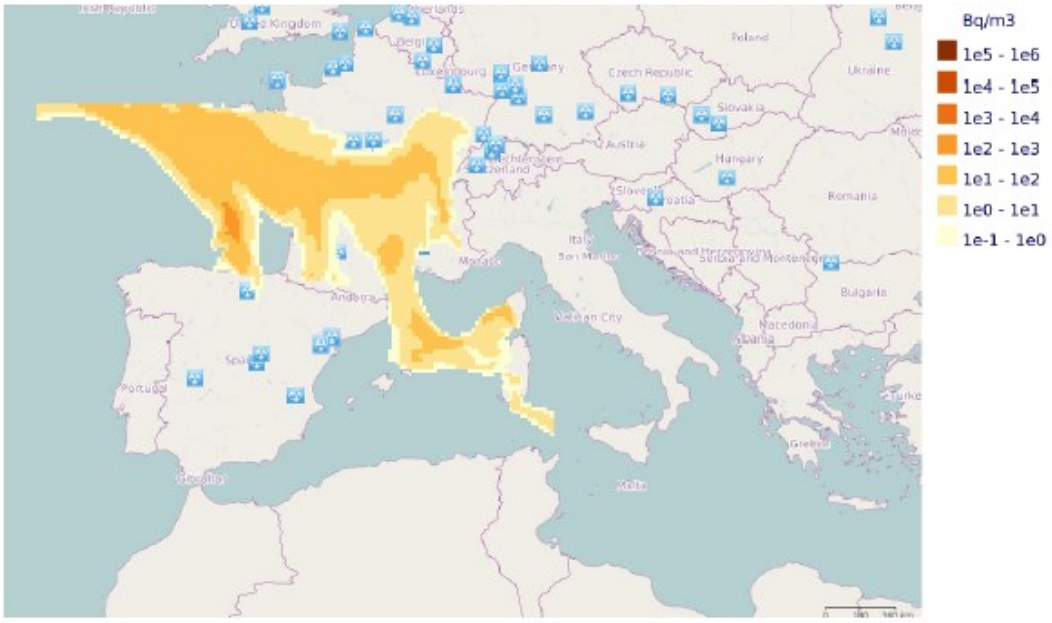


Figure 7: Scenario 1: Volume activity of i-131 in air - (dispersion)

10 Scenario 2: inverse calculation, Station 1

On map prediction of maximum area where radioactive material can spread in -23 hours if release starts 2017-03-20 19:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-19 20:00 UTC
Comment: additions: 2017-09-28T17:45Z metadata added to rsqAnu.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-20 19:00 UTC
Weather: ECMWF
Model: inverse

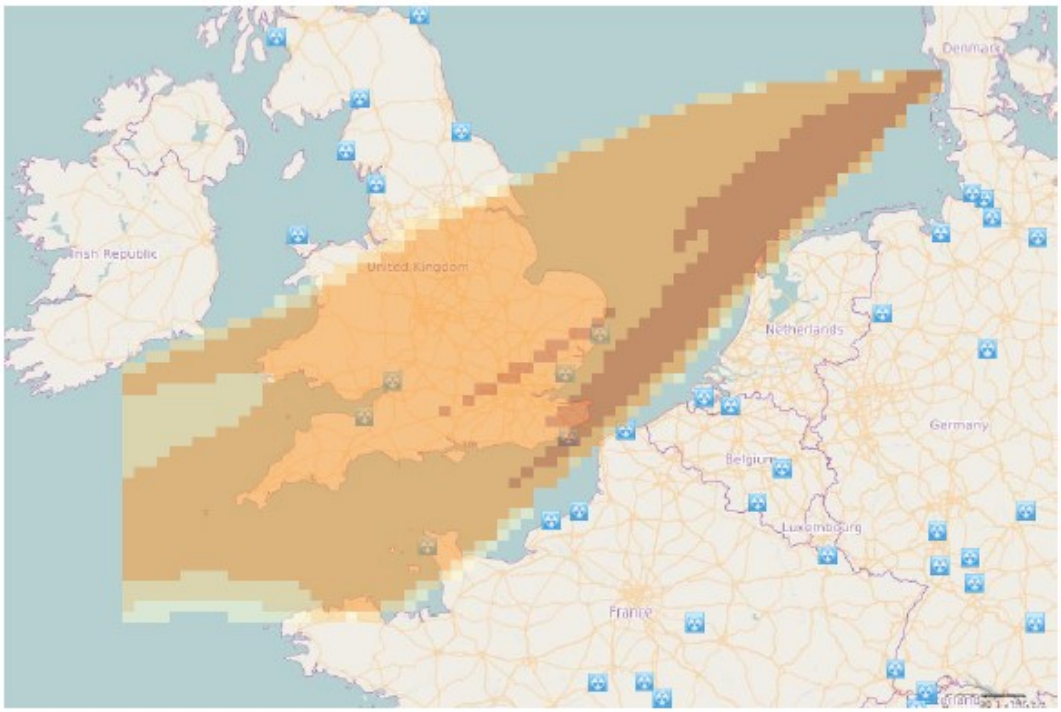


Figure 8: Scenario 2: inverse calculation, Station 1

11 Scenario 2: inverse calculation, Station 2

On map prediction of maximum area where radioactive material can spread in -23 hours if release starts 2017-03-21 01:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-20 02:00 UTC
Comment: ıdditions: 2017-09-28T17:54Z metadata added to R3NiT0.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-21 01:00 UTC
Weather: ECMWF
Model: inverse

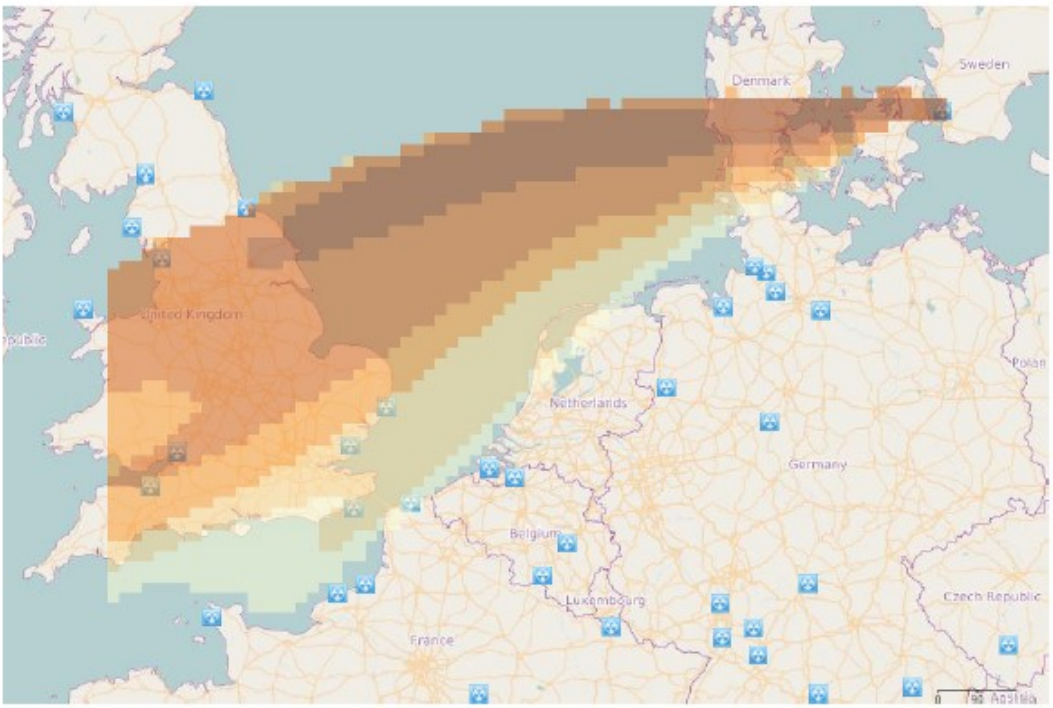


Figure 9: Scenario 2: inverse calculation, Station 2

12 Scenario 2: inverse calculation, Station 3

On map prediction of maximum area where radioactive material can spread in -35 hours if release starts 2017-03-21 08:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-19 21:00 UTC
Comment: additions: 2017-09-28T18:00Z metadata added to 9gbn3a.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-21 08:00 UTC
Weather: ECMWF
Model: inverse

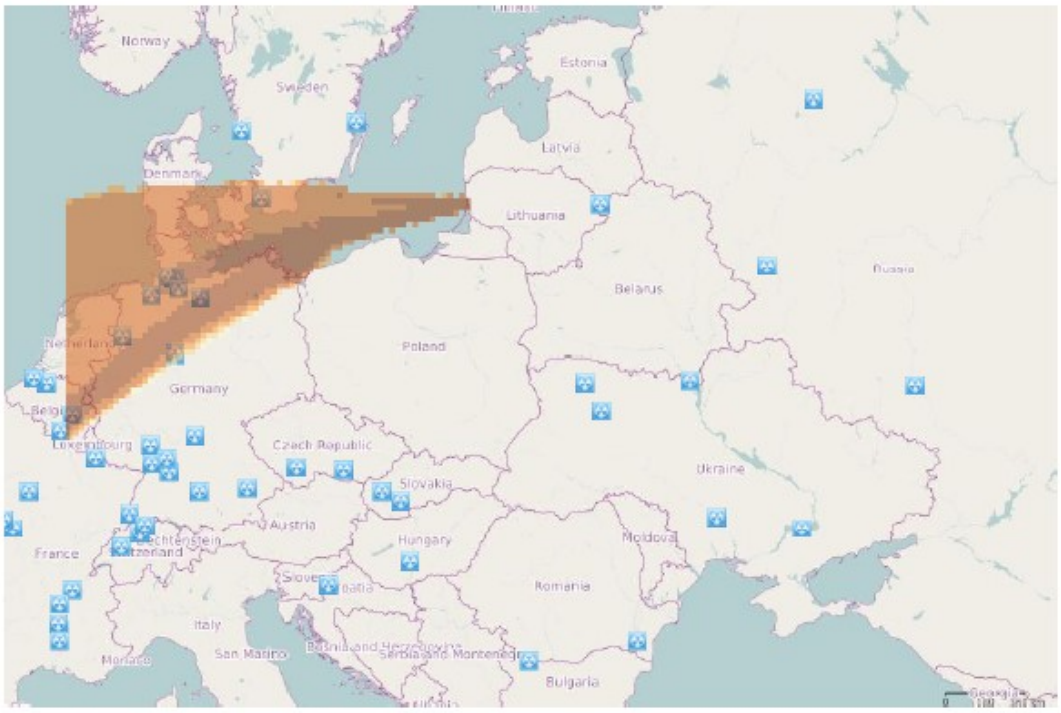


Figure 10: Scenario 2: inverse calculation, Station 3

15 Scenario 2: Volume activity of i-131 in air - (: dispersion)

Selected time: 2017-03-20 08:00 UTC
Comment: additions: 2017-09-28T18:24Z netadata added to zOxAyx.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-19 20:00 UTC

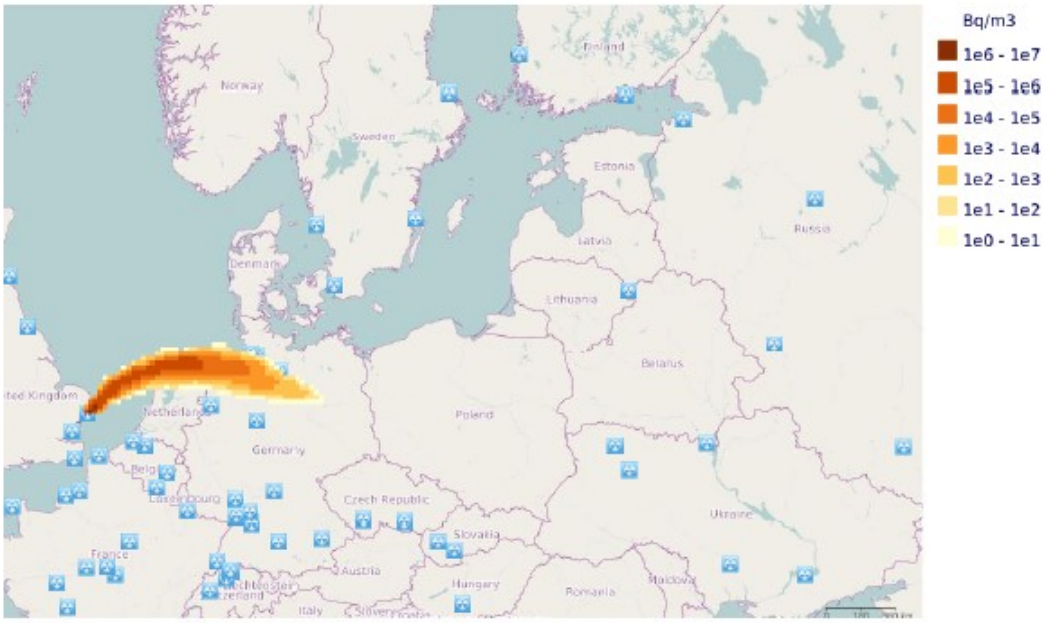


Figure 11: Scenario 2: Volume activity of i-131 in air - (: dispersion)

16 Scenario 2: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-20 20:00 UTC
Comment: additions: 2017-09-28T18:24Z metadata added to zOxAyx.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-19 20:00 UTC

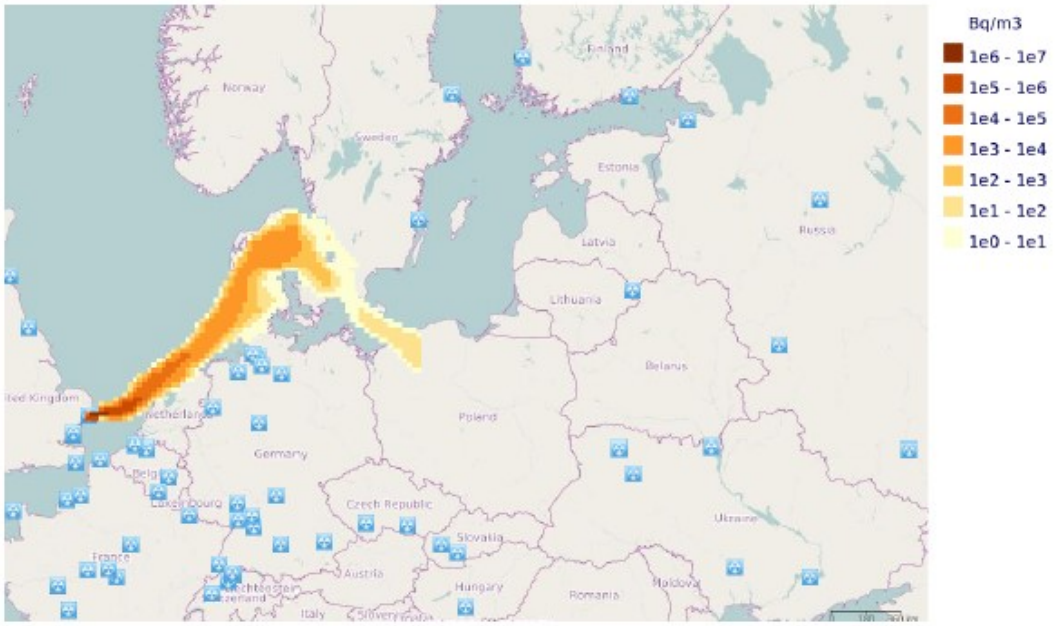


Figure 12: Scenario 2: Volume activity of i-131 in air - (dispersion)

17 Scenario 2: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-21 08:00 UTC
Comment: additions: 2017-09-28T18:24Z ; metadata added to zOxAyx.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-19 20:00 UTC

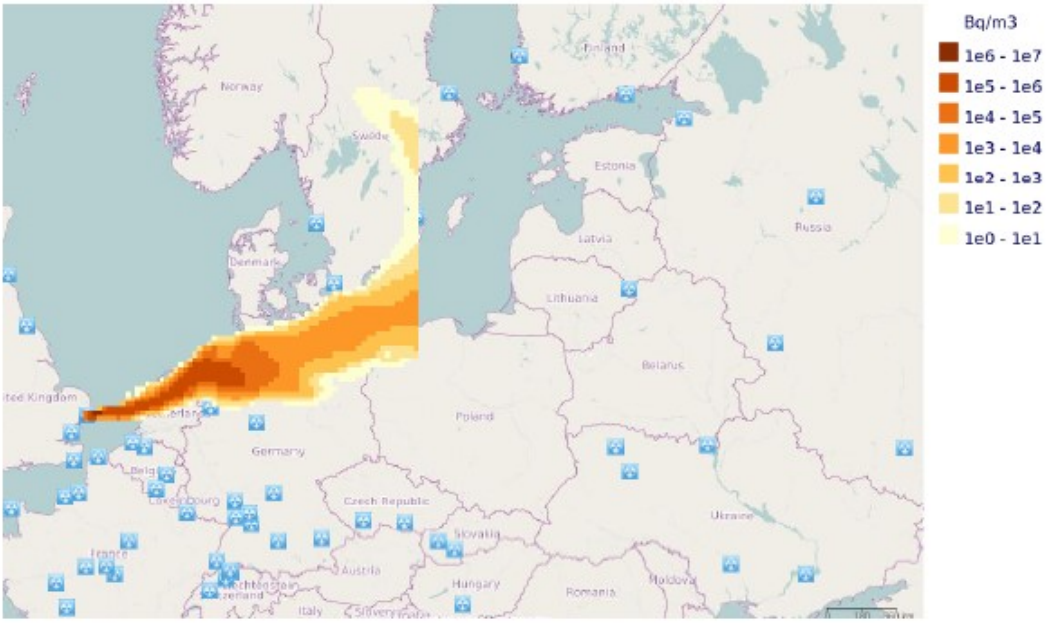


Figure 13: Scenario 2: Volume activity of i-131 in air - (dispersion)

18 Scenario 2: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-21 20:00 UTC
Comment: additions: 2017-09-28T18:24Z metadata added to : zOxAyx.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-19 20:00 UTC

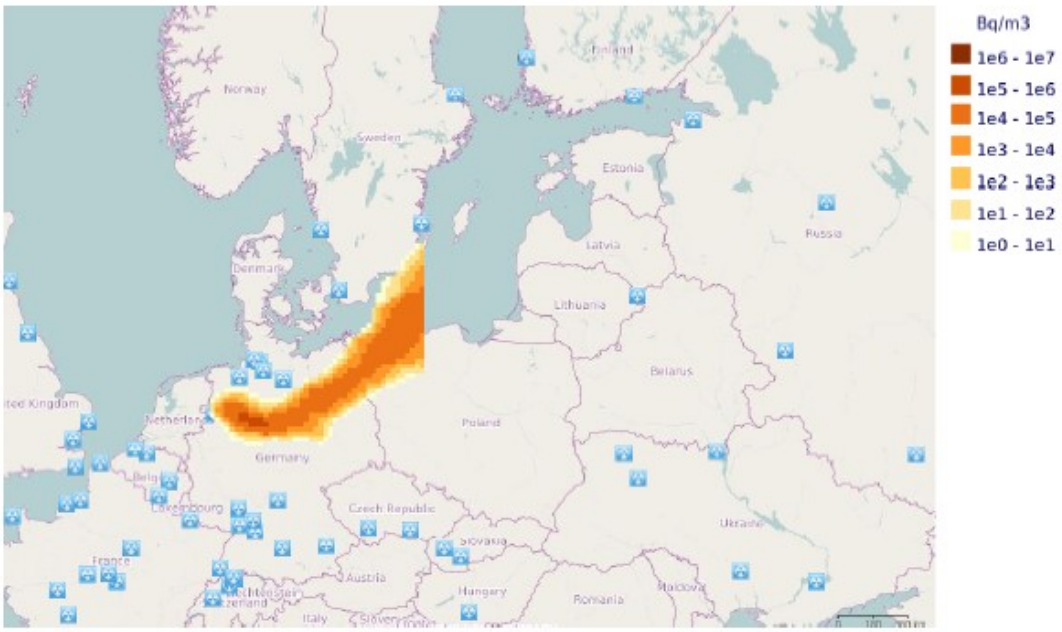


Figure 14: Scenario 2: Volume activity of i-131 in air - (dispersion)

19 Scenario 3: inverse calculation, Station 1

Selected time: 2017-03-22 09:00 UTC
Comment: additions: 2017-09-28T14:40Z metadata added to _fdoyyD.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-22 13:00 UTC
Weather: ECMWF
Model: inverse

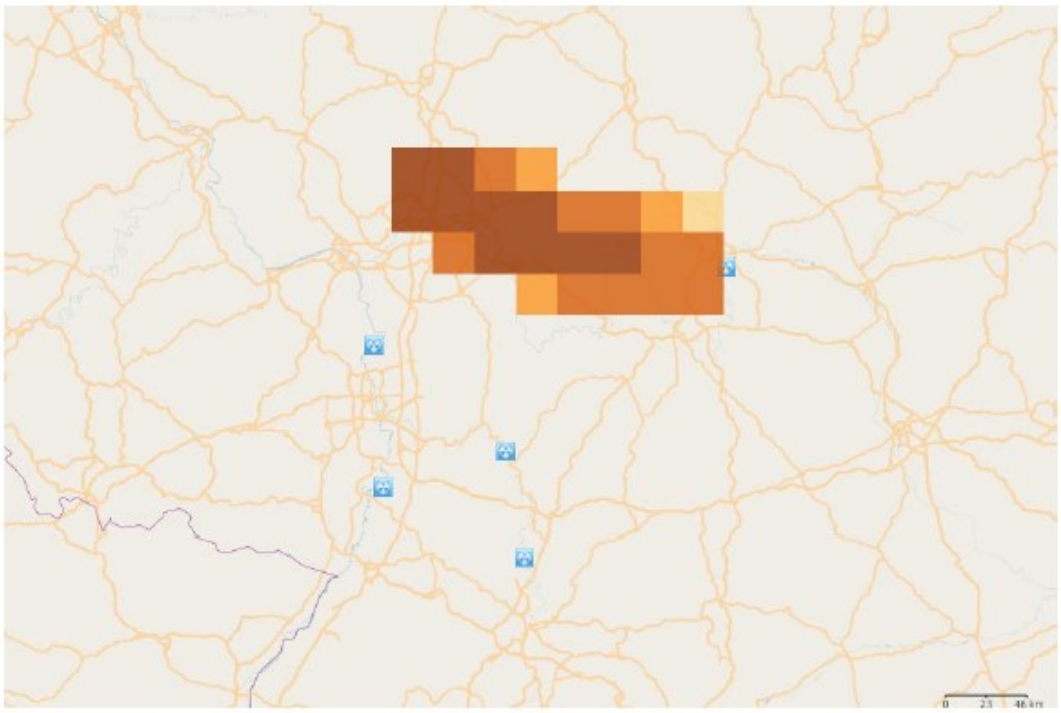


Figure 15: Scenario 3: inverse calculation, Station 1

20 Scenario 3: inverse calculatio, Station 2

On map prediction of maximum area where radioactive material can spread in -23 hours if release starts 2017-03-22 22:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-21 23:00 UTC
Comment: additions: 2017-09-28T14:45Z metadata added to lWdAIA.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-22 22:00 UTC
Weather: ECMWF
Model: inverse

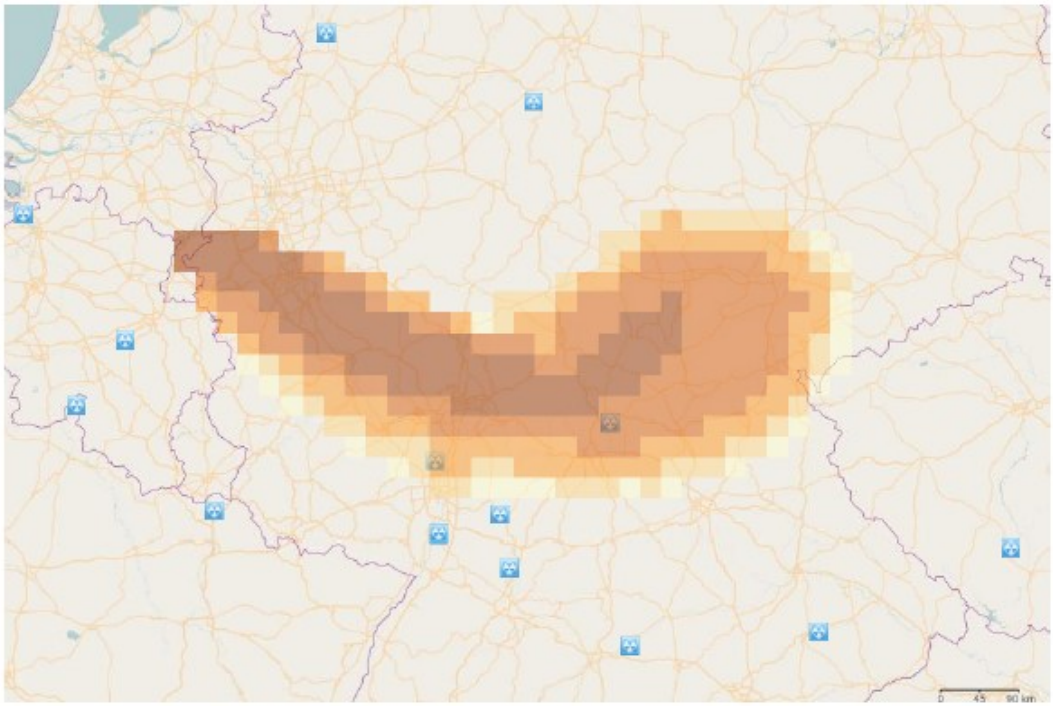


Figure 16: Scenario 3: inverse calculatio, Station 2

21 Scenario 3: inverse calculation, Station 3

On map prediction of maximum area where radioactive material can spread in -23 hours if release starts 2017-03-23 09:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-22 10:00 UTC
Comment: additions: 2017-09-28T14:51Z metadata added to tEy602.nc4
Source v5_4 (r571581)
Calculation start: 2017-03-23 09:00 UTC
Weather: ECMWF
Model: inverse

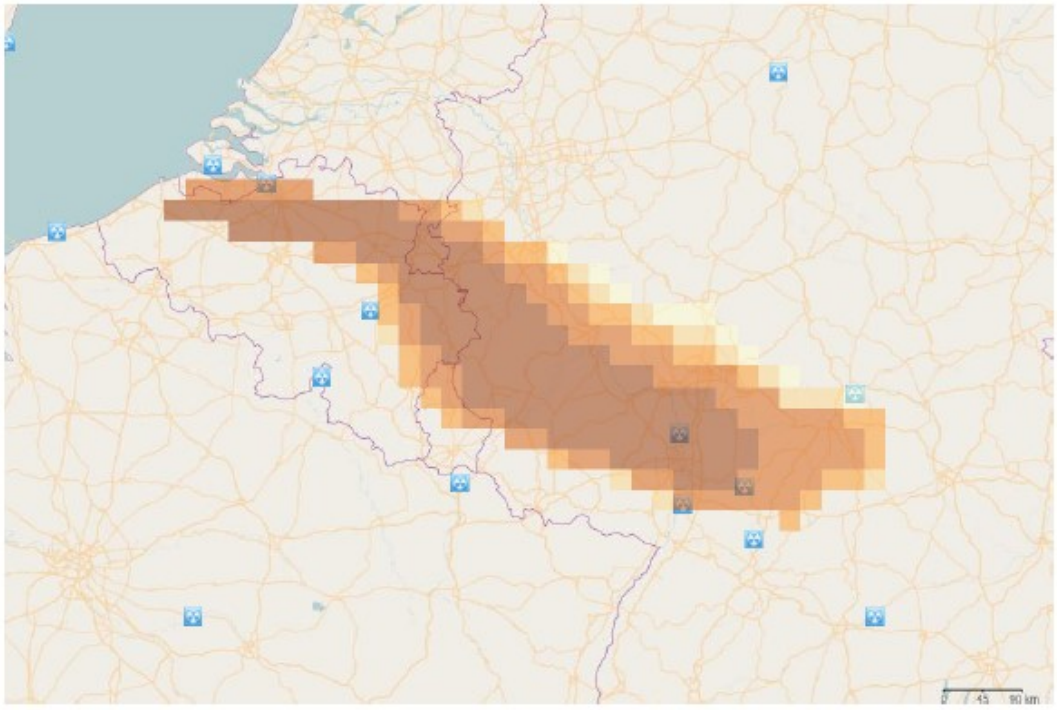


Figure 17: Scenario 3: inverse calculation, Station 3

23 Scenario 3: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-22 20:00 UTC
Comment: additions: 2017-09-28T15:26Z metadata added to ahqlnM.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-22 08:00 UTC

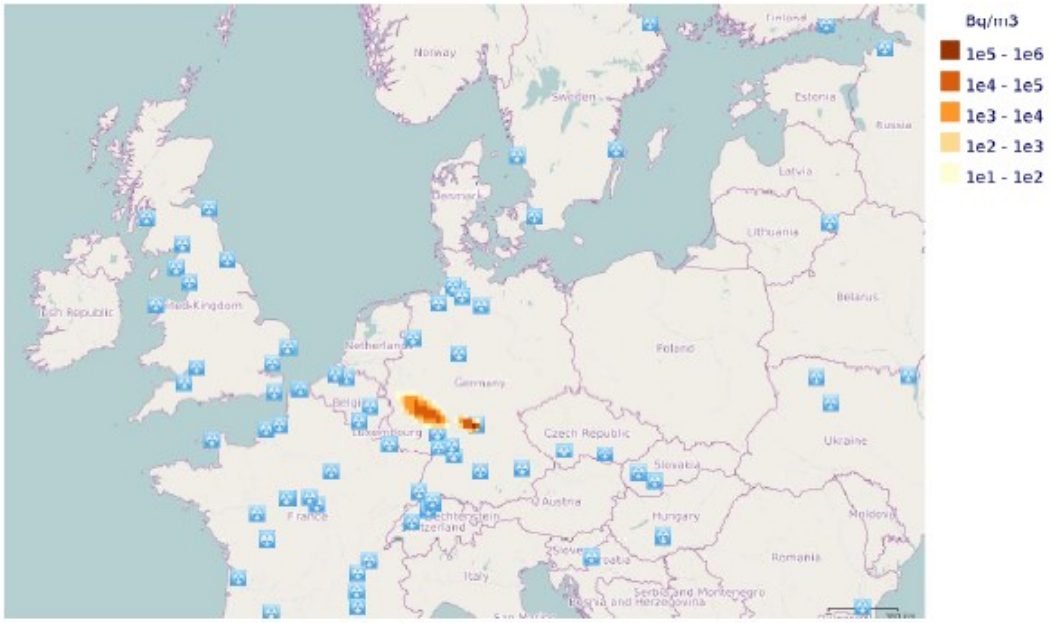


Figure 18: Scenario 3: Volume activity of i-131 in air - (dispersion)

24 Scenario 3: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-23 20:00 UTC
Comment: additions: 2017-09-28T15:26Z metadata added to ahqlnM.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-22 08:00 UTC

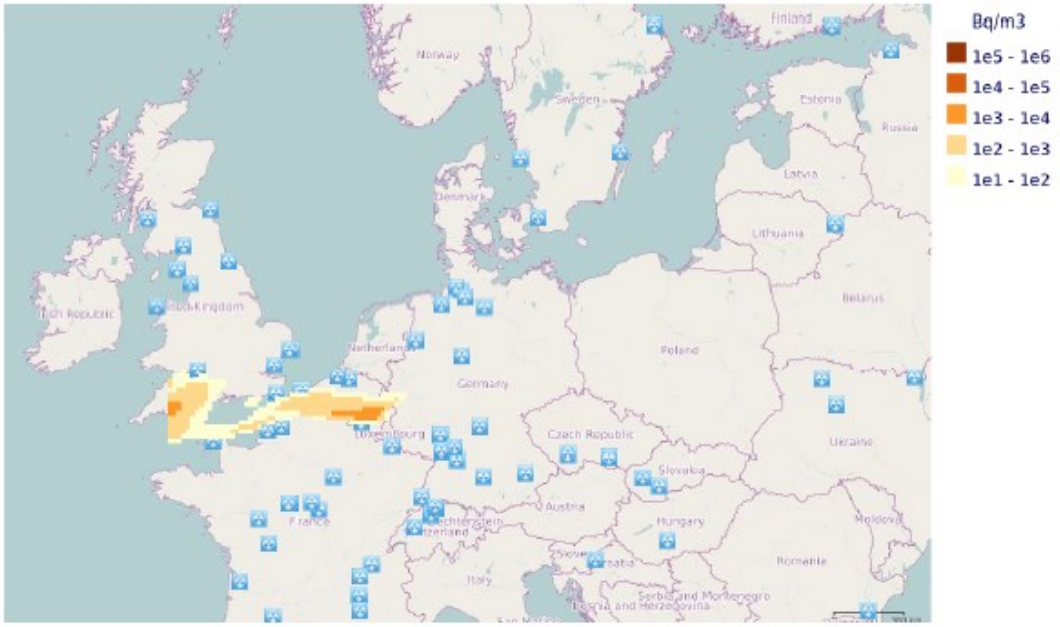


Figure 19: Scenario 3: Volume activity of i-131 in air - (dispersion)

25 Scenario 3: Volume activity of i-131 in air - (dispersion)

Selected time: 2017-03-23 20:00 UTC
Comment: additions: 2017-09-28T15:26Z metadata added to ahqlnM.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-22 08:00 UTC

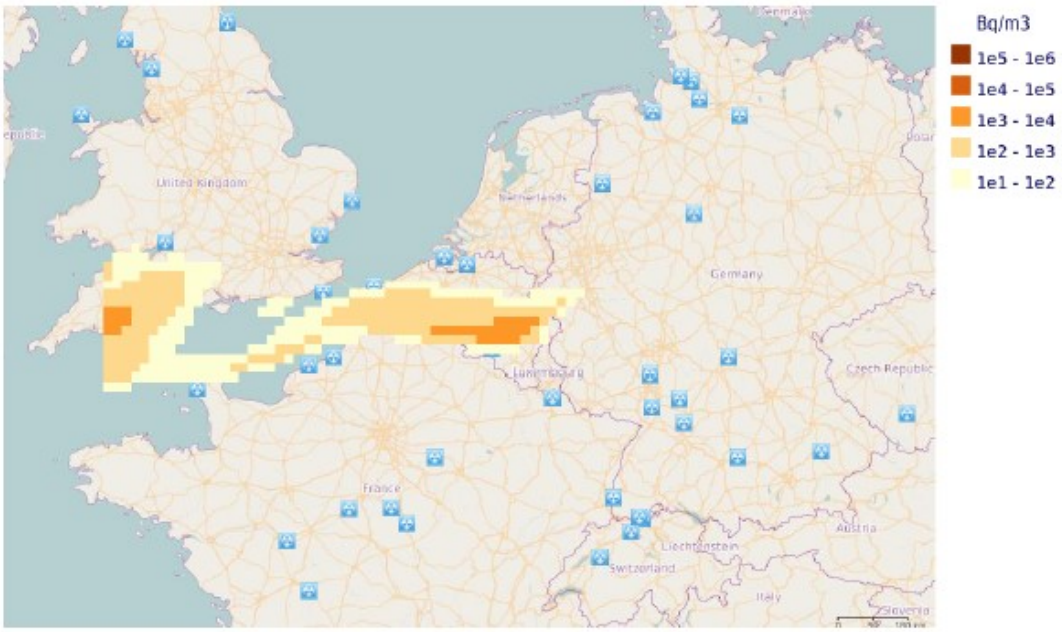


Figure 20: Scenario 3: Volume activity of i-131 in air - (dispersion)

26 Scenario 4: inverse station 1

On map prediction of maximum area where radioactive material can spread in -21 hours if release starts 2017-03-21 11:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-20 14:00 UTC
Comment: additions: 2017-09-27T05:24Z metadata added to dnbYHV.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-21 11:00 UTC
Weather: ECMWF
Model: inverse

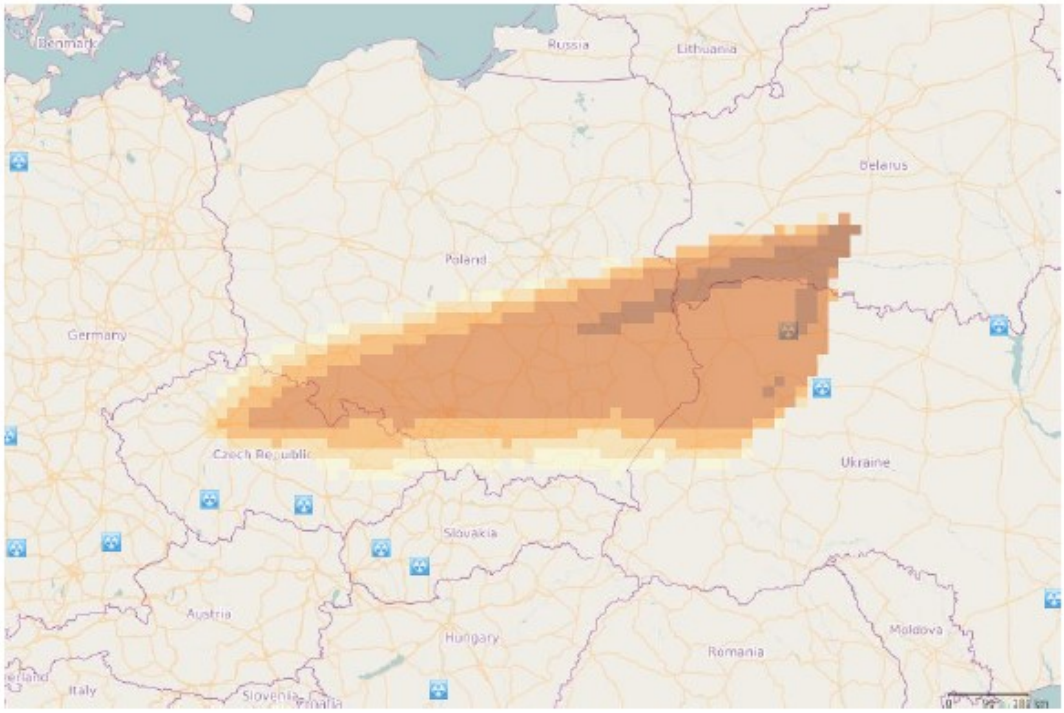


Figure 21: Scenario 4: inverse station 1

27 Scenario 4: inverse Station 2

On map prediction of maximum area where radioactive material can spread in -5 hours if release starts 2017-03-21 14:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-21 09:00 UTC
Comment: additions: 2017-09-27T05:33Z metadata added to NpSkfF.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-21 14:00 UTC
Weather: ECMWF
Model: inverse

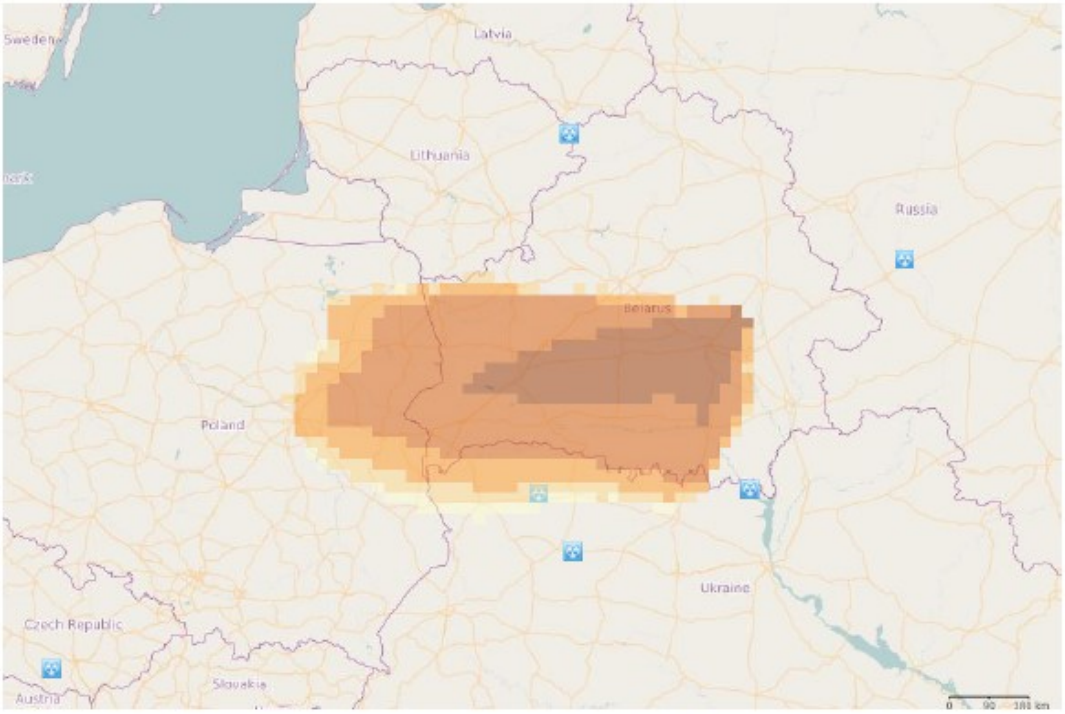


Figure 22: Scenario 4: inverse Station 2

28 Scenario 4: inverse, Station 3

On map prediction of maximum area where radioactive material can spread in -39 hours if release starts 2017-03-22 06:00 UTC.

NB: Radioactive cloud dillutes when it is distributed with the wind. Map is a prediction of areas where the cloud can reach. It does not depict areas of radiation risk nor radiation levels

Selected time: 2017-03-20 15:00 UTC
Comment: additions: 2017-09-26T11:58Z metadata added to QAImqF.nc4
Source: v5_4 (r571581)
Calculation start: 2017-03-22 06:00 UTC
Weather: ECMWF
Model: inverse

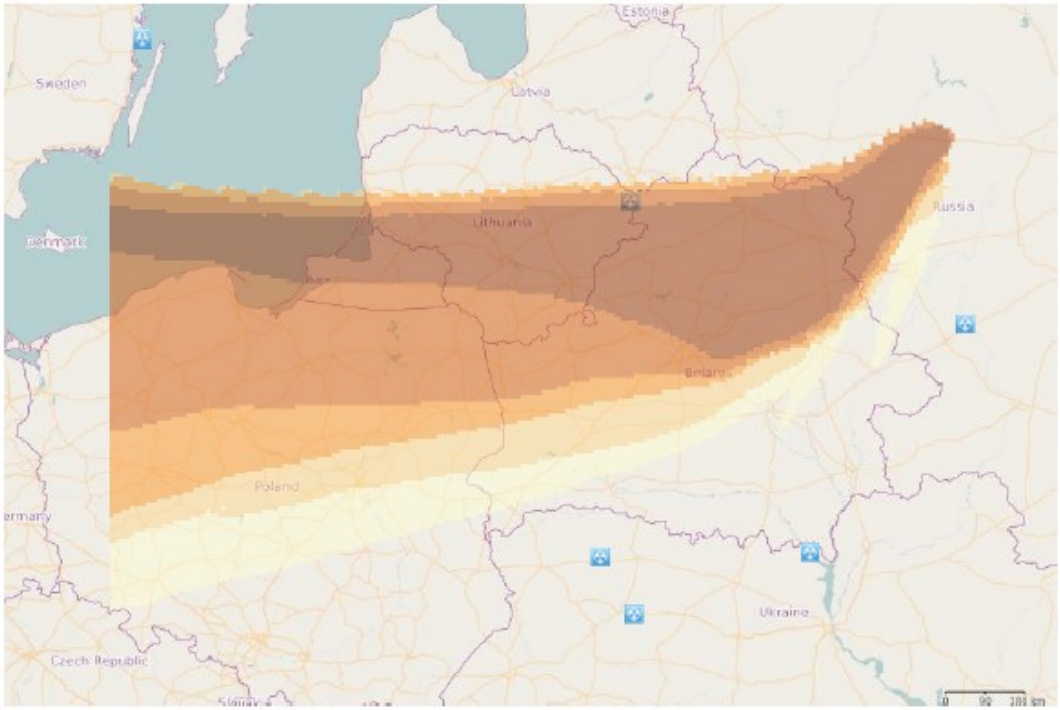


Figure 23: Scenario 4: inverse, Station 3

31 Scenario 4: Volume activity of co-60 in air - (dispersion)

Selected time: 2017-03-21 12:00 UTC
Comment: additions: 2017-09-27T11:23Z metadata added to bIT6hL.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-21 00:00 UTC

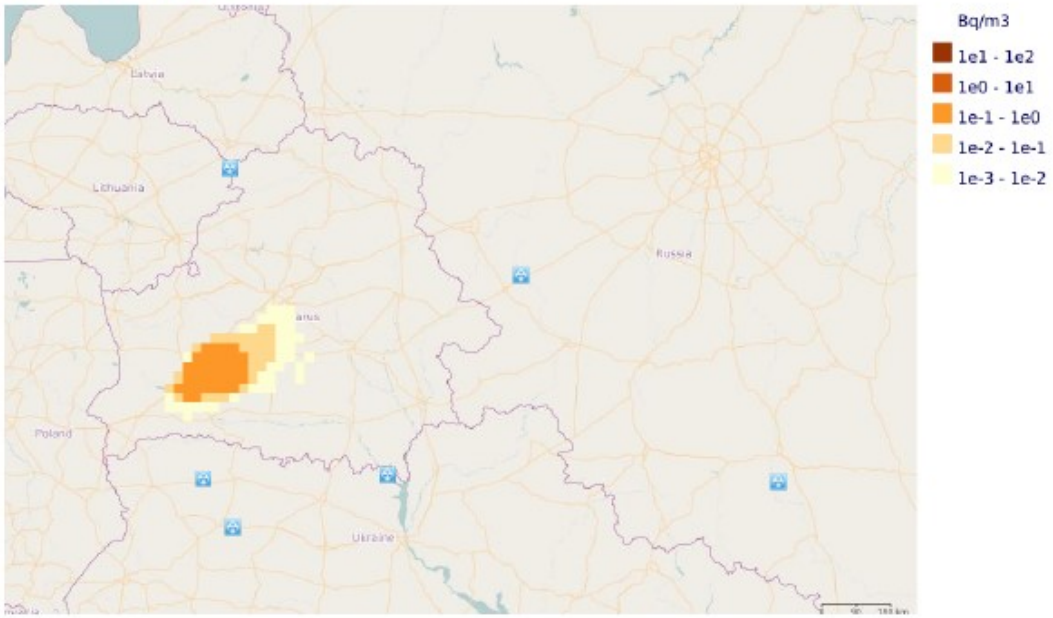


Figure 24: Scenario 4: Volume activity of co-60 in air - (dispersion)

32 Scenario 4: Volume activity of co-60 in air - (dispersion)

Selected time: 2017-03-22 12:00 UTC
Comment: additions: 2017-09-27T11:23Z metadata added to bIT6hL.nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-21 00:00 UTC

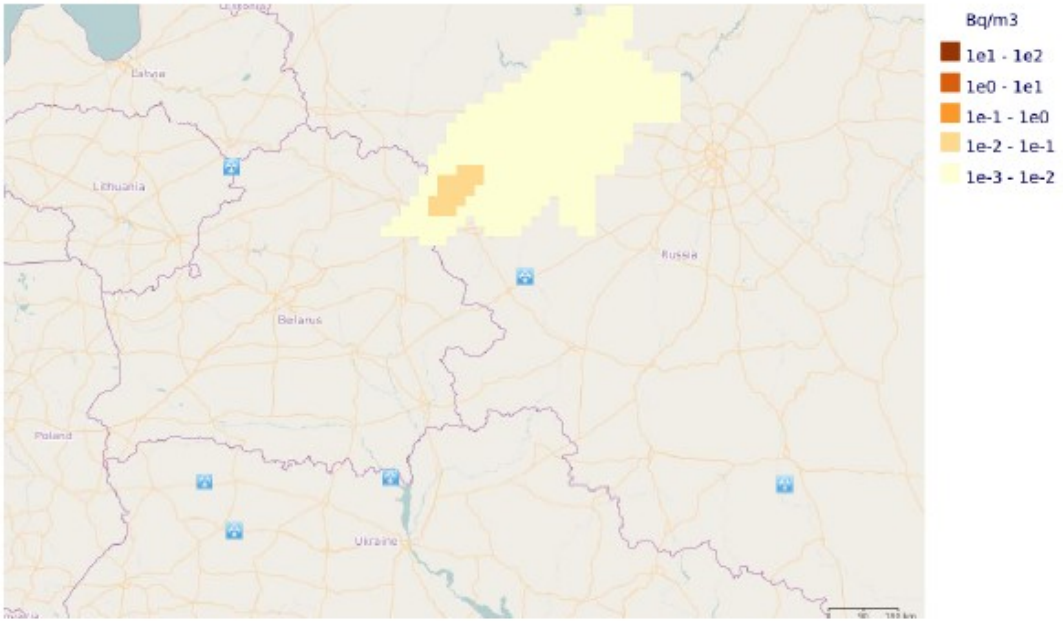


Figure 25: Scenario 4: Volume activity of co-60 in air - (dispersion)

33 Scenario 4: Volume activity of co-60 in air - (dispersion)

Selected time: 2017-03-22 00:00 UTC
Comment: additions: 2017-09-27T11:23Z metadata added to : bIT6hL nc4
Source: v5_4 (r571581)
Model: dispersion
Weather: ECMWF
Start of release: 2017-03-21 00:00 UTC

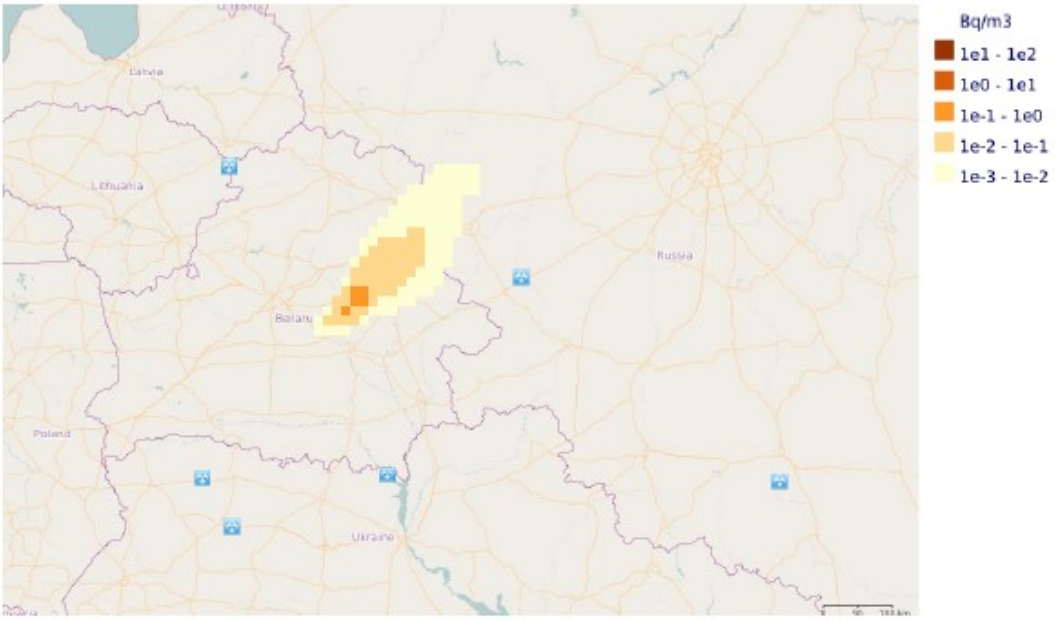


Figure 26: Scenario 4: Volume activity of co-60 in air - (dispersion)

Participant B

NKS EPHSOGAM EXERCISE – October 3rd 2017
METHODS
For analysis of gammaspectra, we generated a calibration file with energy and efficiency calibration in Genie 2000. The calibration file was used to calculate activity concentration in Bq/m3 for all samples. Nuclide identification was performed with Genie standard nuclide library.
For source terms, wind direction and dispersion calculations, we used ARGOS 9.4 decision support system with NWP data provided by [redacted].
In order to estimate the location of the nuclear release in Scenario 1 and 2, we requested support from the [redacted] Meteorological Institute [redacted] and their dispersion and trajectory modelling capabilities. The dispersion model [redacted] was used in invers mode on all 3 stations in scenarios 1 and 2, and by comparing the 3 resulting dispersion results the release point was estimated manually [redacted].

SCENARIO 1
1) LOCATION OF RELEASE

The data suggest a release from a Spanish NPP during March 24th. However, the absence of cesium isotopes (Cs-137 and Cs-134) is puzzling. Never the less, if the release has passed a "Cs filter", we would suggest Asco NPP as the source of the release.

The weather situation at the time is characterized by low wind speeds and a complex weather system, so alternatively, the release could have occurred at a nuclear installation in Southern France.
A suggestion is a CEA (Committee Energie Atomique) installation, Cadarache and the release could have originated from some kind of nuclear experiment.

2) TIME OF RELEASE

The release probably occurred the 25th of March, at 6:00 UTC.

3) IDENTIFIED ISOTOPES AND ACTIVITY CONCENTRATION:

Nuclide Name	Station 1 (Bq/m3)	Station 2 (Bq/m3)	Station 3 (Bq/m3)
Zr-89	0,029		
Y-91M	0,22	0,08	0,08
Y-93	1,15	0,18	
Nb-95M		0,024	
Zr-95	4,16	0,79	0,84
Zr-97	2,3	0,46	0,23
Ru-103	18,95	4,01	4,94
I-124	0,024		
I-131	7,71	1,4	1,18
I-132	0,17		
Te-132	5,14	0,98	0,92
I-133	18,13	1,43	1,62
I-135	0,26		

La-140	5,65	1	0,7

The occurrence of short-lived fission products such as iodine and Te-132 suggests a relatively fresh nuclear release. However, the absence of cesium isotopes contradicts what would be expected from an accident at a NPP.

SCENARIE 2

3) LOCATION AND TIME OF RELEASE

The release occurred from a British NPP, probably at either Wylfa NPP at March 20th from 3:00 to 6:00 UTC, Hartlepool NPP March 20th from 9:00 to 12:00 UTC, or the Torness NPP March 20th from 9:00 to 13:00 UTC. The weather situation at the time is characterized by relatively strong westerly wind (see figure 1).

As in Scenario 1, the absence of cesium isotopes contradicts a release from a NPP – this could potentially be related to the nature of gas-cooled reactors and related accidents from such a reactor?

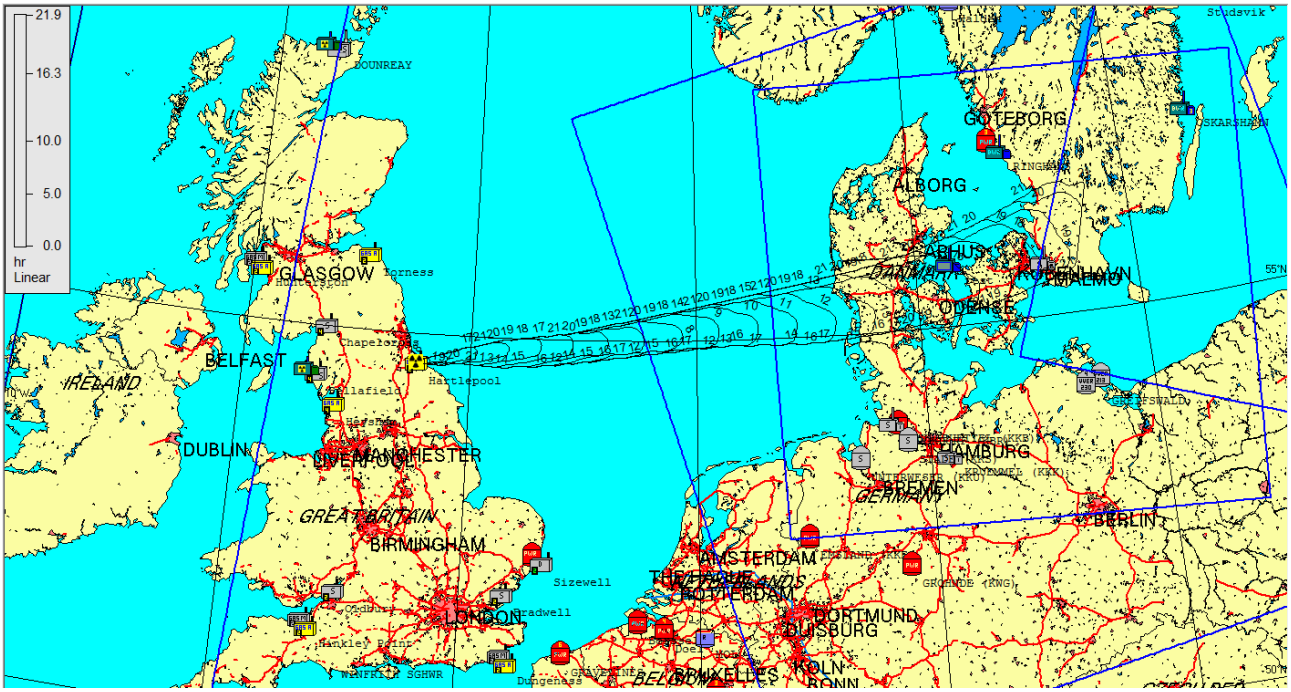


Figure 1: Dispersion calculation with time of arrival from Hartlepool, UK.

3) IDENTIFIED ISOTOPES AND ACTIVITY CONCENTRATION

Nuclide Name	Station 1 (Bq/m3)	Station 2 (Bq/m3)	Station 3 (Bq/m3)
Na-24	9	1	
Zn-69M	5	2	
Kr-87	157		
Zr-89	27	3	1
Y-93	331	180	51
Nb-95M			1
Zr-95	978	881	147
Zr-97	636	373	65

Rh-105	31	12	
Ru-106	42		
Sb-124	9	4	0
Xe-125	3		
I-131	1644	373	88
I-132	415	54	348
Te-132	1610	4606	
Ba-133	130		
I-133	4942	828	181
I-134	32		
I-135	2166	397	9
La-140	1303	571	241
Hg-203	14		
Th-227	485		1

Again, the absence of Cs-isotopes is not what would be expected from a release after an accident at a NPP.

SCENARIO 3

1) LOCATION OF RELEASE – Grafenrheinfeld NPP, Germany

2) TIME OF RELEASE

The time of release has been calculated to 9:00 UTC, March 22nd, using ARGOS 9.4 with Rimpuff dispersion model. The calculated time dependent dose rate compares very well to the data provided for scenario 3, location 3 (see figure 2).

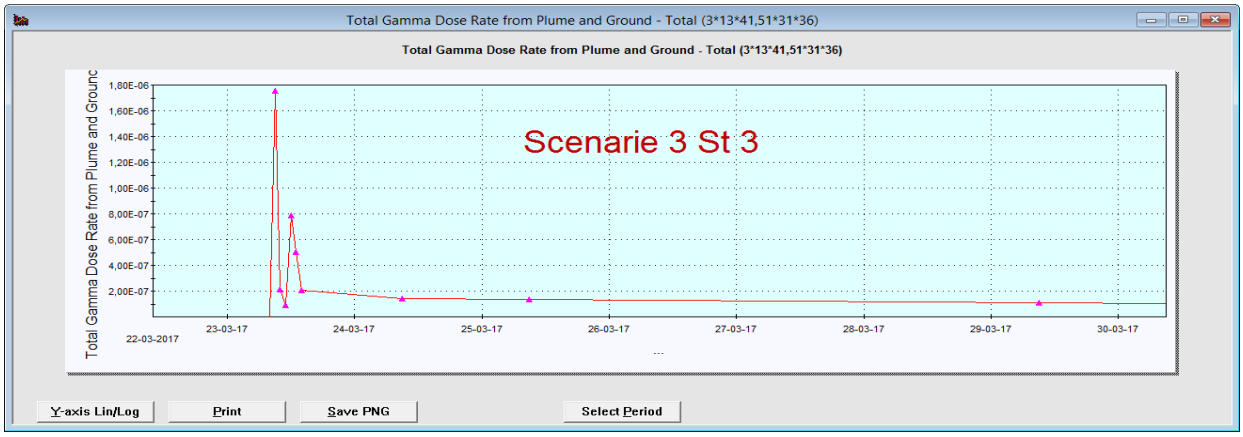


Figure 2: Total gamma dose rate at Station 3 calculated.

3) IDENTIFIED ISOTOPES AND ACITIVITY CONCENTRATION – see table below

Nuclide Name	Station 1 (Bq/m3)	Station 2 (Bq/m3)	Station 3 (Bq/m3)
Be-7	1269		
Zr-89	396	18	3
Zr-95	226	269	
Sb-122	1517	255	59

I-131	177631	17084	2322
I-132	467280	6846	8
Te-132	153052	7095	1281
I-133	219447	19619	1981
Cs-134	22459	2951	1013
I-135	27792	1063	35
Cs-137	22427	3770	1116
Ba-140	24511	5311	1547
Ra-226	205		

Most radionuclides identified are typical from a release from an accident at a NPP.

SCENARIE 4

1) LOCATION OF RELEASE

   The release has probably occurred very close to Station 1, as the identified isotopes are not very mobile and cannot be transported in such amounts for long distances. The concentration of radionuclides decreases in a direction towards NE, which suggest a location of the source of release SE of Station 1.

2) TIME OF RELEASE

   The release probably occurred no earlier than a few hours before sampling.

3) IDENTIFIED ISOTOPES AND ACITIVITY CONCENTRATION – see table below

Nuclide Name	Station 1 (mBq/m3)	Station 2 (Bq/m3)	Station 3 (Bq/m3)
Mn-54	1200	20	9
Co-58	210	3	3
Co-60	450	8	14

The radionuclides identified originate from irradiated metal of some kind. These could be pieces of metal from a decommissioned reactor or a disused industrial source, which has been melted at a scrap melter.

Participant C

NKS EPHSOGAM – gamma spectrometric results from [redacted]

Spectrum analysis in Genie-2000

Results without corrections.

Scenario 1

Station 1

Nuclide	T1/2	Air concentration (Bq/m^3)	1 sigma
La-140	1,68 d	3,0	0,031
I-135	6,57 h	0,195	0,007
I-133	20,9 h	5,4	0,073
Te-132	3,2 d	9,5	0,23
I-132	2,3 h	0,077	0,0028
I-131	8 d	2,9	0,054
Ru-103	39,3 d	5,76	0,11
Zr-97	16,7 h	0,97	0,018
Zr-95	64 d	1,8	0,037
Cs-137	30,17 y	< 0,014	
Cs-134	2,06 y	< 0,01	

Station 2

Nuclide	Air concentration (Bq/m^3)	1 sigma
La-140	0,53	0,0057
I-135	0,01	0,0019
I-133	0,41	0,0077
Te-132	1,8	0,048
I-131	0,47	0,0094
Ru-103	1,2	0,022
Zr-97	0,19	0,0037
Zr-95	0,35	0,0071

Station 3

Nuclide	Air concentration (Bq/m^3)	1 sigma
La-140	0,37	0,0041
I-133	0,48	0,0079
Te-132	1,74	0,043
I-131	0,39	0,0082
Ru-103	1,55	0,025
Zr-97	0,1	0,0023
Zr-95	0,37	0,0074

Scenario 2

Suspected release location: Sizewell NPP UK

Station 1

Nuclide		Air concentration (Bq/m^3)	1 sigma
Zr-95	64 d	427	8,3
Zr-97	16,7	241	3
Te-131m	1,25 d	340	2,4
I-131	8 d	370	5,5
I-132	2,3 h	62,6	1,5
I-133	20,9 h	1422,5	10,3
I-135	6,57 h	790,4	4,3
Te-132	3,2 d	3733	56,5
La-140	1,68 d	587	4
Cs-137	30,17 y	< 1,2	
Cs-134	2,06 y	< 0,84	

Station 2

Nuclide	Air concentration (Bq/m^3)	1 sigma
Zr-95	383,6	7,5
Zr-97	113,6	1,22
Te-131m	35,1	0,27
I-I31	213,2	3
I-132	2,1	0,11
I-133	201,8	1,5
I-135	58,1	0,6
Te-132	2955	44
La-140	313,1	2

Station 3

Nuclide	Air concentration (Bq/m^3)	1 sigma
Zr-95	64,1	1,3
Zr-97	23,8	0,41
Te-131m	21,3	0,21
I-131	19,9	0,42
I-132	Nd	
I-133	48,7	0,7
I-135	3,6	0,13
Te-132	801	12,6
La-140	131,2	0,96

Estimated release (selected nuclide) and time

I-131: ~ 1E+18 Bq

Assumed release time 06.00 20.03.2017 with a sustained release over 6 hours.

Scenario 3

Station 1

Nuclide		Air concentration (Bq/m^3)	1 sigma
Ba-140	12,8 d	17128	1161
Cs-137	30,17 y	8078	172
Cs-134	2,06 y	10414	75
I-135	6,57 h	9189	46
I-133	20,87 h	53337	315
Te-132	3,2 d	100607	1495
I-132	2,3 h	19226	3327
I-131	8 d	48423	650
Zr-95	64 d	1242	23

Station 2

Nuclide	Air concentration (Bq/m^3)	1 sigma
Ba-140	2099	22,8
Cs-137	1356	28,8
Cs-134	1403	10
I-135	221,9	1,4
I-133	3929	24,5
Te-132	10015	149
I-132	61	3,8
I-131	6200	82
Zr-95	124,8	2,4

Station 3

Nuclide	Air concentration (Bq/m^3)	1 sigma
Ba-140	480	5,4
Cs-137	401,6	8,5
Cs-134	437	3,2
I-135	23,9	0,23
I-133	576	4,3
Te-132	1961	30
I-132	2,3	0,075
I-131	1843	24,3
Zr-95	33,8	0,68

Scenario 4

Suspected release: Rivne NPP Ukraina

Station 1

Nuclide		Air concentration (Bq/m^3)	1 sigma
Co-60	5,3 y	0,36	0,0049
Co-58	70,85 d	0,107	0,0026
Mn-54	312 d	0,647	0,012
Fe-55	2,75 y		?

Stasjon 2

Nuclide	Air concentration (Bq/m^3)	1 sigma
Co-60	0,00628	0,00016
Co-58	0,00156	0,000104
Mn-54	0,0105	0,000293
Fe-55	?	?

Stasjon 3

Nuclide	Air concentration (Bq/m^3)	1 sigma
Co-60	0,0112	0,000289
Co-58	0,00135	0,00016
Mn-54	0,00465	0,00023
Fe-55	?	?

Participant D
[redacted] results for the EPHSOGAM exercise

01.10.2017

[redacted] approach:

We would be grateful if you could provide information as to how you approached the problem – software used, how you estimated the release point etc.

We approached the problem in a 5-step approach:

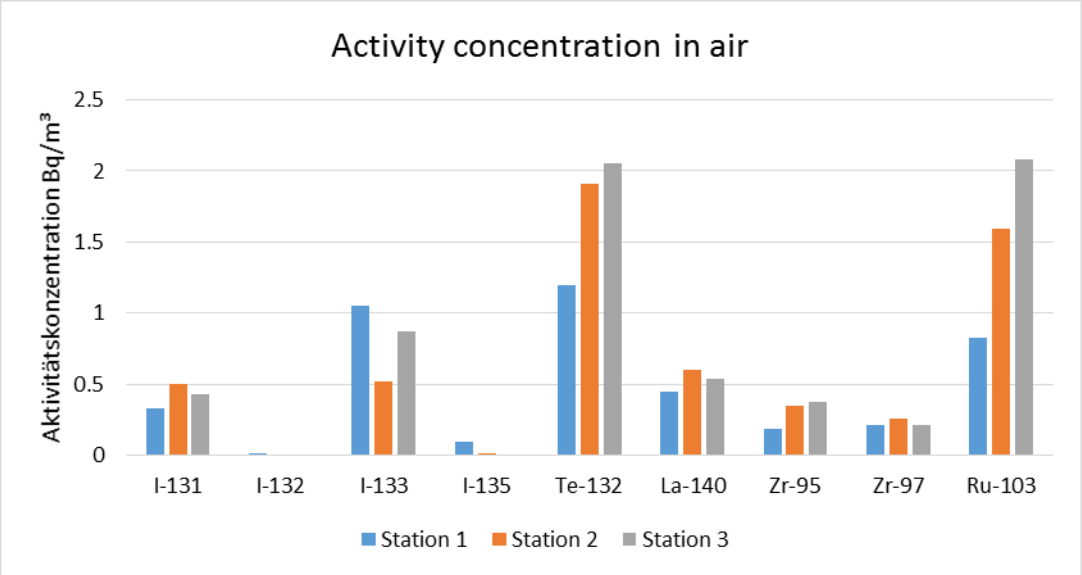
1. Analysis of the gamma spectra with two different software packages, [redacted] and *Interwinner*. Both packages identified the same radionuclides, the calculated activity concentrations in air differed less than 15%. The presented results are those calculated with *Interwinner*.
2. Calculation of backward trajectories with HYSPLIT, then post-processing of the results to identify possible source regions by identifying areas which were hit by backward trajectories from all 3 stations. The HYSPLIT calculations were verified with a WEBGRAPE analysis of "Possible Source Region" (PSR).
3. Identification of potential release sites (i.e. nuclear power plants, research reactors, naval ports) within the possible source regions from step 2, calculating the frequency of trajectories hitting these sites (relative to the total number of trajectories releases from all 3 sites) and ranking the sites according to their frequencies.
4. (Forward) atmospheric dispersion modelling (ADM) from the potential release sites (for up to 5 sites for each scenario; using the RODOS system).
5. Assessing the releases at the potential release sites by applying an inverse modelling approach based on the dispersion modelling results (from step 4) and the calculated activity concentrations (from step 1). The inverse modelling is a Bayes-Method for a posteriori source term calculation, which is based on an approach described by Eckhardt et al. (Atmos. Chem. Phys., 2008) and has been applied in a similar way by Stohl et al. (Atmos. Chem. Phys., 12, 2313–2343, 2012) after the Fukushima Dai-ichi accident.

SCENARIO 1:

S1-1. Isotopes in the sample and concentrations of these isotopes

Attention: Xe-133 has been identified in the gamma data, but the calculated activity concentration is wrong since it was calculated with conversion factors for the air filters, while Xe-133 will be in the surrounding air (and will not deposit on the filters)!

		Activity concentration in air in Bq/m³ (Interwinner)		
Half life	Isotope	Station 1	Station 2	Station 3
8.0233 d	I-131	0.332	0.504	0.431
2.295 h	I-132	0.01		
20.8 h	I-133	1.05	0.518	0.867
6.57 h	I-135	0.096	0.015	
3.204 d	Te-132	1.2	1.906	2.052
1.6785 d	La-140	0.445	0.602	0.533
64.03 d	Zr-95	0.185	0.349	0.375
16.744 h	Zr-97	0.214	0.258	0.207
39.26 d	Ru-103	0.822	1.593	2.077
5.244 d	(Xe-133)	0.02305	0.03616	0.02992
		25.03.2017	26.03.2017	26.03.2017
	Start of sampling	22:00	11:00	08:00
		27.03.2017	26.03.2017	27.03.2017
	End of sampling	15:00	23:00	23:00
		26.03.2017	26.03.2017	27.03.2017
	Reference time	18:30	17:00	03:30



S1-2. Possible source regions and potential release sites

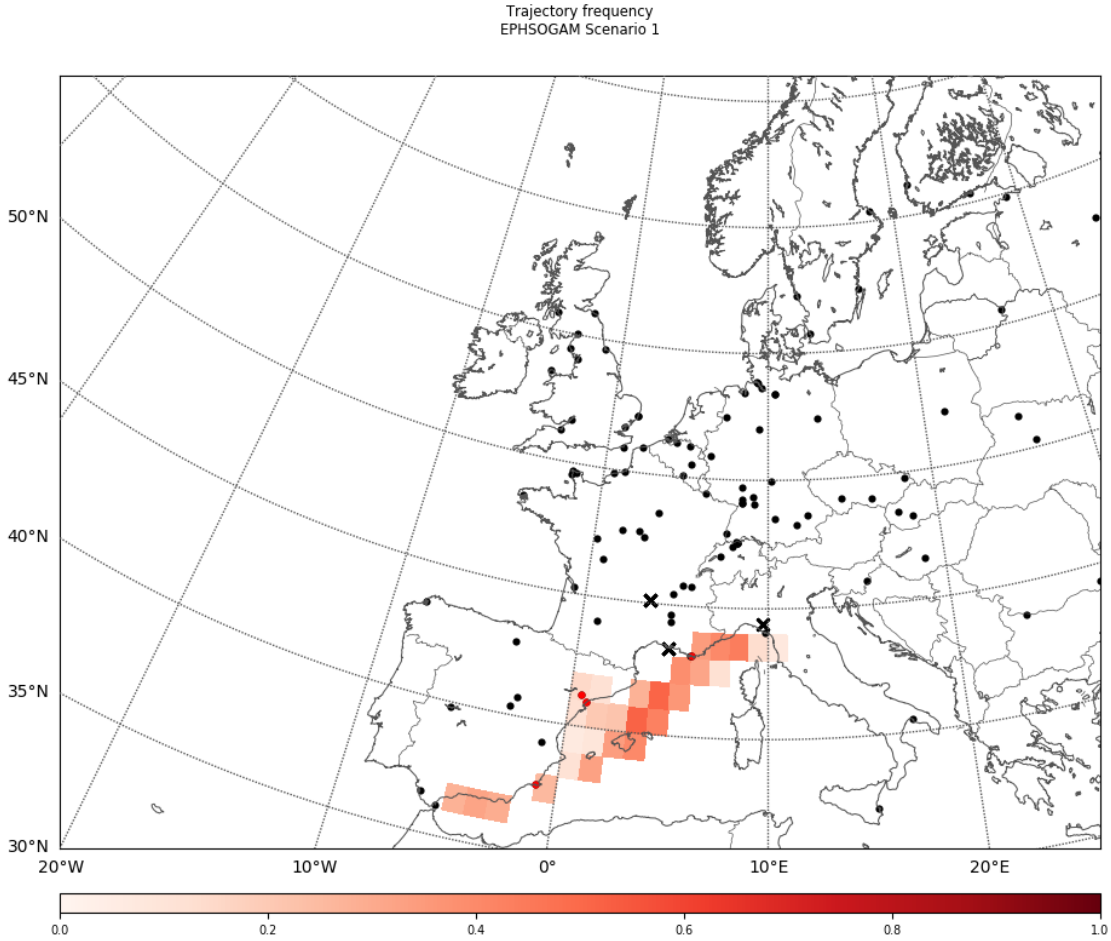


Fig. S1-2a: Possible source regions based on HYSPLIT backward trajectories (areas which were hit by backward trajectories from all 3 stations; color coding according to the frequency of trajectories hitting each area). Red dots and diamonds indicate potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies. (Black crosses indicate the monitoring sites).

Table S1-2a: Potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies of backward trajectories.

Longitude	Latitude	Frequency	start of release	End of release	Site	ADM calculation
6.001	43.119	3.45779e-01	2017-03-25 04:00	2017-03-27 07:00	Toulon naval port	X
-0.993	37.601	2.54909e-01	2017-03-23 08:00	2017-03-25 12:00	Cartagena naval port	X
0.571	41.202	1.52158e-01	2017-03-23 05:00	2017-03-25 01:00	NPP Asco	
0.868	40.949	1.27158e-01	2017-03-23 13:00	2017-03-25 03:00	NPP Vandellos	X

S1-3. Release data (amount, isotopic composition, beginning and end, development over time)

Table S1-3a: Potential release sites and time of release

Longitude	Latitude	Frequency	start of release	End of release	Site	ADM calculation
-0.993	37.601	2.54909e-01	2017-03-23 08:00	2017-03-25 12:00	Cartagena naval port	X
0.868	40.949	1.27158e-01	2017-03-23 13:00	2017-03-25 03:00	NPP Vandellos	X

Table S1-3b: Amount of release

Isotope	Cartagena naval port - Amount of release (Bq)	NPP Vandellos - Amount of release (Bq)
I-131	7.14E+14	2.42E+16
I-132	-	-
I-133	1.65E+16	5.21E+17
I-135	-	-
La-140	1.28E+15	1.75E+17
Ru-103	7.89E+14	1.11E+17
Te-132	2.00E+15	2.77E+17
Xe-133	2.46E+12	5.42E+13
Zr-95	1.74E+14	2.46E+16
Zr-97	3.09E+15	4.00E+17

The release could have occurred in Cartagena at
- 23.3. 06:00-12:00 h
- 24.3. 06:00-18:00 h
- 25.3. 12:00-18:00 h

Or

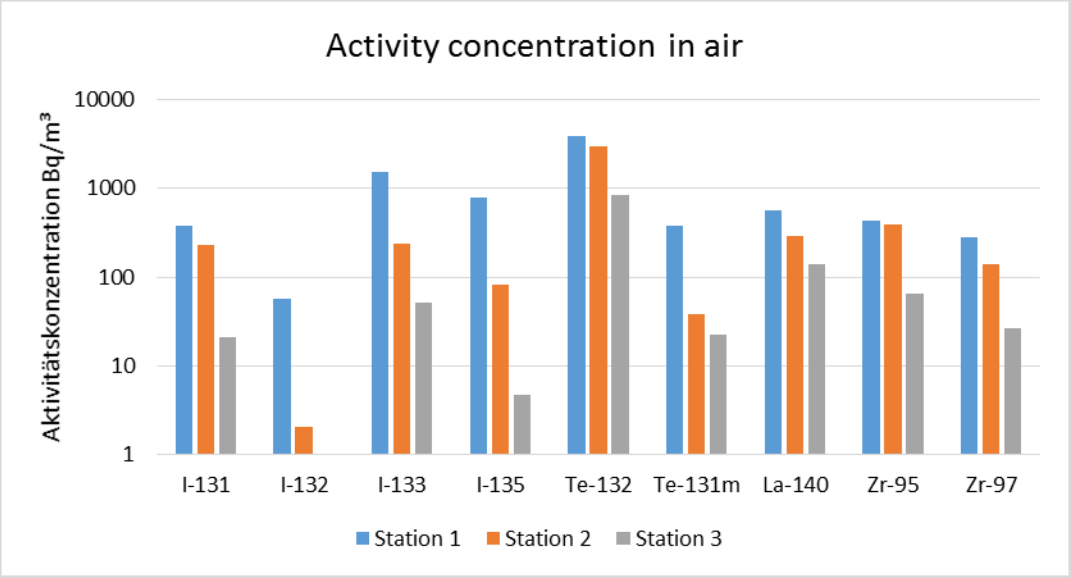
The release occurred in Vandellos at
- 24.3. 06:00-18:00 h

SCENARIO 2:

S2-1. Isotopes in the sample and concentrations of these isotopes

Attention: Xe-133 has been identified in the gamma data, but the calculated activity concentration is wrong since it was calculated with conversion factors for the air filters, while Xe-133 will be in the surrounding air (and will not deposit on the filters)!

		Activity concentration in air in Bq/m³ (Interwinner)		
Half life	Isotope	Station 1	Station 2	Station 3
8.0233 d	I-131	380.9	230.5	20.74
2.295 h	I-132	57.34	2.03	
20.8 h	I-133	1527	234.6	51.08
6.57 h	I-135	791	83.13	4.677
3.204 d	Te-132	3948	2978	845.9
1.25 d	Te-131m	380.7	38.35	22.48
1.6785 d	La-140	558.3	292.3	138.4
64.03 d	Zr-95	433.2	389	64.62
16.744 h	Zr-97	279.4	141.8	26.64
5.244 d	(Xe-133)	40.83		1.898
		20.03.2017	21.03.2017	21.03.2017
	Start of sampling	19:00	00:00	08:00
		20.03.2017	21.03.2017	21.03.2017
	End of sampling	21:00	06:00	11:00
		20.03.2017	21.03.2017	21.03.2017
	Reference time	20:00	03:00	09:30



S2-2. Possible source regions and potential release sites

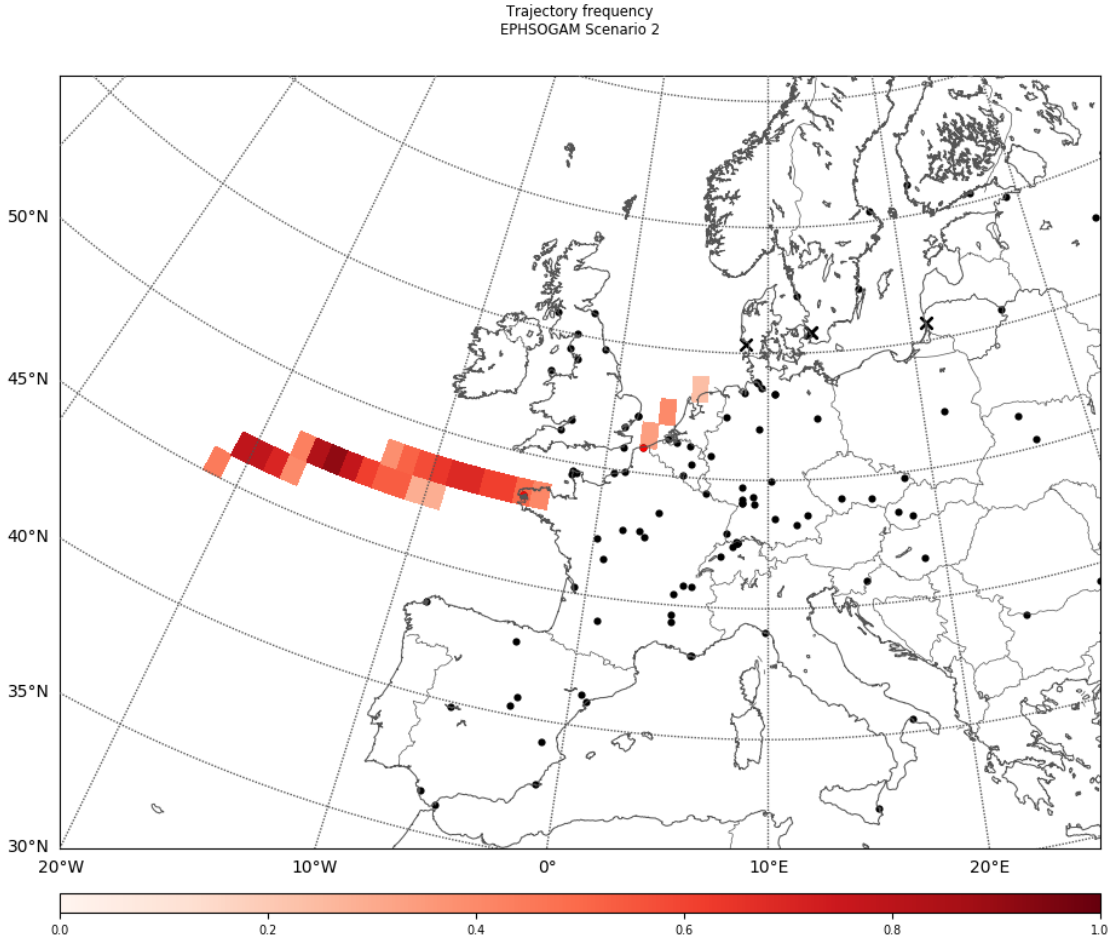


Fig. S2-2a: Possible source regions based on HYSPLIT backward trajectories (areas which were hit by backward trajectories from all 3 stations; color coding according to the frequency of trajectories hitting each area). Red dots indicate potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies. (Black crosses indicate the monitoring sites).

Table S2-2a: Potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies of backward trajectories.

Longitude	Latitude	Frequency	Start of release	End of release	Site	ADM calculation
-4.504	48.380	5.03968e-01	2017-03-19 07:00	2017-03-19 18:00	Brest naval port	
2.138	51.014	3.37302e-01	2017-03-19 22:00	2017-03-20 12:00	NPP Gravelines	X
1.623	52.215	0.00000e+00	2017-03-20 05:00	2017-03-20 07:00	NPP Sizewell	X
-1.880	49.680	0.00000e+00	2017-03-21 04:00:00Z	2017-03-21 04:00:00Z	La Hague	X

S2-3. Release data (amount, isotopic composition, beginning and end, development over time)

Table S2-3a: Potential release sites and time of release

Longitude	Latitude	Frequency	Start of release	End of release	Site	ADM calculation
-4.504	48.380	5.03968e-01	2017-03-19 07:00	2017-03-19 18:00	Brest naval port	
2.138	51.014	3.37302e-01	2017-03-19 22:00	2017-03-20 12:00	NPP Gravelines	X
1.623	52.215	0.00000e+00	2017-03-20 05:00	2017-03-20 07:00	NPP Sizewell	X
-1.880	49.680	0.00000e+00	2017-03-21 04:00:00Z	2017-03-21 04:00:00Z	La Hague	X

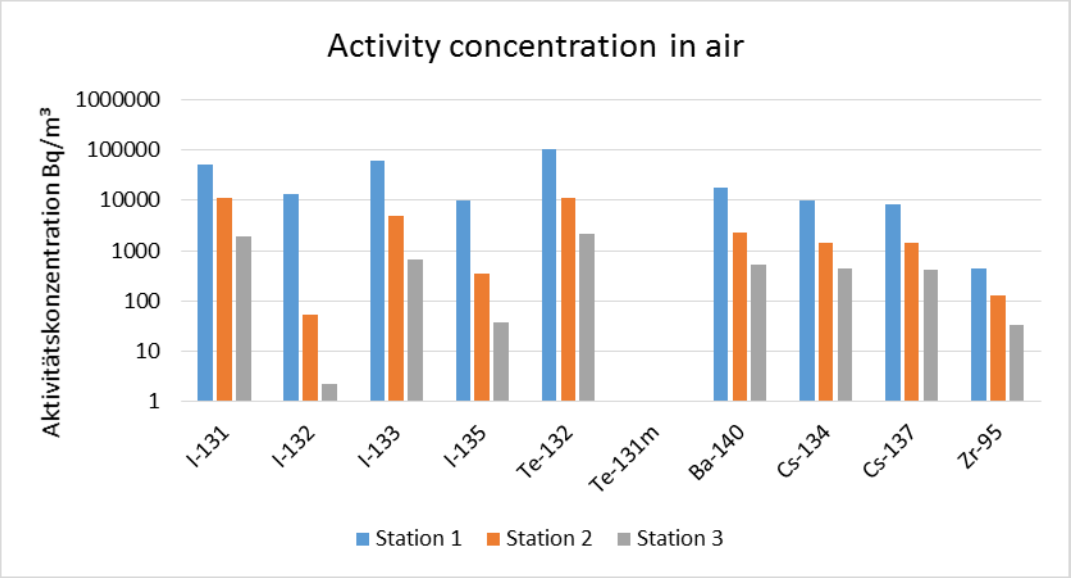
Table S2-3b: Amount of release

Isotope	NPP Sizewell - Amount of release (Bq)	NPP Gravelines - Amount of release (Bq)	La Hague - Amount of release (Bq)
I-131	4.E+14	1.E+15	1.E+15
I-132	0.E+00	0.E+00	0.E+00
I-133	3.E+15	8.E+15	8.E+15
I-135	7.E+15	2.E+16	2.E+16
Te-132	4.E+15	1.E+16	1.E+16
Te-131m	8.E+14	2.E+15	2.E+15
La-140	1.E+15	3.E+15	3.E+15
Zr-95	5.E+14	1.E+15	1.E+15
Zr-97	6.E+14	1.E+15	1.E+15

SCENARIO 3:

S3-1. Isotopes in the sample and concentrations of these isotopes

		Activity concentration in air in Bq/m³ (Interwinner)		
Half life	Isotope	Station 1	Station 2	Station 3
8.0233 d	I-131	50730	10860	1931
2.295 h	I-132	13130	54.94	2.216
20.8 h	I-133	60910	4908	676.7
6.57 h	I-135	10090	345.6	36.57
3.204 d	Te-132	104100	10860	2121
1.25 d	Te-131m	-	-	-
12.765 d	Ba-140	18100	2247	521.4
2.065 Y	Cs-134	10130	1431	444.7
30.04 y	Cs-137	8242	1388	409.3
64.03 d	Zr-95	454.1	126.7	33.15
		22.03.2017	22.03.2017	23.03.2017
	Start of sampling	12:00	22:00	09:00
		22.03.2017	23.03.2017	23.03.2017
	End of sampling	18:00	09:00	17:00
		22.03.2017	23.03.2017	23.03.2017
	Reference time	15:00	03:30	13:00



S3-2. Possible source regions and potential release sites

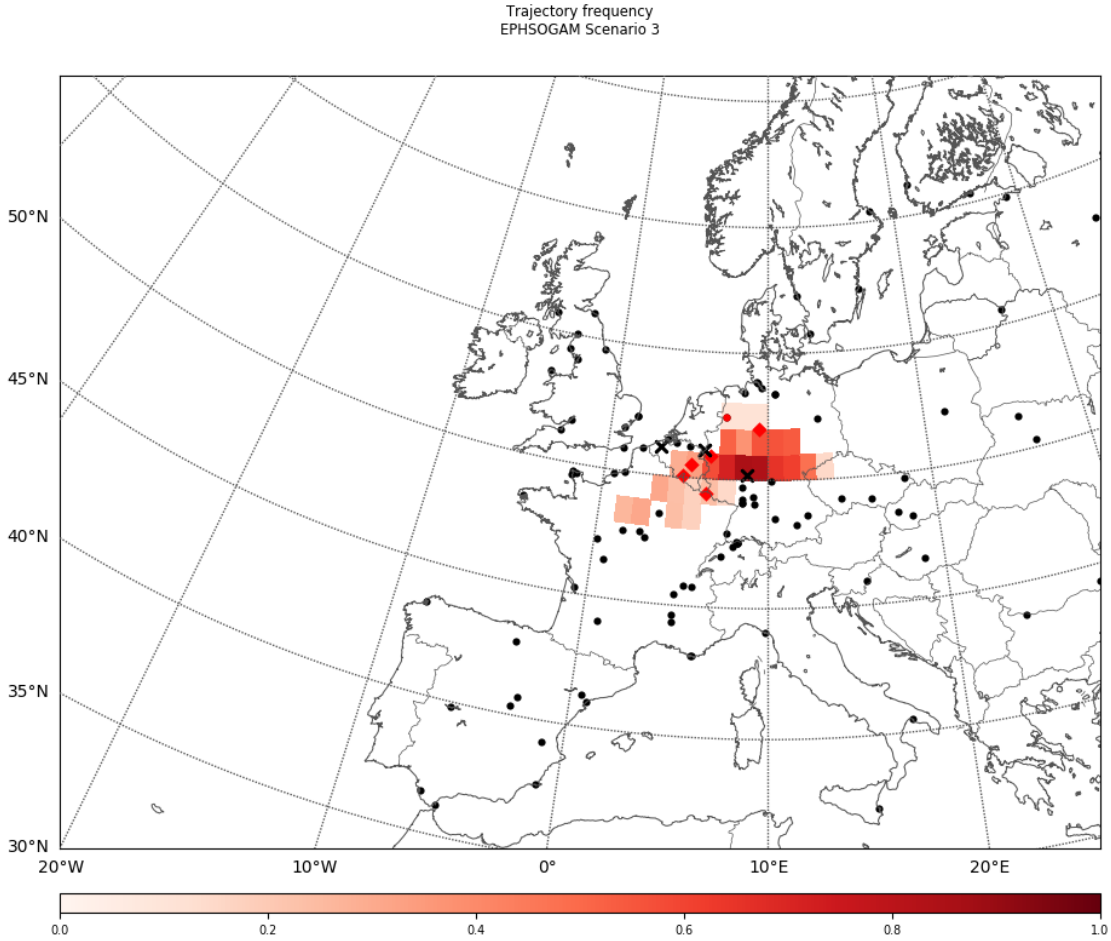


Fig. S3-2a: Possible source regions based on HYSPLIT backward trajectories (areas which were hit by backward trajectories from all 3 stations; color coding according to the frequency of trajectories hitting each area). Red dots and diamonds indicate potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies. (Black crosses indicate the monitoring sites).

Table S3-2a: Potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies of backward trajectories.

Longitude	Latitude	Frequency	Begin of release	Start of release	Site	ADM calculation
6.417	50.904	5.78042e-01	2017-03-21 01:00	2017-03-23 01:00	Research reactor Juelich	X
5.271	50.533	3.37302e-01	2017-03-21 00:00	2017-03-21 12:00	NPP TIHANGE	X
4.791	50.089	2.89683e-01	2017-03-20 23:00	2017-03-21 11:00	NPP CHOOZ	X
6.217	49.416	2.42063e-01	2017-03-20 22:00	2017-03-21 05:00	NPP CATTENOM	
9.411	52.033	1.12434e-01	2017-03-21 15:00	2017-03-21 16:00	NPP GROHNDE	

10.186	49.984	0.00000e+00	2017-03-21 10:00	2017-03-22 15:00	NPP GRAFEN-RHEINFELD	X

S3-3. Release data (amount, isotopic composition, begin and end, development over time)

Table S3-3a: Potential release sites and time of release

Longitude	Latitude	Frequency	Begin of release	End of release	Site	ADM calculation
6.417	50.904	5.78042e-01	2017-03-21 01:00	2017-03-23 01:00	Research reactor Juelich	X
5.271	50.533	3.37302e-01	2017-03-21 00:00	2017-03-21 12:00	NPP TIHANGE	X
4.791	50.089	2.89683e-01	2017-03-20 23:00	2017-03-21 11:00	NPP CHOOZ	X
6.217	49.416	2.42063e-01	2017-03-20 22:00	2017-03-21 05:00	NPP CATTENOM	
9.411	52.033	1.12434e-01	2017-03-21 15:00	2017-03-21 16:00	NPP GROHNDE	
10.186	49.984	0.00000e+00	2017-03-21 10:00	2017-03-22 15:00	NPP GRAFEN-RHEINFELD	X

Table S3-3b: Amount of release

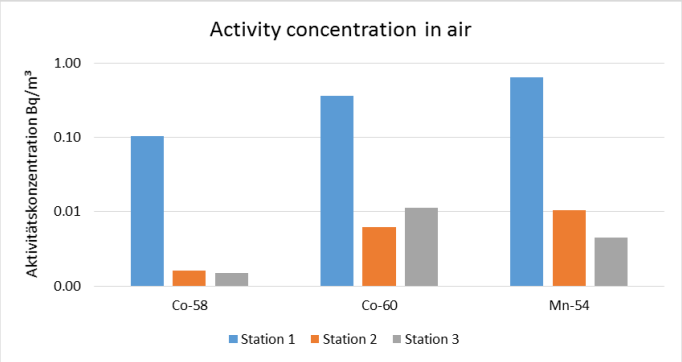
Isotope	GRAFENRHEINFELD - Amount of release (Bq)	TIHANGE - Amount of release (Bq)
Ba-140	7.11E+15	1.96E+15
Cs-134	3.66E+15	1.47E+15
Cs-137	2.97E+15	1.35E+15
I-131	3.15E+16	1.21E+16
I-132	-	-
I-133	1.17E+17	2.34E+16
I-135	-	-
Te-131m	0.00E+00	0.00E+00
Te-132	5.29E+16	1.18E+16
Zr-95	1.67E+14	1.12E+14

The release could have occurred in Grafenrheinfeld at
- 21.3. 12:00 h – 22.3. 12:00 h

SCENARIO 4:

S4-1. Isotopes in the sample and concentrations of these isotopes

		Activity concentration in air in Bq/m³ (Interwinner)		
Half life	Isotope	Station 1	Station 2	Station 3
70.86 d	Co-58	0.11	0.001597	0.00149
5.271 y	Co-60	0.36	0.006275	0.01122
312.13 d	Mn-54	0.64	0.01049	0.004451
		21.03.2017	21.03.2017	22.03.2017
	Start of sampling	11:00	14:00	06:00
		21.03.2017	22.03.2017	22.03.2017
	End of sampling	14:00	09:00	15:00
		21.03.2017	21.03.2017	22.03.2017
	Reference time	12:30	23:30	10:30



S4-2. Possible source regions and potential release sites

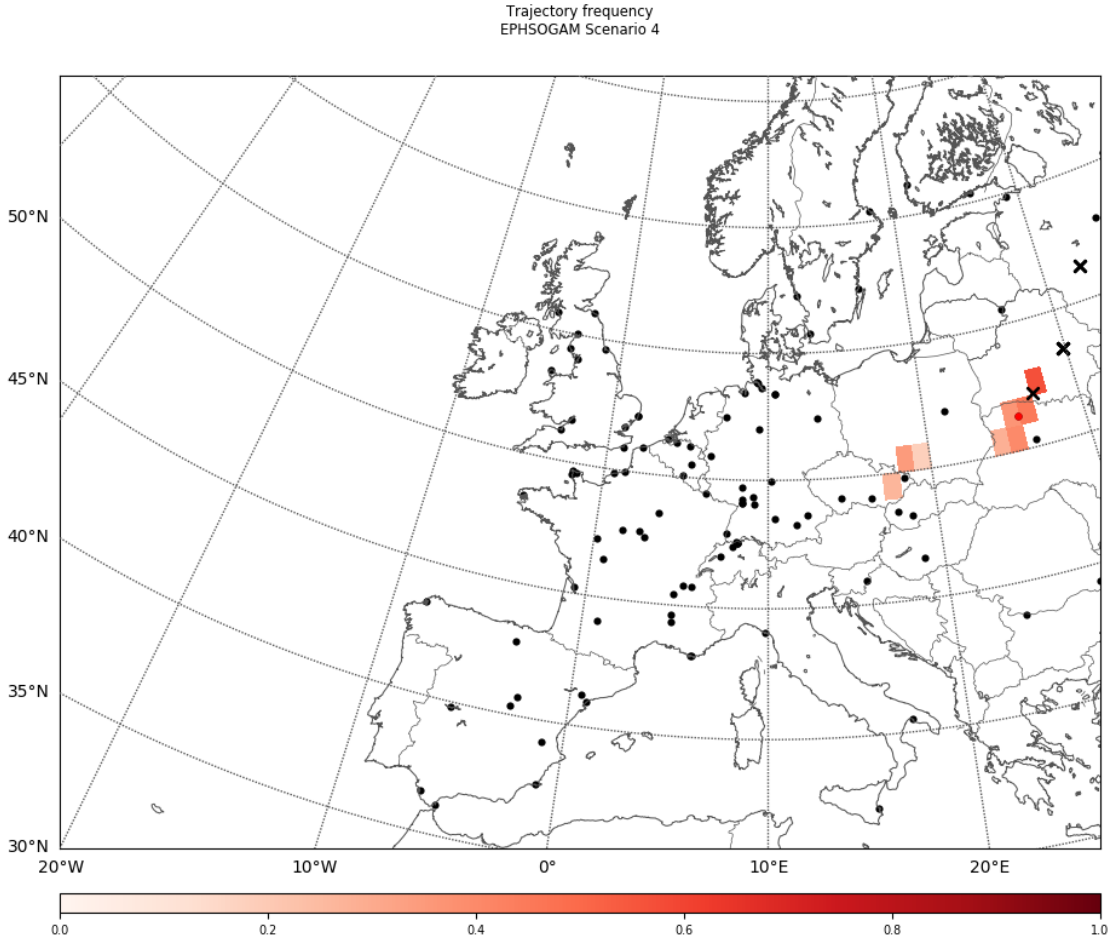


Fig. S4-2a: Possible source regions based on HYSPLIT backward trajectories (areas which were hit by backward trajectories from all 3 stations; color coding according to the frequency of trajectories hitting each area). Red dots indicate potential release sites (i.e. nuclear power plants, research reactors, naval ports) with highest frequencies. (Black crosses indicate the monitoring sites).

Table S4-2a: Potential release sites (i.e. nuclear power plants, research reactors, naval ports, large industrial areas) with highest frequencies of backward trajectories.

Longitude	Latitude	Frequency	Start of release	End of release	Site	ADM calculation
25.891	51.327	3.66667e-01	2017-03-20 15:00:00Z	2017-03-21 11:00:00Z	NPP ROVNO	X
18.308	49.790	0.00000e+00	2017-03-19 13:00:00Z	2017-03-20 14:00:00Z	KUNCICE OSTRAVA CZ (large industrial area)	X

S4-3. Release data (amount, isotopic composition, begin and end, development over time)

Table S4-3a: Potential release sites and time of release

Longitude	Latitude	Frequency	Begin of release	Start of release	Site	ADM calculation
25.891	51.327	3.67e-01	2017-03-20 15:00:00Z	2017-03-21 11:00:00Z	NPP ROVNO	X
18.308	49.790	0.0e+00	2017-03-19 13:00:00Z	2017-03-20 14:00:00Z	KUNCICE OSTRAVA CZ (large industrial area)	X

Table S4-3b: Amount of release

Isotope	NPP Rovno - Amount of release (Bq)	OSTRAVA - Amount of release (Bq)
Co-58	3.E+10	3.E+11
Co-60	9.E+10	9.E+11
Mn-54	2.E+11	2.E+12

Participant E

[redacted]/2C313/01/17
Version 2.0

NKS EPHSOGAM Activity

"Early Phase Source Term Estimation from Gamma Spectra"

[redacted]

[redacted]

October 2017

1. EXERCISE APPROACH

The software used in this exercise has been the Decision Support System JRODOS version 2017Feb Update1. This System can compute weather forecast for atmospheric dispersion and deposition calculations, using local scale dispersion models, allowing the prognosis of activity concentrations, dose rates and potential doses. Recent updates of the System include a Source Term Reconstruction tool, which was initially thought to be used in this exercise.

The identification of the release location and time has been made using the Local Scale Model Chain (LSMC) of JRODOS, for the atmospheric dispersion and deposition calculations in the near range, with RIMPUFF dispersion model, NOMADS GRIB2 re-analysis meteorological data (from 20th March 2017 00:00h to 28th March 00:00h), assuming 1h of emission and ^{137}Cs with a constant release amount of 1.0E+20Bq, as radionuclide tracer.

Regarding the radionuclides released in each site, the different samples were analyzed using Genie 2K Canberra Software, following the laboratory routines. The theoretical detector was calibrated using the given spectrum data. The activity concentrations were computed following the details described in the "Instructions and Details" document:

- There is no decay during the acquisition of the spectrum and no correction was done.
- No parent-daughter ingrowth relationships were considered.
- No natural radionuclides ended up on the air filters.
- No coincidence-summing effect was corrected.
- The reference time used was the time when the acquisition started.
- The dead time was not considered in the analysis.

The calibration of the detectors was carried out using an isotope mixture consisted of 10000Bq of each of the following: ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{85}Sr, ^{88}Y, ^{60}Co and ^{137}Cs.

The nuclear data used for the library construction was taken from the Table of Isotopes hosted at Lund University Sweden (http://nucleardata.nuclear.lu.se/toi/) and the Laboratoire National Henri Becquerel (http://www.nucleide.org). Due to the wide range of possible isotopes present in the sample, only the most probable fission and activation radionuclides were considered. These radionuclides were selected considering the nuclear accident of Fukushima and the source term of the radionuclides discharged into the atmosphere in a hypothetical accident in a [redacted] (NPP).

In relation to the estimation of the source term, despite all the attempts to use the Source Term Reconstruction tool included in JRODOS, it has not been possible. The tool, as it is right now, requires the creation in the release scenario of "real-time target format" (rttf) files, with ten minutes time steps for both, the dose rate measurements at the stations included in the scenario, and the meteorological data. The creation of these rttf files, in particular for the meteorological data, is a large consuming task, so, giving the time set for the exercise, it was decided not to use this tool.

Instead, the quantities released (Q) have been identified, for each scenario, performing simulations using the relation,

$$Q = Q_0 (A_{measured} | A_{calculated})$$

where,
Q = is the source rate (Bq)
Q_0 = is an assumed constant released amount, of each of the radionuclides identified, of 1.0E+20Bq
$A_{measured}$ = is the activity concentration measured from the spectra (Bq/m^3)
$A_{calculated}$ = is the activity concentration calculated in the simulations (Bq/m^3)

A brief description of the approach used for the exercise is described.

2. RELEASE LOCATION AND TIME OF RELEASE

The first step was to locate in a map the monitoring stations of each Scenario. For that purpose, a shape layer containing the coordinates of each station was created using QGis version 2.18 software. This layer was loaded in the JRODOS System, giving the map shown in figure 1.

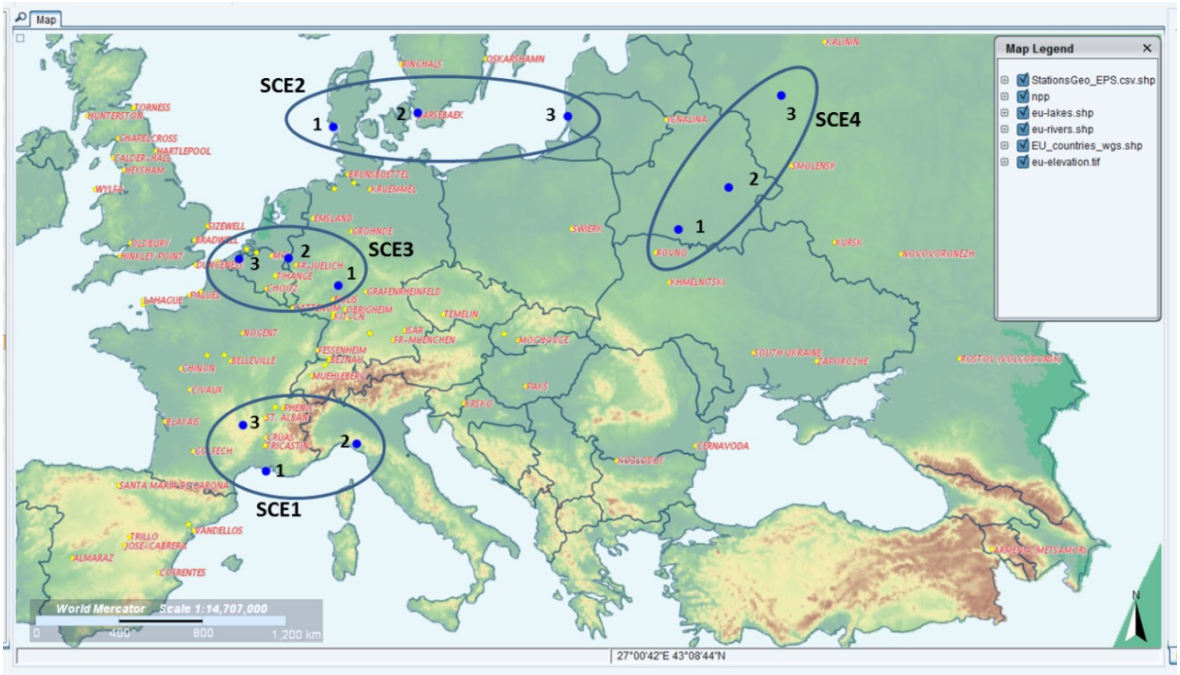


Figure 1.- Location of the monitoring stations in each scenario considered in the exercise

Knowing the pattern of the stations and the sampling dates, the next step was to locate the release point and release time in each Scenario, except in the case of Scenario 3 (SCE3) whose location had been set at Grafenrheinfeld Nuclear Power Plant (NPP) in Germany. In SCE3, tests were made to try to match the trajectory of the predicted cloud to the monitoring station pattern and sampling dates, in order to determine the time of release. The best match sets the **emission date on 22/3/2017 at 7:00h**, with 48h of prognosis. Figure 2, shows how the trajectory of the predicted total effective gamma dose rate (mSv/h), follows the monitoring station pattern given in the exercise. The estimated cloud time arrival to the different stations, for this emission date, is shown in figure 3.

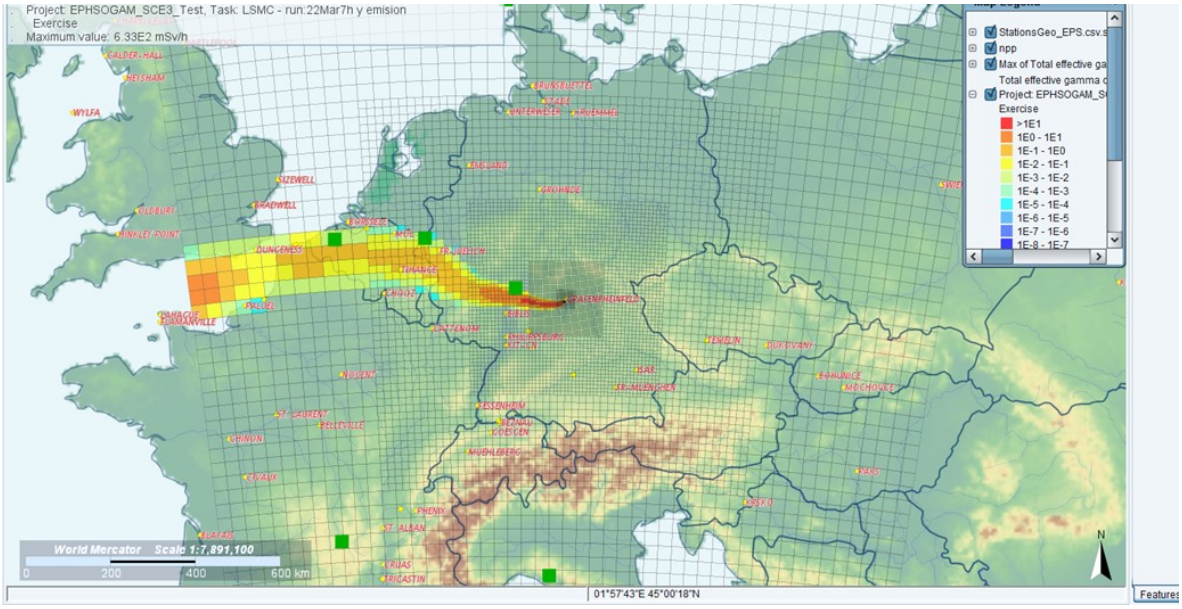


Figure 2.- SCE3-Grafenrheinfeld predicted total effective gamma dose rate all nuclides (mSv/h)

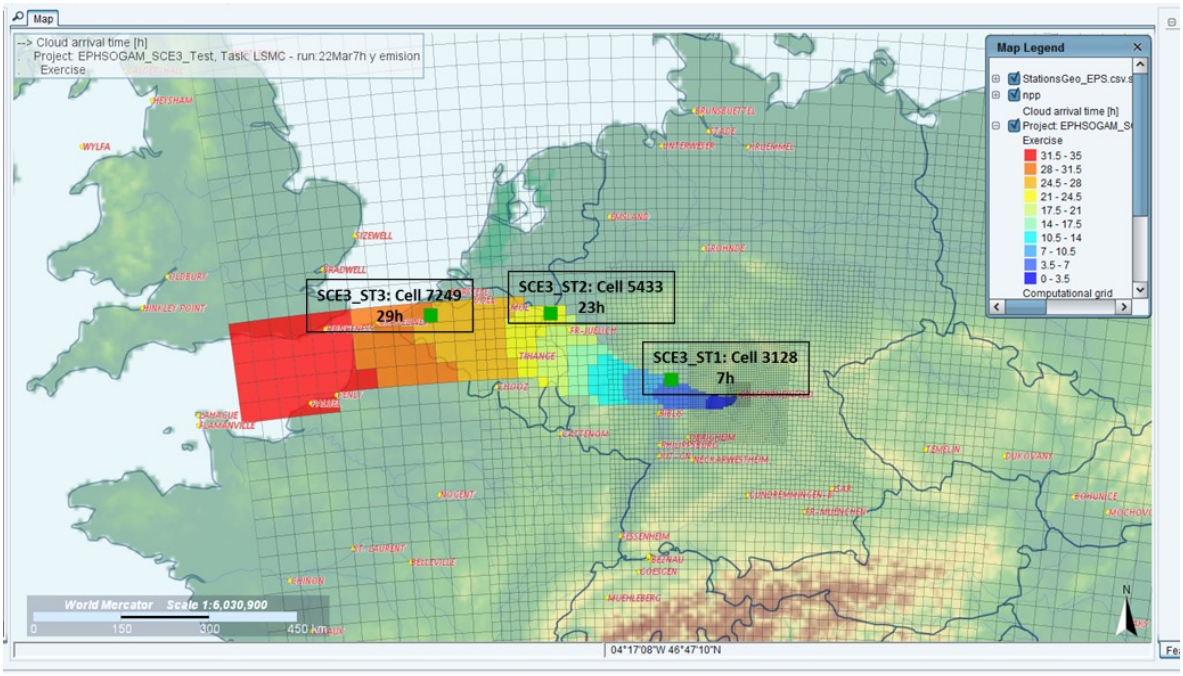


Figure 3.- SCE3-Grafenrheinfeld estimated cloud arrival time at the different stations

The comparison between the cloud arrival given dates and the estimated dates (Table 1), shows a small time delay in the estimations, although the dates are included in the sampling period.

Table 1.- Cloud arrival time to the different Stations Grafenrheinfeld NPP

	Sampling Period		**Cloud arrival given dates**		**Cloud arrival estimated dates (emission start. 22/3/2017 at 7:00h)**	
ST1	22/3/2017	12:00h	22/3/2017	13:00h	22/3/2017	14:00h
	22/3/2017	18:00h				
ST2	22/3/2017	22:00h	22/3/2017	22:00h	23/3/2017	5:00h

	23/3/2017	9:00h				
ST3	23/3/2017	9:00h	23/3/2017	9:00h	23/3/2017	12:00h
	23/3/2017	17:00h				

The analysis of the total gamma dose rate information, suggests other releases between 7:00h and 15:00h of the 22/03/2017.

For the other three Scenarios, the tests to try to match the trajectory of the predicted cloud to the monitoring station pattern were made to determine, both the release locations and the time of release. Assuming that the emission point would be presumably located in a NPP in the vicinity of the first station, different tests were performed at different sites, adjusting the emission date with the sampling dates of each station.

In the case of Scenario 1 (SCE1), the location of the different meteorological stations is such, that coupling the cloud trajectory to the pattern they form, makes difficult to anticipate the release location. For this reason, several tests have been carried out at different sites, trying different release times: Tricastin and Phenix (France), Muelenberg (Switzerland), Krsko (Eslovenia), Ascó, Vandellós and Cofrentes (Spain).

From the tests performed, two are the sites that showed a cloud trajectory which fitted most, although not exactly, to the monitoring station pattern, Ascó NPP and Tricastin NPP.

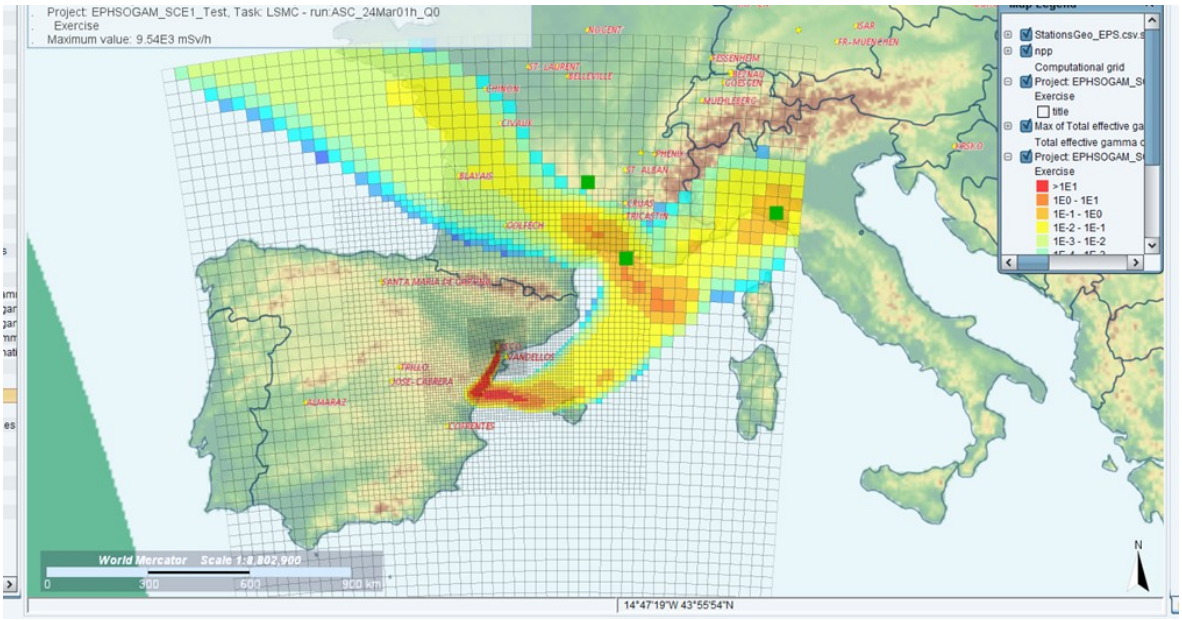


Figure 4.- SCE1-Ascó predicted total effective gamma dose rate all nuclides (mSv/h)

For the Ascó NPP site different emission dates were tested, setting the best match the **emission date on 24/3/2017 at 1:00h**. Considering 98h of prognosis, the cloud, just after reaching Station 1 splits in two directions one towards the West and the other towards the East. The West direction doesn´t reach Station 3, being very close to it, whereas the East direction reaches fully Station 2. Figure 4 shows the trajectory of the predicted total effective gamma dose rate (mSv/h). The estimated cloud arrival time at Stations 1 and 2 is shown in figure 5. Although the trajectory of the plume could fit with the station pattern, the comparison between the given and estimated cloud arrival dates, shows that the predicted

dates arrive earlier than the given ones and even before the sampling period, as seen in table 2.

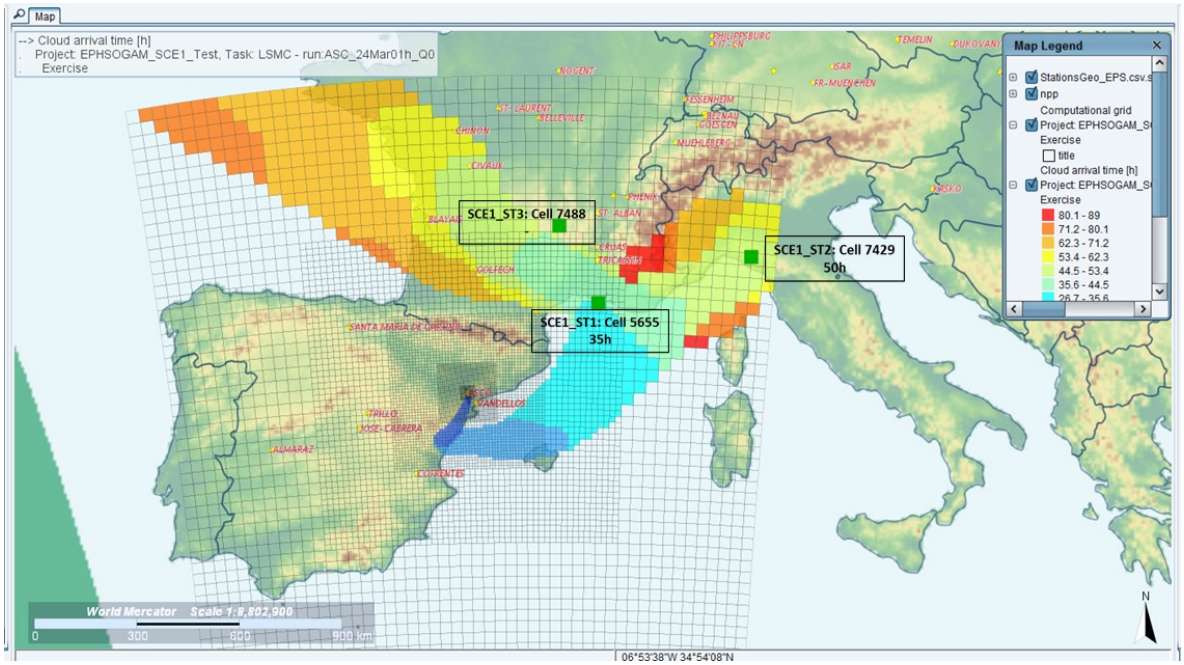


Figure 5.- SCE1-Ascó estimated cloud arrival time to the different stations

Table 2.- Cloud arrival time to the different Stations from Ascó NPP

	Sampling Period		Cloud arrival given dates		Cloud arrival estimated dates (emission start. 24/3/2017 at 1:00h)	
ST1	25/3/2017	22:00h	26/3/2017	0:00h	25/3/2017	12:00h
	27/3/2017	15:00h				
ST2	26/3/2017	11:00h	26/3/2017	6:00h	26/3/2017	3:00h
	26/3/2017	23:00h				
ST3	26/3/2017	8:00h	26/3/2017	7:00h		-
	27/3/2017	23:00h				

In the case of Tricastin NPP site, after testing several emission dates, the best match of the cloud trajectory with the monitoring station pattern is set when the **emission date occurs on 20/3/2017 at 2:00h**. At this release time, and with a prognosis of 179 h, the cloud goes through the three stations, as shown in figure 6. The estimated cloud arrival time to each of the stations is shown in figure 7. It can be seen (Table 3), that the estimated cloud arrival dates occur long before the given cloud arrival dates and even before the given sampling period, as should be, considering the emission date. However, this has been the only situation in which the plume has reached the three stations following the pattern given.

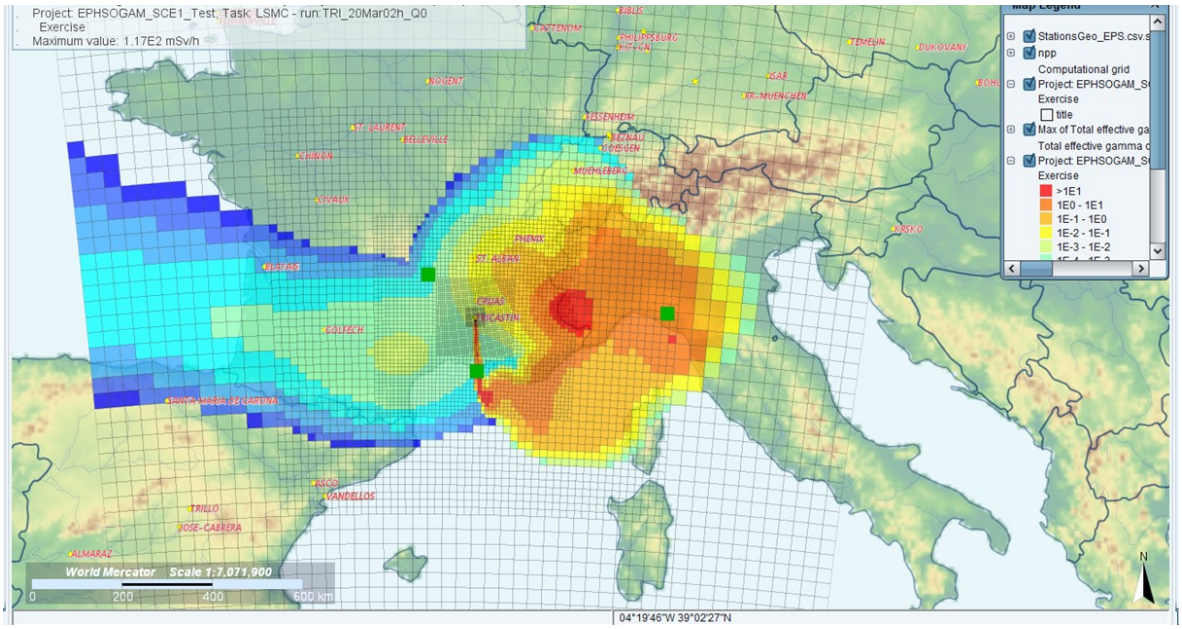


Figure 6.- SCE1-Tricastin predicted total effective gamma dose rate all nuclides (mSv/h)

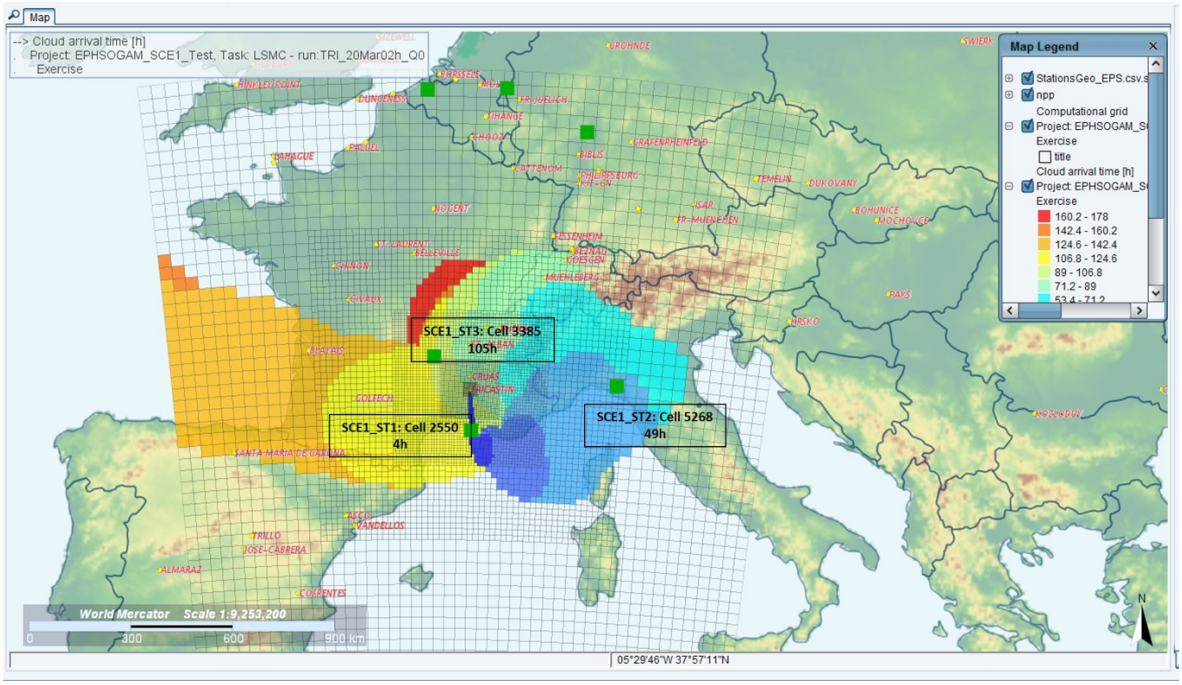


Figure 7.- SCE1-Tricastin estimated cloud arrival time to the different stations

Table 3.- Cloud arrival time to the different Stations from Tricastin NPP

	Sampling Period		**Cloud arrival given dates**		**Cloud arrival estimated dates (emission start. 20/3/2017 at 2:00h)**	
ST1	25/3/2017	22:00h	26/3/2017	0:00h	20/3/2017	6:00h
	27/3/2017	15:00h				
ST2	26/3/2017	11:00h	26/3/2017	6:00h	22/3/2017	3:00h
	26/3/2017	23:00h				
ST3	26/3/2017	8:00h	26/3/2017	7:00h	24/3/2017	11:00
	27/3/2017	23:00h				

The tests carried out for Scenario 2 (SCE2) included sites in United Kingdom (Hartlepool, Sizewell, Bradwell, Oldbury and Hinkley Point), France (Gravelines) and The Netherlands (Borsselle). The plume trajectories emitted from both NPPs, Olbury and Hinckley Point, were very similar and adjusted to the monitoring station pattern. Figure 8 shows the trajectory from Oldbury, setting the **emission date on 20/3/2017 at 2:00h**. From that hour to 6:00h the release is continuous, reaching Station 3.

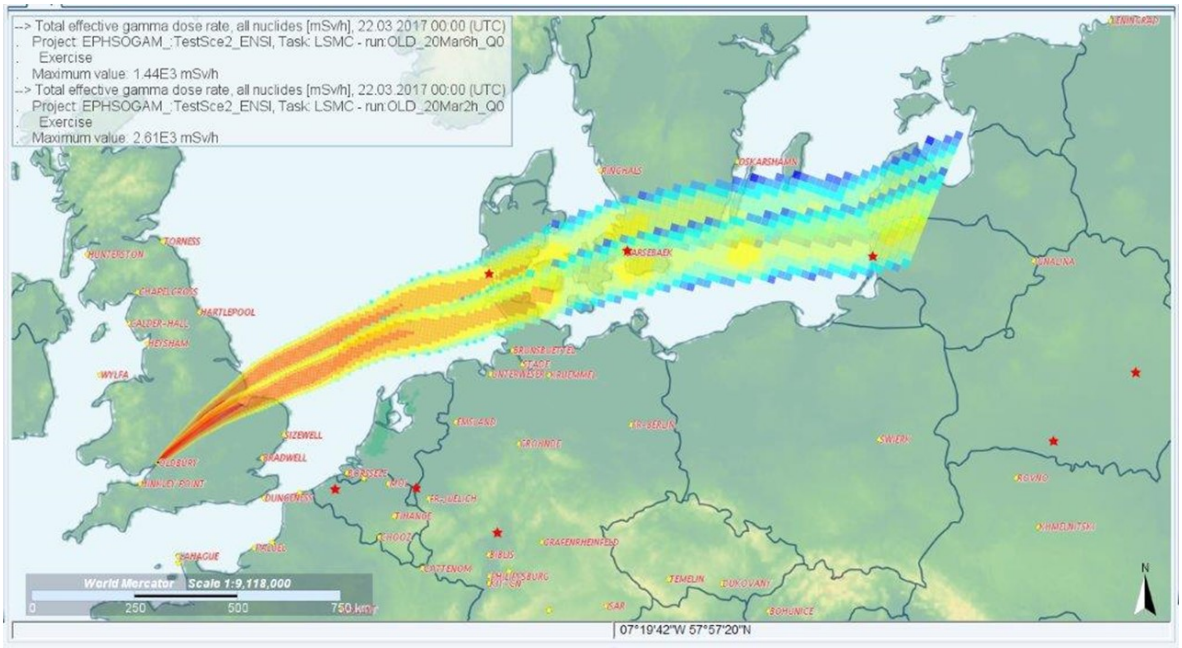


Figure 8.-SCE2-Oldbury predicted total effective gamma dose rate all nuclides (mSv/h).

Table 4.- Cloud arrival time to the different Stations from Oldbury NPP

	Sampling Period		**Cloud arrival given dates**		**Cloud arrival estimated dates (emission start. 20/3/2017 at 2:00h)**	
ST1	20/3/2017	19:00h	20/3/2017	17:00h	20/3/2017	17:00h
	20/3/2017	21:00h				
ST2	21/3/2017	0:00h	20/3/2017	23:00h	20/3/2017	22:00h
	21/3/2017	6:00h				
ST3	21/3/2017	8:00h	21/3/2017	6:00h	21/3/2017	4:00
	21/3/2017	11:00h				

The estimated cloud arrival time to each of the stations is shown in figure 9. It can be seen (Table 4), that the estimated cloud arrival dates fit with the given cloud arrival dates, following the pattern on the monitoring stations.

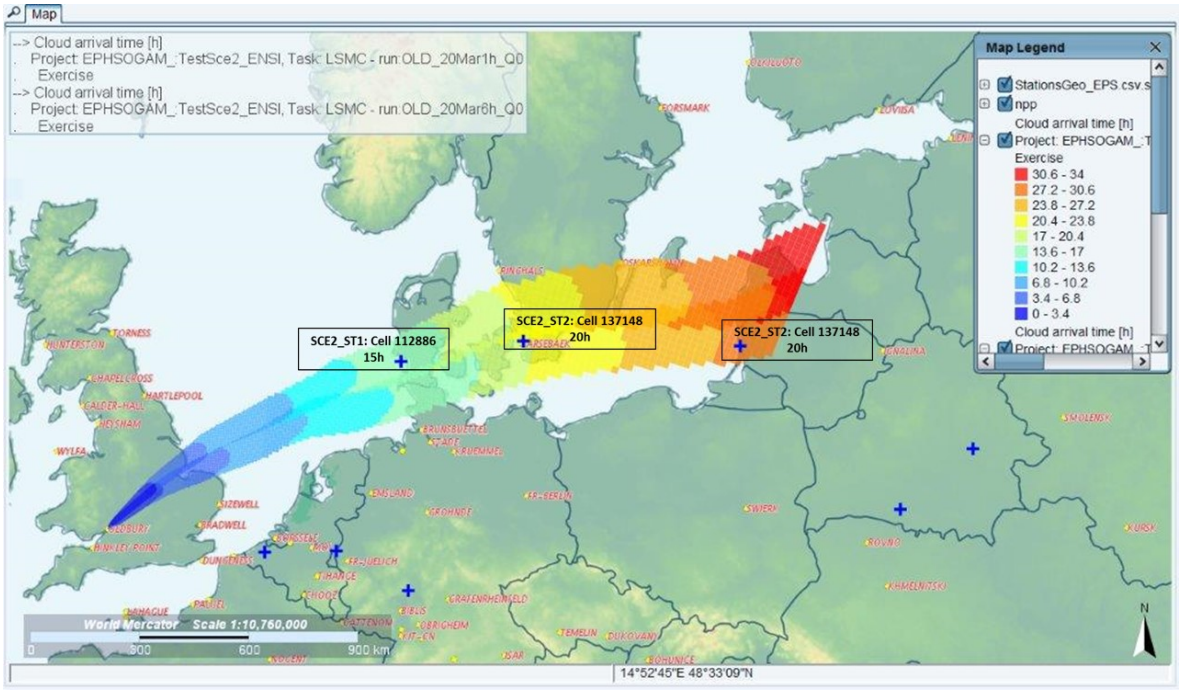


Figure 9.- SCE2-Oldbury estimated cloud arrival time to the different stations

Finally, for Scenario 4 (SCE4), it was assumed that the release occurred directly from Rovno NPP (Ukraine), being the nearest facility to station 1. The tests were made to try to match the trajectory of the predicted cloud to the monitoring station pattern and sampling dates.
The best match sets the **emission date on 21/3/2017 at 7:00h**, with 36h of prognosis.

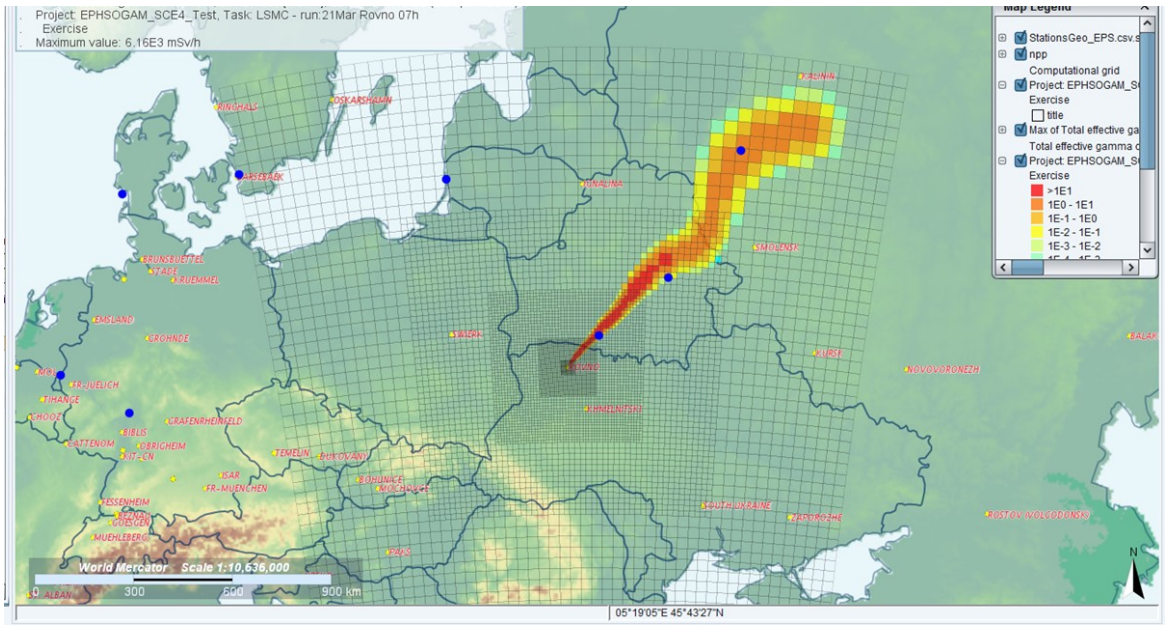


Figure 10.- SCE4-Rovno estimated cloud arrival time to the different stations

Figure 10 shows how the trajectory of the predicted total effective gamma dose rate (mSv/h), follows the monitoring station pattern given in the exercise.

The estimated cloud arrival time to the different stations, for this emission date, is shown in Figure 11. No information is given for this scenario, on the cloud arrival dates at each station

so, no comparison with the estimated dates has been possible, however, they belong to the sampling period, as shown in table 5.

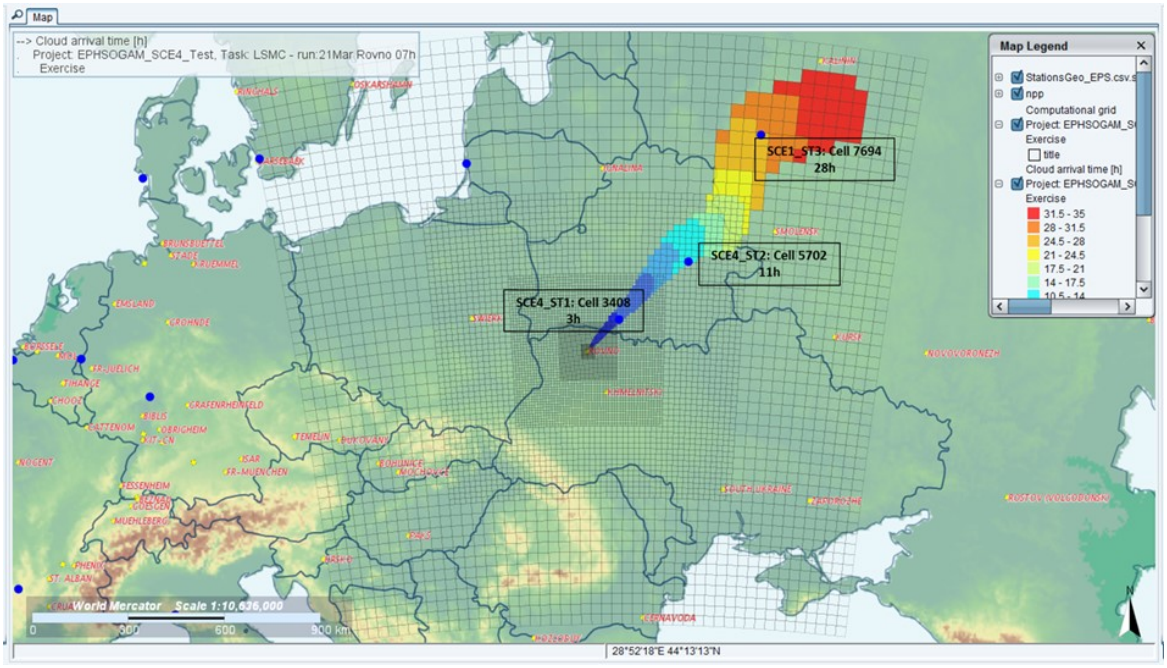


Figure 11.- SCE4-Rovno calculated cloud arrival time to the different stations

Table 5.- Cloud arrival time to the different Stations from Rovno NPP

	Sampling Period		**Cloud arrival given dates**		**Cloud arrival estimated dates (emission start. 20/3/2017 at 2:00h)**	
ST1	21/3/2017	11:00h			21/3/2017	11:00h
	21/3/2017	14:00h				
ST2	21/3/2017	14:00h			21/3/2017	18:00h
	22/3/2017	9:00h				
ST3	22/3/2017	6:00h			22/3/2017	11:00
	22/3/2017	15:00h				

Finally, table 6 summarizes the release location and emission dates estimated in this exercise based in the results of modeling with the system JRODOS for each Scenario.

Table 6.- Release location and time of release in each scenario.

SCENARIO	**Location of release**	**Time of release**
SCE1	Ascó NPP (Spain) or	24/3/2017 at 1:00h
	Tricastin NPP (France)	20/3/2017 at 2:00h
SCE2	Oldbury NPP (UK)/Hinkley Point (UK)	20/3/2017 at 2:00h
SCE3	Grafenrheinfeld NPP (Germany)	22/3/2017 at 7:00h
SCE4	Rovno NPP (Ukraine)	21/3/2017 at 7:00h

3. RADIONUCLIDES IN THE SAMPLE

To identify the radionuclides released in each site, the different samples were analyzed using Genie 2K Canberra Software, following the laboratory routines. The theoretical detector was calibrated using the given spectrum data.

Due to the complexity of the spectrum, two criteria were established to decide if an isotope is considered as detected: *i)* when all its photopeaks match with those contained in the library and *ii)* when the activities computed for this photopeaks are statistically indistinguishable and no dispersion is observed. The isotopes detected in each scenario were:

a) Scenario 1: ^{95}Zr, ^{103}Ru, ^{131}I, ^{132}Te, ^{133}I, ^{140}La. On the other hand, the ^{97}Zr was considered because it has a logical relationship with the different locations.

b) Scenario 2: ^{95m}Nb, ^{95}Zr, ^{97}Zr, ^{131}I, ^{131m}Te, ^{132}Te, ^{133}I, ^{133}I, ^{135}I, ^{140}La. As in the previous case, ^{69m}Zr was considered.

c) Scenario 3: ^{95}Zr, ^{105}Rh, ^{131}I, ^{132}I, ^{133}I, ^{134}Cs, ^{135}I, ^{137}Cs, ^{140}Ba.

d) Scenario 4: ^{54}Mn, ^{58}Co, ^{60}Co. In this case, the isotopes come from an activation process.

Tables 7, 8, 9 and 10 show, for each station in each Scenario, the isotopes detected and the activity concentrations measured.

Table 7.- Isotopes identified and their measured activity concentrations in SCE1

SCENARIO 1			
	ST1	**ST2**	**ST3**
Isotope	**Activity concentration (Bq/m^3)**		
Zr-95	1.78E+00	3.36E-01	3.65E-01
Zr-97	7.92E-01	2.02E-01	1.02E-01
Ru-103	5.94E+00	1.27E+00	1.56E+00
I-131	3.01E+00	4.95E-01	4.05E-01
Te-132	8.49E+00	1.59E+00	1.55E+00
I-133	4.40E+00	4.15E-01	4.75E-01
I-135	1.03E-01	0.0	0.0
La-140	3.03E+00	5.36E-01	3.75E-01

Table 8.- Isotopes identified and their measured activity concentrations in SCE2

SCENARIO 2			
	ST1	**ST2**	**ST3**
Isotope	**Activity concentration (Bq/m^3)**		
Zr-95	4.16E+02	3.84E+02	6.40E+01
Zr-97	2.42E+02	1.18E+02	2.42E+01
I-131	3.79E+02	2.22E+02	2.09E+01
Te-131m	2.64E+02	2.77E+01	1.68E+01
Te-132	3.39E+03	2.83E+03	7.28E+02
I-133	1.33E+03	1.94E+02	4.75E+01
I-134	7.86E-01	0.0	0.0

I-135	7.58E+02	5.79E+01	3.62E+00
La-140	5.78E+02	3.17E+02	1.33E+02
Nb-95m	0.0	4.87E+00	7.46E-01

Table 9.- Isotopes identified and their measured activity concentrations in SCE3

SCENARIO 3			
	ST1	**ST2**	**ST3**
Isotope	**Activity concentration (Bq/m^3)**		
Rh-105	8.16E+00	2.72E+01	8.16E+00
I-131	1.91E+03	6.23E+03	1.91E+03
I-132	1.93E+00	6.34E+01	1.93E+00
Te-132	1.73E+03	9.50E+03	1.73E+03
I-133	5.69E+02	3.91E+03	5.69E+02
Cs-134	4.35E+02	1.39E+03	4.35E+02
I-135	2.32E+01	2.16E+02	2.32E+01
Cs-137	4.03E+02	1.37E+03	4.03E+02
Ba-140	4.95E+02	2.10E+03	4.95E+02
Zr-95	0.0	1.25E+02	0.0
Np-239	0.0	1.71E+02	0.0
Am-241	0.0	3.46E+00	0.0

Table 10.- Isotopes identified and their measured activity concentrations in SCE4

SCENARIO 4			
	ST1	**ST2**	**ST3**
Isotope	**Activity concentration (Bq/m^3)**		
Mn-54	6.39E-01	1.04E-02	4.61E-03
Co-58	1.06E-01	1.61E-03	1.45E-03
Co-60	3.58E-01	6.17E-03	1.11E-02

4. SOURCE TERM RECONSTRUCTION

As said before, it has not been possible to use the Source Term Reconstruction tool included in JRODOS. Instead, the quantities released (Q) have been identified by performing simulations using the following relation,

$$Q = Q_0 (A_{measured} | A_{calculated}) \qquad (1)$$

where,
Q = is the source rate (Bq)
Q_0 = is an assumed constant released amount, of each of the radionuclides identified, of 1.0E+20Bq
$A_{measured}$ = is the activity concentration measured from the spectra (Bq/m^3)
$A_{calculated}$ = is the activity concentration calculated in the simulations (Bq/m^3)

To obtain this $A_{calculated}$ values, a calculation methodology has been developed. It is a rough approach and for this reason only the results for SCE3 are given. Two studies of the scenario have been carried out to characterize the relationships of the measured values among the three stations and the meteorological pattern.

In the first place, a set of point emissions (1h) of a radionuclide tracer (^{131}I) has been modelled along the sampling period of the exercise, using NOMADS GRIB2 re-analysis meteorological data. This modelling was used to characterize all the possible emissions and to derive the relationships among:

- Effective doses (mSv)/Activity concentrations (Bq s/m^3)
- Activity concentrations (Bq s/m^3)/Emitted Bq
- Activity concentration relationships among the three stations (ST2/ST1, ST3/ST1 and ST3/ST2).

A second emission modelling, including all the radionuclides identified in the sample, was made to obtain the relationships of the tracer, considering the same released amount each (1.0E+20Bq) at the first hour of the calculation period.

The starting point is the activity concentration measured values, in each station of SCE3. These have been transformed into ^{131}I equivalents for calculations purposes.

Once made the transformation and knowing the ^{131}I concentration relationships among the three stations, an hourly release from 7:00h to 15:00h of 22/3/2017 has been modeled. The best fit of the measured values with the concentration relationships is chosen.

From the activity concentration measured values and using equation (1), the Q values are obtained in ^{131}I equivalents. These are finally recalculated to the corresponding radionuclide. Table 11 shows the estimated source term results (Q_RN).

Table 11.- Activity concentration measured values (Bq h/m^3), the transformed into ^{131}I equivalents, the best fit of the measured values, the Q estimated values in ^{131}I equivalent and respective the corresponding radionuclide.

	Integrated Air Concentration (Bq.h/m3)			Fraction equiv to I-131	Equiv I-131 (Bq.s.m^{-3} I-131)			Q estim (Bq I-131)	Q_RN(eq) (Bq)
Isotope	Stat1	Stat2	Stat3		Stat1	Stat2	Stat3		
Am-241		3,46E+00		2067,96	0,00E+00	2,58E+07	0,00E+00	1,23E+18	5,93E+14
Ba-140	1,72E+04	2,10E+03	4,95E+02	0,25	1,57E+07	1,92E+06	4,51E+05	9,12E+16	3,60E+17
Cs-134	9,89E+03	1,39E+03	4,35E+02	0,35	1,23E+07	1,74E+06	5,42E+05	8,26E+16	2,39E+17
Cs-137	7,96E+03	1,37E+03	4,03E+02	0,23	6,49E+06	1,12E+06	3,29E+05	5,32E+16	2,35E+17
I-131	4,91E+04	6,23E+03	1,91E+03	1,00	1,77E+08	2,24E+07	6,86E+06	1,07E+18	1,07E+18
I-132	1,70E+04	6,34E+01	1,93E+00	0,03	1,69E+06	6,28E+03	1,90E+02	2,99E+14	1,09E+16
I-133	5,13E+04	3,91E+03	5,69E+02	0,03	5,54E+06	4,22E+05	6,15E+04	2,01E+16	6,70E+17
I-135	8,96E+03	2,16E+02	2,32E+01	0,07	2,16E+06	5,20E+04	5,59E+03	2,48E+15	3,71E+16
Np-239		1,71E+02			0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Rh-105	2,12E+02	2,72E+01	8,16E+00	0,02	1,27E+04	1,62E+03	4,86E+02	7,72E+13	4,67E+15
Te-132		9,50E+03	1,73E+03		0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Zr-95	1,25E+03	1,25E+02		0,25	1,11E+06	1,11E+05	0,00E+00	5,27E+15	2,14E+16
Total from measurements					2,22E+08	5,36E+07	8,25E+06		
Total adjusted to relationships among					9,82E+09	5,27E+07	7,96E+07	2,55E+18	

The results are referred to the total amount released. Although several approaches have been used to attempt to obtain the emission breakdown over time in terms of equivalents of ^{131}I and the possible extrapolation for each radionuclide, the results have not been sufficiently conclusive to be considered acceptable and, therefore, have been not included in this document.

Participant F

EPHSOGAM EXERCISE 11-13 SEPTEMBER 2017

Participant number 12

GENERAL REMARKS

Measurements

The Genie-2000 routine gamma analysis software with our standard emergency gamma-library was used to analyse the filter data. We examined the 'un-identified peak list' and extended the library as required.

1. We assumed that noble gases were not included in the data as was stated in the instructions. If released at all, they fall outside the measurement window of the filter- and GDR measurements.
2. All measurement data was given in UTC.

Meteo

We used NL-HIRLAM NWP data from the meteo office with 11 km resolution and 14 pressure layers of which 11 in the mixing layer. The prognosticated precipitation from the .- HIRLAM model was included in the modeling.

Modeling

We used our national dispersion model, implemented in JRODOS.

Strategy

We estimated a release location based on meteorological expert judgement and backward trajectories from the HIRLAM model from the timing of the GDR data. An indication of the object type was inferred from the retrieved nuclides on the filter data. Further refinement of release location, height and duration was done via trial and error runs with the l model. Finally, the release strength was scaled to match the measured activity concentrations at the three stations. We do not use dedicated software supporting source term estimation from measurements.
Further notes:

1. The tails after the first peak in de GDR time series suggests deposition. These deposition signals are about 10x higher than expected based on our deposition calculations.
2. A remarkable number of dose rate plots show a drop at 6:00 in the morning. This may be a model feature, e.g. the effect of sun rise on the mixing layer. Warming up increases the mixing layer resulting in a lower air concentration. This suggest that the exponential falling GDR signal is from air concentration and not (as was first understood) deposition.
3. We disregarded the GDR tails in the interpretation of the data for cloud arrival time

SCENARIO #1

Isotopes and concentrations in the samples: Identification of important radionuclides in the samples in Bq/m^3. Reported values are the average activity concentrations during the sampling period.

Nuclide / location	Location 1 (Bq/m^3)	Location 2 (Bq/m^3)	Location 3 (Bq/m^3)
95Zr	1.79E0	3.44E-1	3.66E-1
97Zr	9.85E-1	1.90E-1	9.73E-2
103Ru	5.82E0	1.21E0	1.51E0
131I	2.99E0	4.88E-1	3.96E-1
132I	7.30E-2	<	<
132Te	1.01E1	1.81E0	1.75E0
133I	5.21E0	3.94E-1	4.55E-1
135I	2.07E-1	<	<
140La	3.08E0	5.33E-1	3.73E-1

Where: Not conclusive. Backward trajectories suggest a release location along the East to South coast of Spain, Western part of the Mediterranean Sea.

When: Not conclusive. Initial guess is between March 22 22:00 and March 23 22:00 UTC

What isotopes were released and how much: Identified isotopes are given in table above. Magnitude of the release depends on release location and is therefore unknown.

Observations and conclusions: Nuclides identified suggests fission fragments. However Cs was not found on the filter, which rules out a NPP accident. Backward trajectories were not conclusive on the origin of the release but excluded a release from the South-East of France. There is large uncertainty due to difficult wind fields in proximity of the Alps. Measured concentrations at the stations are very low, suggesting a far away release location.

Approach: Backward trajectories suggest a release locations south of the stations (see figures). Nuclide composition could not be matched to a specific object.

SCENARIO #2

Isotopes and concentrations in the samples: Identification of important radionuclides in the samples in Bq/m^3. Reported values are the average activity concentrations during the sampling period.

Nuclide / location	Location 1 (Bq/m^3)	Location 2 (Bq/m^3)	Location 3 (Bq/m^3)
95Zr	4.24E2	3.82E2	6.41E1
97Zr	2.32E2	1.10E2	2.33E1
131I	3.66E2	2.19E2	2.01E1
131mTe	3.69E2	3.5E1	2.22E1
132I	5.64E1	1.92E0	<
132Te	3.93E3	2.91E3	8.44E2
133I	1.29E3	1.87E2	4.62E1
135I	7.76E2	5.48E1	3.48E0
140La	5.79E2	3.14E2	1.32E2

Where: Not conclusive. Backward trajectories suggest a release from the North Sea, South-East part of UK or (less likely) North-West part of France. Relative strength of the GDR signals suggests a large accident, i.e. close to Denmark or even larger release from the South of England (e.g. Bradwell). Bradwell and a location at the North Sea would fit the timing of the GDR data.

When: Not conclusive, assuming a release from Bradwell: March 20, 07:00 UTC. A location at sea Long 5.95, Lat 54.164 March 20 at 12:00 UTC works as well.

What isotopes were released and how much: See table above. Assuming a release from Bradwell:
I-131: 4E16 Bq
Zr-95: 5E16 Bq
La-140: 7E16 Bq
Te-132: 5E17 Bq
Te-131m: 4e16 Bq

Assuming a location at Sea Long 5.95 Lat 54.164
I-131 2.7E15 Bq
I-132 4.1E14 Bq
I-133 9.4E15 Bq
I-135 5.7E15 Bq
La-140 4.2E15 Bq

Observations and conclusions: The presence of Te-131m was not understood: neutron activation of Te-130 seems the most logical way. As this is a rather slow process this observation points to long term nuclear fuel storage at, e.g. Cap La Hague. However, the total absence of I-129 (a very long lived Iodine isotope) does not support a Cap La Hague scenario. The distance from Cap La Hague to Denmark implicates a very high (unrealistic) release. Bradwell would fit the data but seems unlikely since no Cs was found on the filter. Analysis relied on the backward trajectories from the first GDR peaks at the three stations. All locations along the trajectory could be matched to the timing of the GDR data (see figures).

Backward trajectories from station 1-3.

Forward dispersion calculation showing Total Gamma dose rate after cloud passage from the two release candidates (Bradwell, North Sea)

SCENARIO #3

Isotopes and concentrations in the samples: Identification of important radionuclides in the samples in Bq/m^3. Reported values are the average activity concentrations during the sampling period.

Nuclide / location	Location 1 (Bq/m^3)	Location 2 (Bq/m^3)	Location 3 (Bq/m^3)
95Zr	1.43E3	1.49E2	4.39E1
131I	4.94E4	6.24E3	1.85E3
132I	1.15E4	4.88E1	2.11E0
132Te	1.00E5	1.04E4	2.06E3
133I	4.68E4	3.75E3	5.55E2
134Cs	9.94E3	1.38E3	4.36E2
135I	7.14E3	2.02E2	<
137Cs	8.40E3	1.36E3	4.03E2
140Ba	1.76E4	2.16E3	4.99E2

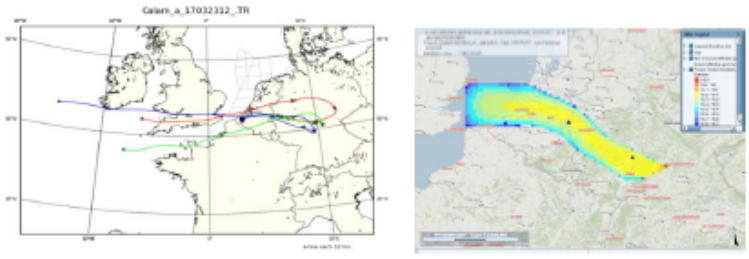
Where: Grafenrheinfeld nuclear power plant

When: Best estimate of release start is 22 March 05:00 UTC with a duration of >10 hours (10-16)

What isotopes were released and how much: Scaling based on activity concentration from station 1:
I-131: 4E16 Bq
Cs-134: 2E15 Bq
Cs-137: 2E15 Bq
Ba-140: 7E15 Bq

Observations and conclusions: Relative strength of nuclide strongly suggests an NPP accident. A release via the stack at 160 m was assumed. Noble gases were (of course) not detected on the filter samples. We neglected the noble gas release in the analyses and assumed it was released before the aerosols and therefore not included in the GDR data. Shape of the typical deposition tail in the GDR was not understood. Deposition seems much too high.

Approach: The release location was estimated based on backward trajectories from the - HIRLAM model. Results indicated a release location in mid-Germany. Nuclide composition suggested a nuclear accident, indicating an NPP as most likely release object. Matching the time-of-arrival of the first GDR maxima at the three stations selected Grafenrheinfeld as best release location.



Backward trajecty and dispersion calculation from Grafenrheinfeld.

SCENARIO #4

Isotopes and concentrations in the samples: Identification of important radionuclides in the samples in Bq/m^3. Reported values are the average activity concentrations during the sampling period.

Nuclide / location	Location 1 (Bq/m^3)	Location 2 (Bq/m^3)	Location 3 (Bq/m^3)
54Mn	6.5E-1	1.0E-2	4.6E-3
58Co	1.1E-1	1.6E-3	1.4E-3
60Co	3.6E-1	6.3E-3	1.1E-2

Where: PWR type Russian nuclear power plant at Rovno. The observed nuclides are corrosion products typically found in PWR type primary coolant water.

When: Our best estimate of the start of release is 21 March 04:00 UTC with a release duration of 3 hours. This release is based on the observation that the activity concentration at location 2 is just slightly higher than at location 3. This suggests that the sampling period at location 2 does not exactly coincide with the cloud passage.

What isotopes were released and how much: Scaling based on activity concentration from station 1:
Mn-54: 6E11 Bq
Co-58: 1E11 Bq
Co-60: 3.6E11Bq

Observations and conclusions: These corrosion nuclides are filtered from the primary coolant water using ion exchange materials. Possibly during transport a severe incident occurred with an explosion or fire releasing the radionuclides into the atmosphere. Shorter lived corrosion products, such as Fe-59 and Cr-51, are not likely to be found; the ion exchange material is stored for some time before transport.

Figure showing Total effective gamma dose rate after cloud passage

Participant G

[redacted]

[redacted] performed the NKS EPHSOGAM exercise on the 5 September 2017 at the [redacted] premises in [redacted]. The [redacted] working group consisted of [redacted] (ARGOS), [redacted] (Gamma analysis), [redacted] (Gamma analysis), [redacted] (Gamma analysis), [redacted] (ARGOS) and [redacted] (Gamma analysis).
The exercise consisted of 4 scenarios where a foreign laboratory has asked for assistance of analysing data.

Gamma analysis

The gamma analysis was performed in Genie 2000 (Canberra) with the nuclear decay data from Brookhavens ENDF/B-VII.1 database. The data was extracted on the 5 September 2017 by the NUCLEONICA webpage application Gamma Library++.

The analysis procedure was done with the assumptions given in the *NKS EPHSOGAM – INSTRUCTIONS AND DETAILS* document under the *Gamma Data* paragraph. The energy and efficiency calibrations were done with the provided spectra and with the assumption that the calibration source contained 10 000.0 Bq of each radionuclide at the moment of the spectra acquisition. The efficiency-, energy- and shape calibration can be found in Figure 5-7.
Nuclide identification was first done in the NUCLEONICA web application WESPA++. Shortly, the spectra was read into WESPA++, calibrated, and the gamma ray peaks were identified. We used the full JEFF-3.1 database with 1325 radionuclides and 54 004 gamma lines in the identification process. This application has the advantage that once a radionuclide is selected, all its gamma line will be visible in the spectra with the right intensity, i.e. it is easy to exclude radionuclides not present in the spectra. Further, when a radionuclide is assigned to one gamma-line, all the other associated lines are marked in the spectra. We found this as very useful in the identification process. Some additional work was done to analyse radionuclides with only one line as interfering gamma energies with other nuclides could occur. This resulted in a list of radionuclides that was judged to be present in the spectra. From this list a gamma library was constructed and the analysis for the determination of the activity concentration was done in Genie 2000. The results of the activity concentrations are given in Table 1-12 for each scenario and station.

ARGOS analysis

The dispersion and dose calculations were made with the RIMPUFF model on the ARGOS platform. The numerical weather prediction model is the HIRLAM model provided by the [redacted]. The model with a resolution of 11 km and a 48 h prognosis length is nowadays updated with a higher resolution model [redacted].

The sampling stations 1-3 in scenario 1 are just outside the saved weather data area as can be seen in the Figure below. Also, no data was available before 14:00 on March 20, 2017.

[redacted] was not able to use the back tracking trajectories or long-range models within this exercise.

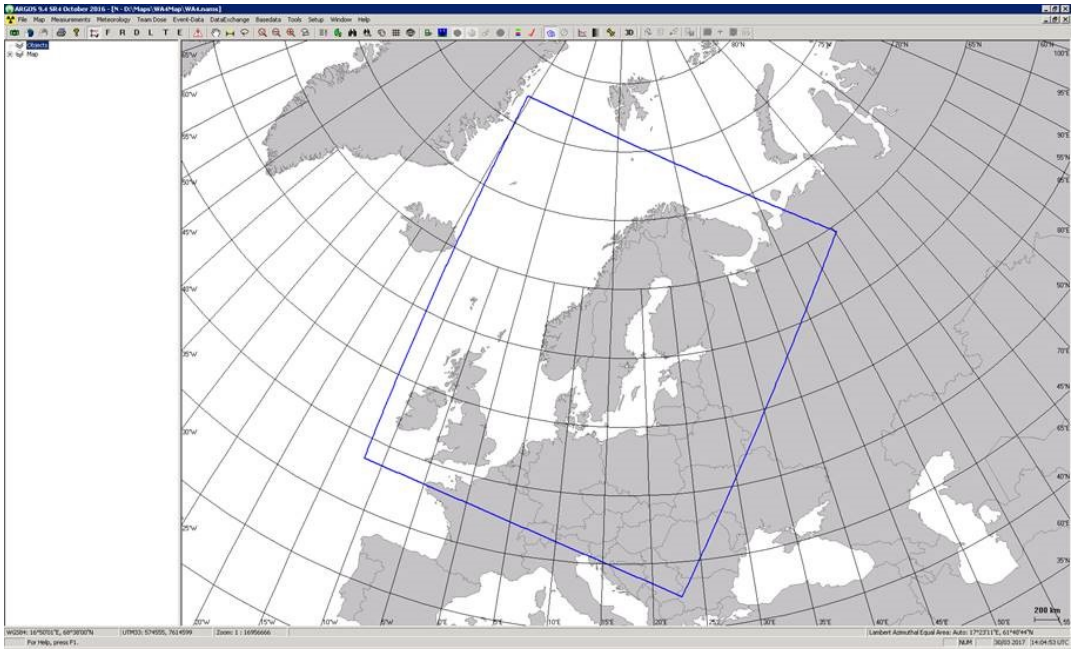


Figure 1 show the area where weather data was saved. The data was provided by SMHI.

The problems were approached in the following way:
We started with scenario 3 in which the release point was known. Then the parameters of the simulations could be tuned to do the test more efficient (saving simulation time).

A large release of Kr-85 at 20 m height with a long duration (6 hours) was used to find out the release point and release time. Using a rough model of the release and looking only at the plume air concentration reduced the simulation time. The sampling station having the highest dose rate values was expected to be the station closest to the release point. The nearest station also gave information on the release duration (unless there was frequently changes in wind direction).

After the release time had been deduced the prognosis length and/or the distance from the release point were increased. The time of arrival at the three different sampling stations were compared with the dose rate graphs.

When the release point and time was deduced the next step was to use the list of radionuclides and the activity concentration from the gamma spectra analysis. The relation between the activity concentrations among the different radionuclides were kept in the assumed released activity. This was used as input to a new refined dispersion and dose rate calculation. The maximum value of the total dose rate (ground and cloud) at a given time in the grid cell with the sampling station coordinates was used to compare with the corresponding value in the graph and to see if the amount released should be increased or reduced.

In the scenario 2 and 4, the list of radionuclides was also a way to guess the release point. By trying with some different release points some release points were ruled out.

Results

Scenario 1

No dispersion and dose calculations were made.
In table 1-3 the identified radionuclides are listed with the calculated air concentrations.

Scenario 2

1. *Where you think the release occurred – a GPS coordinate, a circle drawn in Google Earth, a facility name, etc.*
In scenario 2 the release point is believed to be the heat flux reactor in Petten, Netherlands (wgs84: Lat 52° 47'' 29', Long 4° 40'' 39'). See figure 2 below.

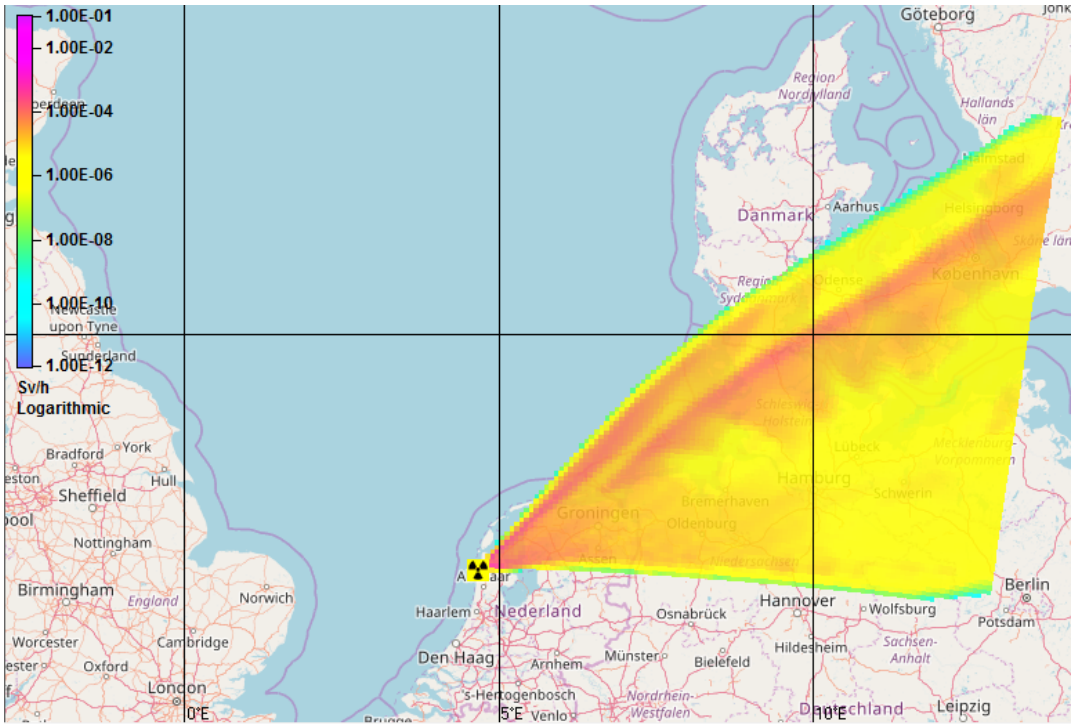


Figure 2 ARGOS simulation of dispersion from the release point of the reactor in Petten.

2. *When you think the release occurred.*
With the help of the total dose rate from nearest station 1 and 2 the release start was estimated to be around 14:00 March 20, 2017. The release duration was set to about 18 hours.

3. *What isotopes do you think were released and how much of each.*
In table 4-6 the identified radionuclides are listed with the calculated air concentrations. The ARGOS estimated release source term is presented in table 13.

4. *Any other observation or conclusion you would like to draw – how the release developed over time, etc etc.*
Since we didn't have any weather data before 14:00 the conclusions are not fully deduced. Moreover, there might be more than one release interval.

Scenario 3

1. *Where you think the release occurred – a GPS coordinate, a circle drawn in Google Earth, a facility name, etc.*
In scenario 3 the release point was already identified to be the Graphenrheinfeld NPP in Germany.

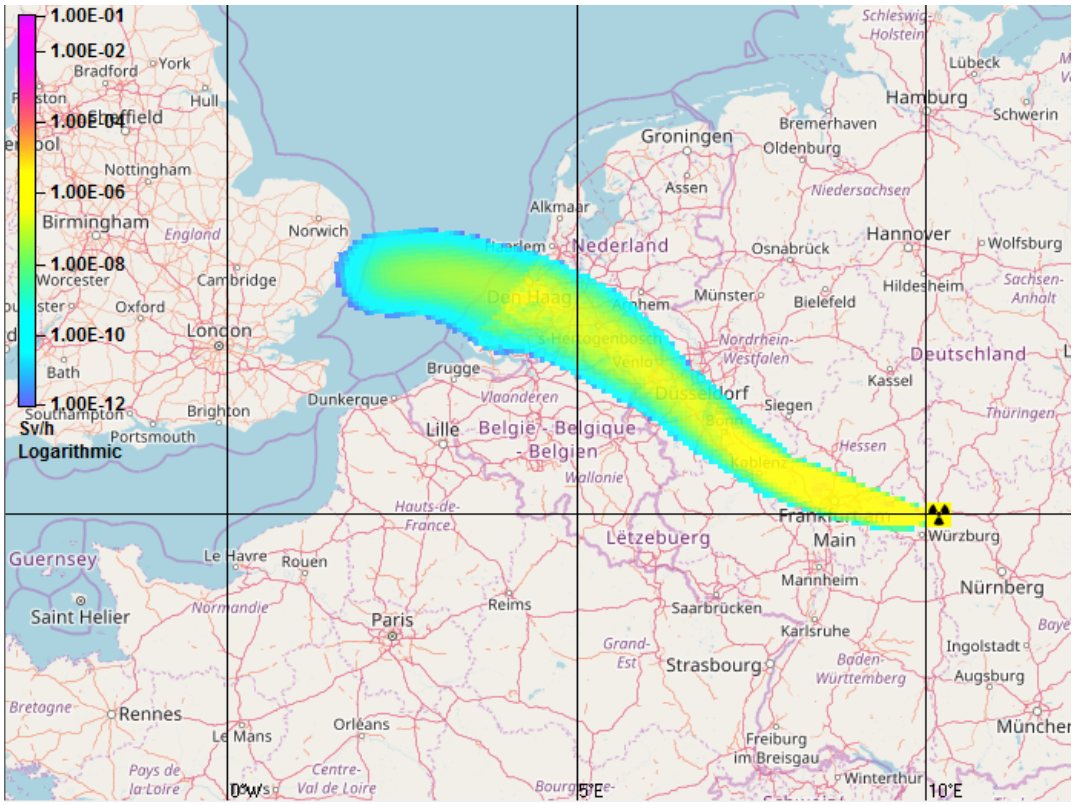


Figure 3 ARGOS simulation of dispersion from the release point Graphenrheinfeld NPP

2. *When you think the release occurred.*
With the help of the total dose rate from all stations the release start was estimated to be around 08:00 March 22, 2017. The release duration was set to about 4 hours.

3. *What isotopes do you think were released and how much of each.*
In table 7-9 the identified radionuclides are listed with the calculated air concentrations. The ARGOS estimated release source term is presented in table 14.

Scenario 4

1. *Where you think the release occurred – a GPS coordinate, a circle drawn in Google Earth, a facility name, etc.*
In scenario 4 the release point is believed to be near the nuclear reactor site Rivne/Rovno in Ukraine (wgs84: Lat 51° 19'' 40 ', Long 25° 53'' 30').

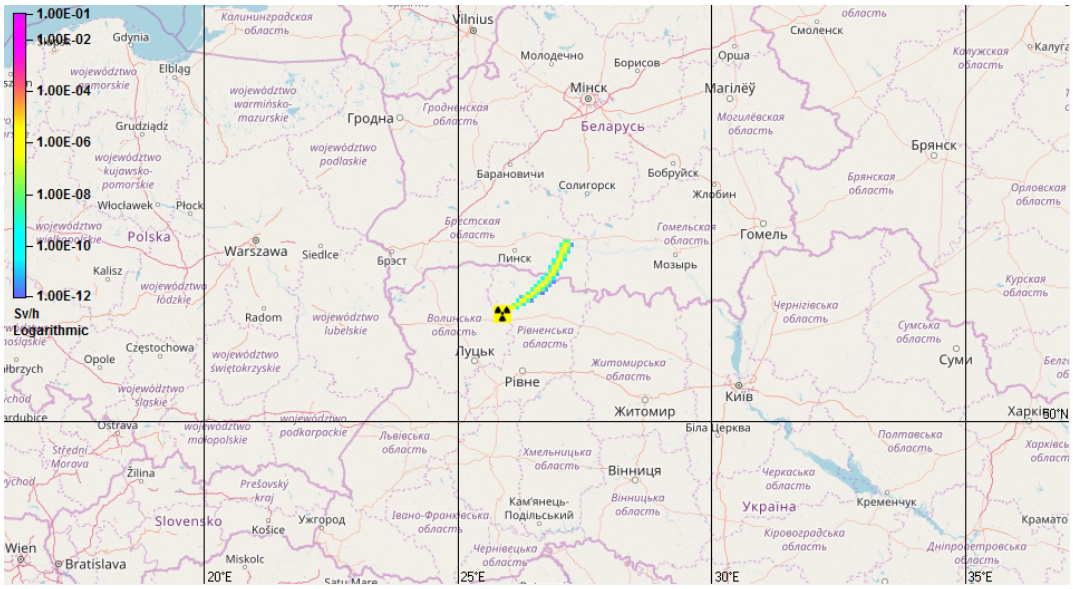
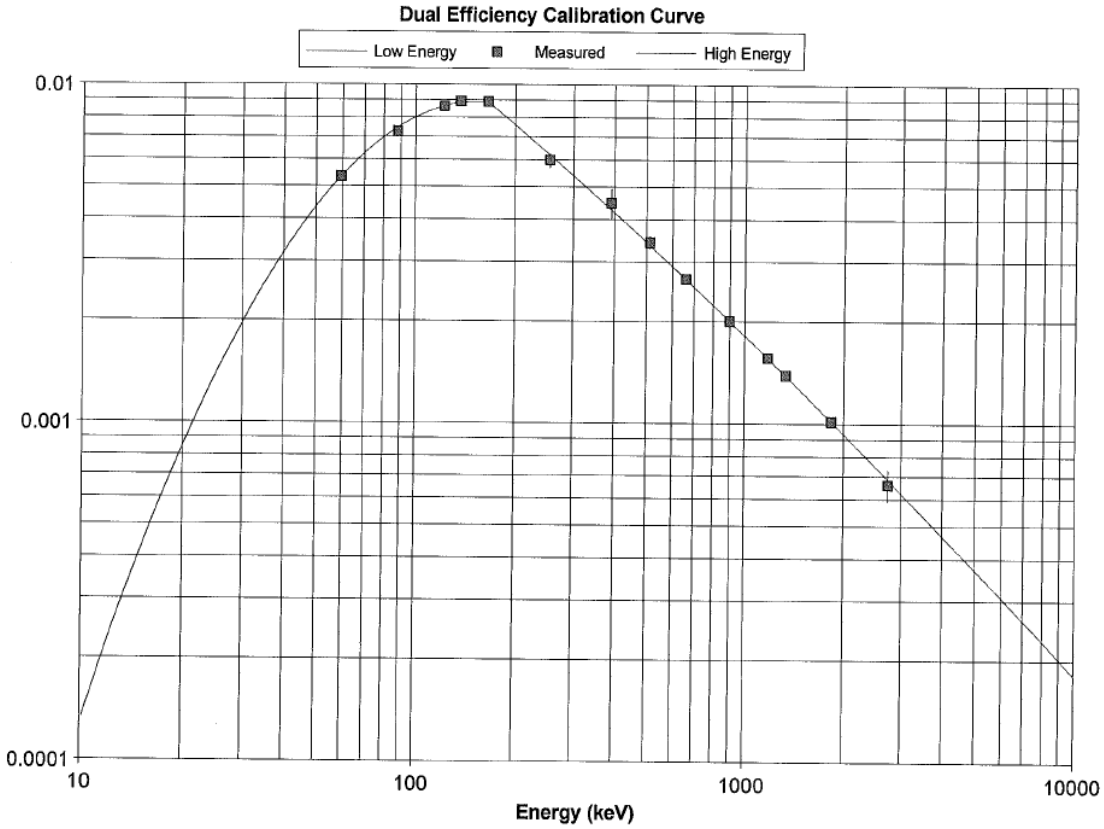


Figure 4 ARGOS simulation of dispersion from the release point reactor site Rivne/Rovno

2. *When you think the release occurred.*
With the help of the total dose rate from nearest station 1 the release start was estimated to be around 7:00 March 21, 2017. The start time for the airborne sampling was used since there was no dose rate graphs available.

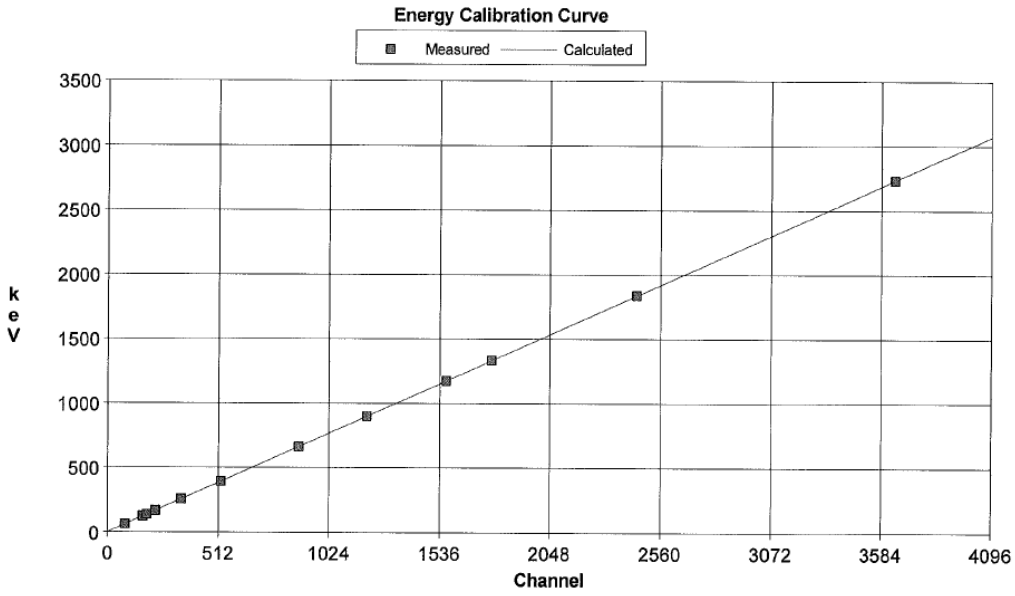
3. *What isotopes do you think were released and how much of each.*
In table 10-12 the identified radionuclides are listed with the calculated air concentrations. No ARGOS estimation of the released amount was made. However, it is assumed to be a small release during a few hours.

4. *Any other observation or conclusion you would like to draw – how the release developed over time, etc etc.*
Since the nuclides identified are corrosion products it could be from some cooling water boiling off or a waste handling fire.



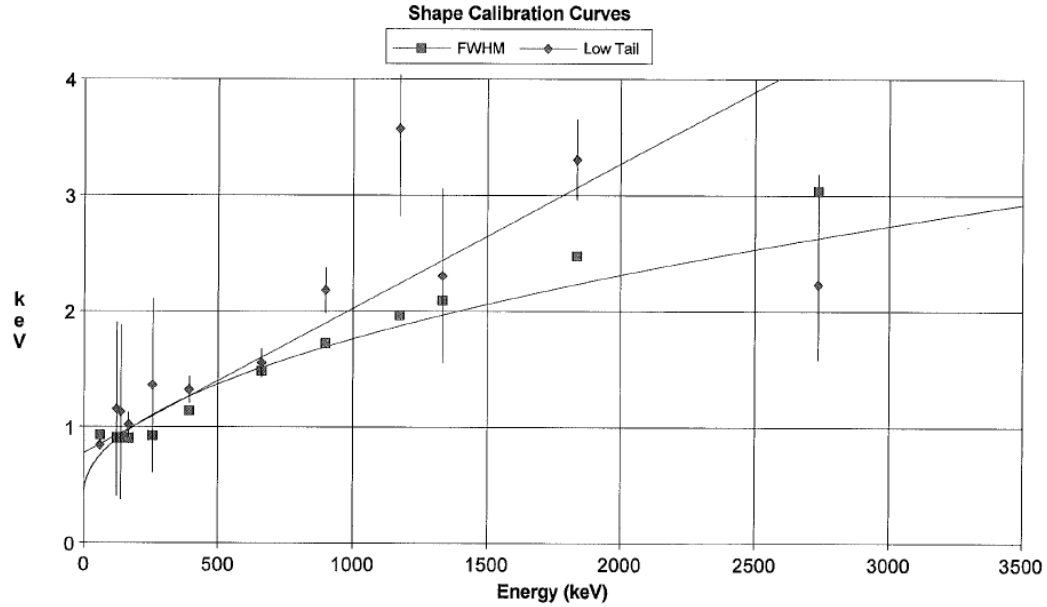
Datasource: C:\Users\gammaSSM\Desktop\Calibration\Calibration.cnf
ln(Eff) = -1.907e+001 + 5.690e+000*ln(E) - 5.642e-001*ln(E)^2
ln(Eff) = -1.851e+000 - 2.573e-001*ln(E) - 6.943e-002*ln(E)^2 + 1.918e-003*ln(E)^3

Figure 5 Efficiency calibration



Datasource: C:\Users\gammaSSM\Desktop\Calibration\Calibration.cnf
Energy = -7.506e-001 keV + 7.500e-001*Ch
FWHM = 4.280e-001 keV + 4.213e-002*E^1/2
Lo Tail = 7.734e-001 keV + 1.248e-003*E

Figure 6 Energy calibration



Datasource: C:\Users\gammaSSM\Desktop\Calibration\Calibration.cnf
Energy = -7.506e-001 keV + 7.500e-001*Ch
FWHM = 4.280e-001 keV + 4.213e-002*E^1/2
Lo Tail = 7.734e-001 keV + 1.248e-003*E

Figure 7 Shape Calibration, note that some energies was removed in this calibration in order to gain reasonable curve fits to the data.

Tabell 1 Air filter concentration, Scenario 1 Location 1

Nuclide	Nuclide Id Confidence	Wt mean Activity [Bq/m^3]	Wt mean Activity Uncertainty [Bq/m^3]
^{95}Zr	1.000	1.805	0.011
^{97}Zr	1.000	0.934	0.046
^{103}Ru	1.000	5.902	0.065
^{131}I	0.979	3.207	0.030
^{132}I	0.866	0.0665	0.0051
^{133}I	1.000	5.40	0.11
^{135}I	0.999	0.1832	0.0075
^{132}Te	0.998	4.37	0.17
^{140}La	1.000	3.100	0.014

Tabell 2 Air filter concentration, Scenario 1 Location 2

Nuclide	Nuclide Id Confidence	Wt mean Activity [Bq/m^3]	Wt mean Activity Uncertainty [Bq/m^3]
^{95}Zr	1.000	0.3419	0.0024
^{97}Zr	0.999	0.185	0.010
^{103}Ru	1.000	1.228	0.014
^{131}I	0.979	0.5191	0.0049
^{133}I	1.000	0.417	0.010
^{132}Te	0.998	0.869	0.036
^{140}La	1.000	0.5445	0.0029

Tabell 3 Air filter concentration, Scenario 1 Location 3

Nuclide	Nuclide Id Confidence	Wt mean Activity [Bq/m^3]	Wt mean Activity Uncertainty [Bq/m^3]
^{95}Zr	1.000	0.366	0.0023
^{97}Zr	0.999	0.0916	0.0043
^{103}Ru	1.000	1.530	0.016
^{131}I	0.979	0.4213	0.0040
^{133}I	1.000	0.476	0.012
^{132}Te	0.998	0.793	0.032
^{140}La	1.000	0.3798	0.0021

Tabell 4 Air filter concentration, Scenario 2 Location 1

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
ZR-95	1.000	4.227785E+002	1.566962E+000
ZR-97	0.995	3.458034E+002	9.391573E+000
I-131	0.927	3.787056E+002	2.629332E+000
Te131m	0.997	3.960149E+002	1.210021E+000
I-132	0.852	5.869699E+001	2.382204E-001
TE-132	0.998	2.604089E+002	2.067603E+001
I-133	1.000	1.397094E+003	2.139953E+001
I-135	1.000	7.740673E+002	9.879326E+000
LA-140	1.000	5.930375E+002	1.461596E+000

Tabell 5 Air filter concentration, Scenario 2 Location 2

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
ZR-95	1.000	3.804725E+002	1.338600E+000
ZR-97	1.000	1.278970E+002	3.129201E+000
I-131	0.979	2.341520E+002	1.480328E+000
Te131m	0.999	3.632730E+001	1.309080E-001
I-132	0.724	2.222356E+000	3.408312E-002
TE-132	0.998	3.435495E+003	8.384624E+001
I-133	1.000	1.953575E+002	3.161250E+000
I-135	1.000	5.738152E+001	7.769394E-001
LA-140	1.000	3.194285E+002	7.059652E-001

Tabell 6 Air filter concentration, Scenario 2 Location 3

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
ZR-95	1.000	6.354095E+001	2.867278E-001
ZR-97	0.998	2.491779E+001	1.001744E+000
I-131	0.927	2.145885E+001	2.110378E-001
Te131m	1.000	2.256958E+001	3.190532E-001
TE-132	0.998	1.203617E+002	7.325090E+000
I-133	1.000	4.742599E+001	1.046020E+000
I-135	1.000	3.458848E+000	1.588321E-001
LA-140	1.000	1.348615E+002	4.169069E-001

Tabell 7 Air filter concentration, Scenario 3 Location 1

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
ZR-95	0.981	1.225285E+003	3.297548E+000
I-131	0.948	5.116168E+004	7.316584E+001
I-132	0.867	1.908378E+004	2.356784E+002
TE-132	0.965	1.276198E+005	4.277889E+003
I-133	1.000	5.295682E+004	7.566588E+002
CS-134	1.000	1.014164E+004	1.015742E+001
I-135	1.000	8.879537E+003	1.060792E+001
CS-137	1.000	8.110296E+003	2.249853E+001
BA-140	0.639	5.800957E+003	4.309512E+001

Tabell 8 Air filter concentration, Scenario 3 Location 2

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
ZR-95	0.978	1.233075E+002	4.397394E-001
I-131	1.000	6.578040E+003	9.654847E+000
I-132	0.867	5.271089E+001	7.905156E-001
TE-132	0.965	5.038694E+003	1.655938E+002
I-133	1.000	3.929492E+003	5.627947E+001
CS-134	1.000	1.403211E+003	1.451065E+000
I-135	1.000	2.148757E+002	5.371238E-001
CS-137	1.000	1.363570E+003	3.826384E+000
BA-140	1.000	1.456406E+003	9.262821E+000

Tabell 9 Air filter concentration, Scenario 3 Location 3

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
ZR-95	0.965	3.314523E+001	2.011388E-001
I-131	1.000	1.966728E+003	3.221796E+000
I-132	0.652	2.295517E+000	1.067466E-001
TE-132	0.965	1.008617E+003	3.364699E+001
I-133	1.000	5.686580E+002	8.345987E+000
CS-134	1.000	4.372312E+002	5.780370E-001
I-135	1.000	2.330333E+001	1.663888E-001
CS-137	1.000	4.035230E+002	1.191386E+000
BA-140	1.000	4.154807E+002	2.792602E+000

Tabell 10 Air filter concentration, Scenario 4 Location 1

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
MN-54	1.000	6.370404E-001	3.499799E-003
CO-58	0.983	1.052103E-001	1.521283E-003
CO-60	1.000	3.588913E-001	2.156970E-003

Tabell 11 Air filter concentration, Scenario 4 Location 2

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
MN-54	1.000	1.046459E-002	2.126024E-004
CO-58	0.984	1.534656E-003	9.198984E-005
CO-60	1.000	6.253807E-003	1.404021E-004

Tabell 12 Air filter concentration, Scenario 4 Location 3

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (Bq /m3)	Wt mean Activity Uncertainty
MN-54	1.000	4.565191E-003	2.021506E-004
CO-58	0.983	1.399401E-003	1.357206E-004
CO-60	1.000	1.119833E-002	2.490677E-004

Tabell 13 Estimated releases, Scenario 2.

Nuclide	Activity [Bq]
^{131}I	2,9E+17
^{132}I	4,5E+16
^{133}I	1,1E+18
^{135}I	5,9E+17
^{140}La	4,6E+17
^{131m}Te	3,0E+17
^{132}Te	2,0E+17
^{95}Zr	3,2E+17
^{97}Zr	2,7E+17

Tabell 14 Estimated releases, Scenario 3.

Nuclide	Activity [Bq]
^{140}Ba	2,7E+16
^{134}Cs	4,8E+16
^{137}Cs	3,8E+16
^{131}I	2,4E+17
^{132}I	9,0E+16
^{133}I	2,5E+17
^{135}I	4,2E+16
^{132}Te	6,0E+17
^{95}Zr	5,8E+15

Bibliographic Data Sheet **NKS-400**

Title	Early Phase Source Term Estimation From Gamma Spectra (EPHSOGAM)
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ISBN	978-87-7893-488-8
Date	December 2017
Project	NKS-B / EPHSOGAM
No. of pages	190
No. of tables	30
No. of illustrations	14
No. of references	6
Abstract max. 2000 characters	As evidenced by the Fukushima Accident and events during 2017 in relation to ^{131}I and ^{106}Ru, estimation of the release term in the early phases of a nuclear accident is fraught with difficulties. Provision of an early estimate of quantitative and qualitative information regarding a release establishes a firm foundation for early actions and underpins the ultimate response measures implemented. Early phase monitoring data facilitates the drawing of conclusions regarding the nature of a release, its duration, possible location etc. The EPHSOGAM activity was aimed at the provision of a fit-for-purpose, robust and comprehensive virtual exercise for personnel involved in early phase response. The activity involved the dissemination of technical materials, derived from a simulated incident, from which participants were required to generate an estimate of the release location, amount of activity released and any other information they were fit to provide. The technical data included meteorological and gamma spectrometric data typically available in the aftermath of an incident and the activity tested various aspects of the abilities of the participant organisations. A description of the materials provided, their development and the participants responses are provided. The results highlight the complex interplay between a variety of factors affecting the participants abilities with respect to release location and characterisation of the release.
Key words	Dispersion modelling, back-trajectories, gamma spectrometry

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