DETECT WP1

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Introduction

The DETECT project, full title "Design of optimised systems for monitoring of radiation and radioactivity in case of a nuclear or radiological emergency in Europe" is Contract No. 232662 under the European Commissions Seventh Framework Program.
The objective of the project is *"to develop a methodology for optimising the design of monitoring systems for timely and effective decision making in an emergency"*. This is obtained through application of "cost functions" to a set of potential gamma dose rate scenarios for a number of different areas. The 3 year project started 1st January 2009.

At the "End User Workshop" 4th to 6th April 2011 in Plitvice, Croatia, it turned out, that the end users wanted much more nuclear power plants to choose between as threats to their countries than earlier envisaged and so the amount of gamma dose rate scenario calculations, the applicable calculation areas, the release profiles, and the file structure to be delivered for these calculations was all totally changed, i.e. most of the WP1 work until then was declared obsolete and the description of that part is here put into appendix A.

WP1 Objectives

The objective of Work Package 1 is to produce the set of gamma dose rate scenarios needed by Work Package 2 for their application of cost functions, i.e. to conduct a Pan-European radiological "Radiation Threat Database". This is accomplished by simulating a high number of atmospheric dispersion cases of releases from a number of European nuclear power plants potentially threatening the selected areas.

Specific tasks has included:

A) generation of a full year of numerical weather predictions covering Europe with reasonable resolution spatially as well as in time;
B) definition of representative nuclear threats for selected areas, i.e. release scenarios and power plants;
C) calculation of ground level gamma radiation fields based on atmospheric dispersion modelling with the RIMPUFF program;
D) creation of a comprehensive Pan-European radiation threat data base (DB).

Numerical weather prediction

Based on 2.5 degree spatial and 6 hour timely resolved NCEP/NCAR reanalysis data, Kalnay et al. (1996), provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at http://www.esrl.noaa.gov/psd/, meteorological data covering Europe on an approximately 45 km resolution grid, see figure 1, has been calculated with the WRF (Weather Research & Forecasting, "http://www.wrf-model.org/index.php") model for all of year 2007 with an output time resolution of 1 hour, and the native "netCDF" output format has been translated into the format needed by the RIMPUFF programme.

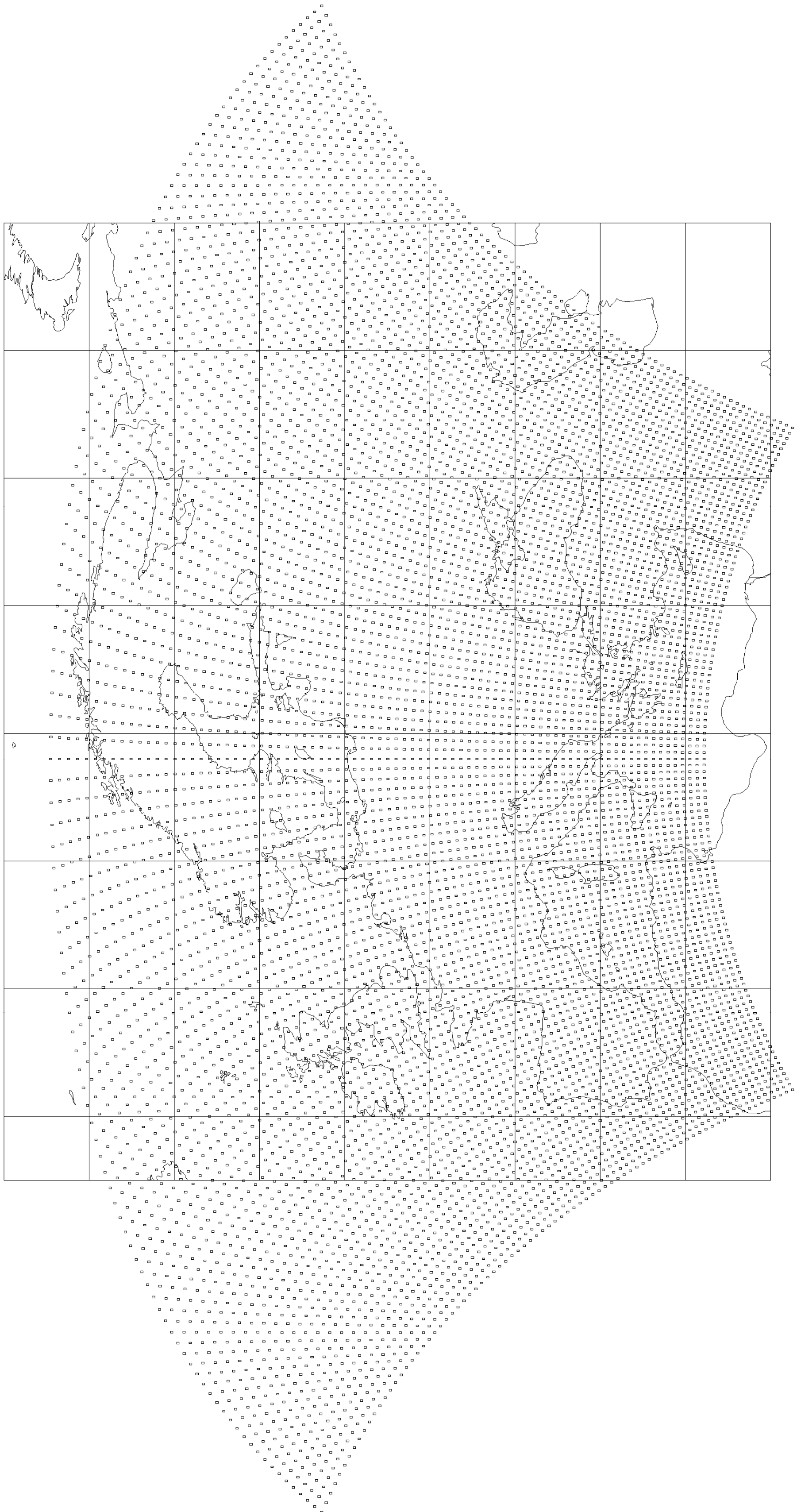


Figure 1: WRF calculation points covering Europe, resolution approximately 45 km.

Atmospheric dispersion programme RIMPUFF

RIMPUFF (RIsø Mesoscale PUFF model), Mikkelsen et al. (1984), is a puff dispersion model, i.e. it treats a continuous release as a series of releases of individual puffs, each containing the amount released within the time to next puff release. It reads three dimensional numerical weather predictions in a proprietary ascii format, downscales this information taking local topography and land use into account, calculates Monin-Obukhov parameters using a meteorological pre-processor, applies the Carruthers formulas, Carruthers (1992), for short range puff growth and the Mikkelsen formula, Mikkelsen et. al (2007), further from the release site, all based on the local meteorological conditions and turbulence. RIMPUFF models plume (puff) rise due to temperature differences between the release and the surrounding atmosphere, Macdonald (2003), who in turn refers to Briggs (1975), it includes decay of nuclear isotopes (decay chains), models wet and dry deposition of aerosols and of elemental and organic bound iodine, and calculates gamma radiation to ground due to airborne, Thykier-Nielsen et al. (1993), as well as ground deposited, semi-infinite model, nuclear isotopes.

Release site selection

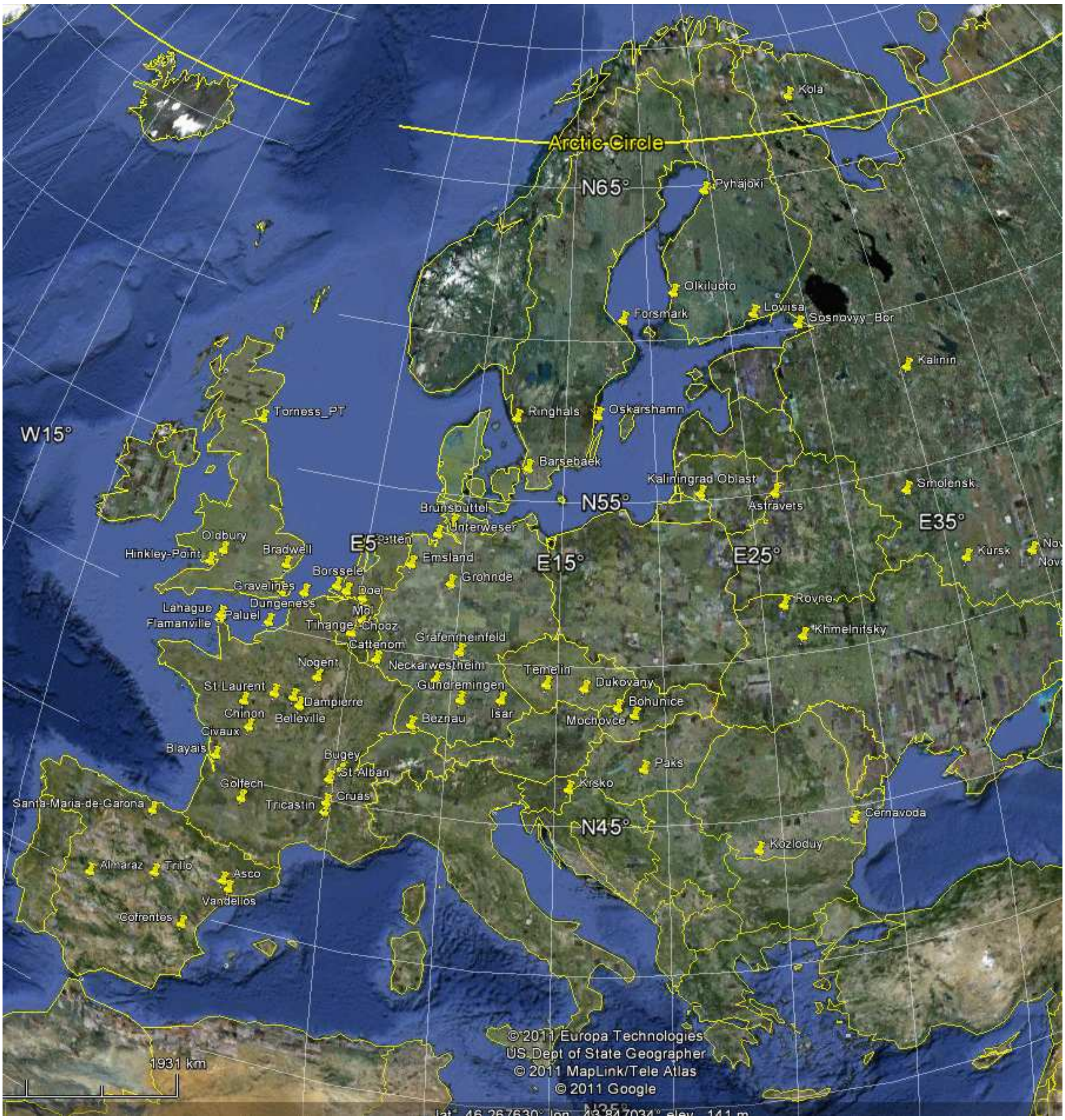
As an outcome of the Plitvice meeting the end users were asked to specify which plants they found might be a potential threat to their individual countries, and so be wanted as release site in the DETECT radiation threat database. This led to a list of 60 power plants:

NPP name	longitude [deg]	latitude [deg]	NPP name	longitude [deg]	latitude [deg]
Almaraz	-5.6983	39.8066	Hinkley_Point	-3.1314	51.2096
Asco	0.5683	41.1997	Isar	12.2931	48.6056
Barsebaek	12.9200	55.7447	Khmelnitsky	26.6478	50.3026
Belleville	2.8748	47.5095	Kola	32.4867	67.4667
Beznau	2.2283	47.5517	Kozloduy	23.7689	43.7461
Blayais	-0.6927	45.2550	Krsko	15.5155	45.9382
Bohunice	17.6924	48.4966	Lahague	-1.8787	49.6773
Borssele	3.7161	51.4332	Loviisa	26.3474	60.3706
Bradwell	0.8989	51.7416	Mochovce	18.4587	48.2595
Brunsbuttel	9.2015	53.8924	Mol	5.0957	51.2157
Bugey	5.2714	45.7975	Neckarwestheim	9.1731	49.0400
Cattenom	6.2159	49.4135	Nogent	3.5185	48.5168
Cernavoda	28.0581	44.3213	Oldbury	-2.5704	51.6488
Chinon	0.1692	47.2237	Olkiluoto	-38.5578	61.2366
Chooz	4.7886	50.0901	Paks	18.8529	46.5729
Civaux	0.6519	46.4551	Paluel	0.6349	49.8582
Cofrentes	-1.0510	39.2131	Petten	4.6776	52.7879
Cruas	4.7549	44.6315	Ringhals	12.1074	57.2580
Dampierre	2.5164	47.7333	Rovno	25.8912	51.3261
Doel	4.2581	51.3242	Santa_Maria_de_Garona	-3.2071	42.7751
Dukovany	16.1501	49.0847	Sosnovyy_Bor	29.0502	59.8522
Dungeness	0.9624	50.9130	St_Alban	4.7563	45.4080
Emsland	7.3206	52.4717	St_Laurent	1.5785	47.7202
Flamanville	-1.8862	49.5360	Temelin	14.3773	49.1797
Forsmark	18.1750	60.4030	Tihange	5.2734	50.5354
Golfech	0.8465	44.1066	Torness_PT	-2.4088	55.9680
Grafenrheinfeld	10.1857	49.9836	Tricastin	4.7314	44.3306

Gravelines	2.1334	51.0133	Trillo	-2.6228	40.7015
Grohnde	9.4092	52.0347	Unterweser	8.4780	53.4990
Gundremingen	10.4015	48.5151	Vandellos	0.8652	40.9508

Of these Barsebaek in Sweden and Brunsbuttel and Unterweser in Germany are now closed down, but another five operating plus four planned and interesting sites have been identified and processed:

Astravets	26.1199	54.7619	Novovoronezh	39.2022	51.2745
Ignalina	26.5601	55.6046	Oskarshamn	16.6678	57.4129
Kalinin	35.0591	57.9056	Pyhäjoki	24.2640	64.5300
Kaliningrad	22.1624	54.9393	Smolensk	33.2394	54.1678
Kursk	35.6038	51.6747			



Release scenario
Also the release scenario was changed and ended as a two step scenario with a high release rate the first hour and a somewhat lower rate the following 11 hours, release height 50 m, no heat input, the same scenario for both long and short range calculations.

Nuclide	release rate [Bq/s]	
	1st hour	2nd-12th hour
Te-132	1.0E+15	1.0E+13
I -131	1.0E+15	1.0E+13
I -132	1.0E+15	1.0E+13
Xe-133	1.0E+15	1.0E+13
Xe-135	1.0E+15	1.0E+13
Cs-137	1.0E+15	1.0E+11

Dispersion calculations
The dispersion calculations have included long range calculations, i.e. out to 1000 km from the plant, and finer resolved short range calculations, out to 100 km. To cover "all" meteorological conditions, a high number of calculations have been performed equally distributed over the year. For each selected site a short range and a long range calculation have been started for every 30 hours throughout 2007, i.e. 4 calculations per 5 days, a total of 292 calculations per site and range type, the simulation time being 168 hours - i.e. one week – for the long range calculations, 24 hours for the short range. If all puffs have left the calculation area before this defined end of calculation, the deposited nuclides just decay and radiate during the remaining time. For long

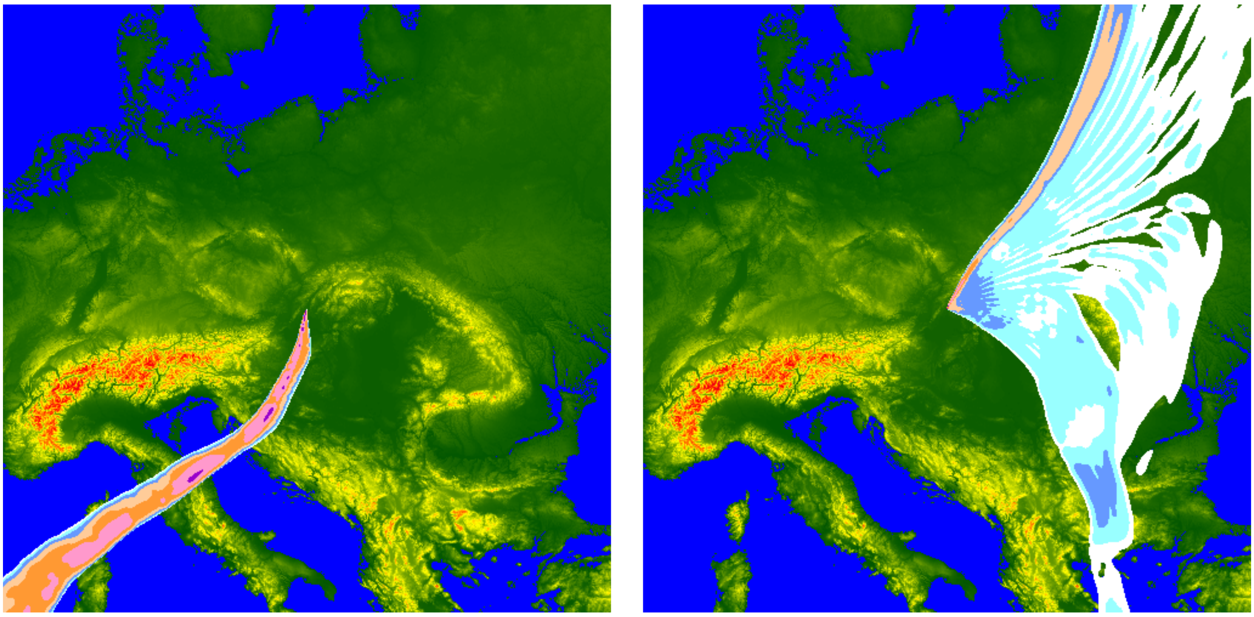


Figure 2: Gamma dose fields after 168 hours for two releases from Bohunice in rather different meteorological situations. Long range calculations.

range calculations the grid resolution is 4 km, the calculation area 2000*2000 km, and the releasing power plant is located within 4 km from the centre. The output time resolution is one hour. For short range calculations the area is 202*202 km and the power plant is within 1 km from the centre. The output grid resolution is here "telescopic": 0.5 km out to 5 km from the plant, 1 km out to 20 km, 2 km out to 50 km, and 3 km out to 100 km, see figure 3. The output time resolution is 10 minutes.

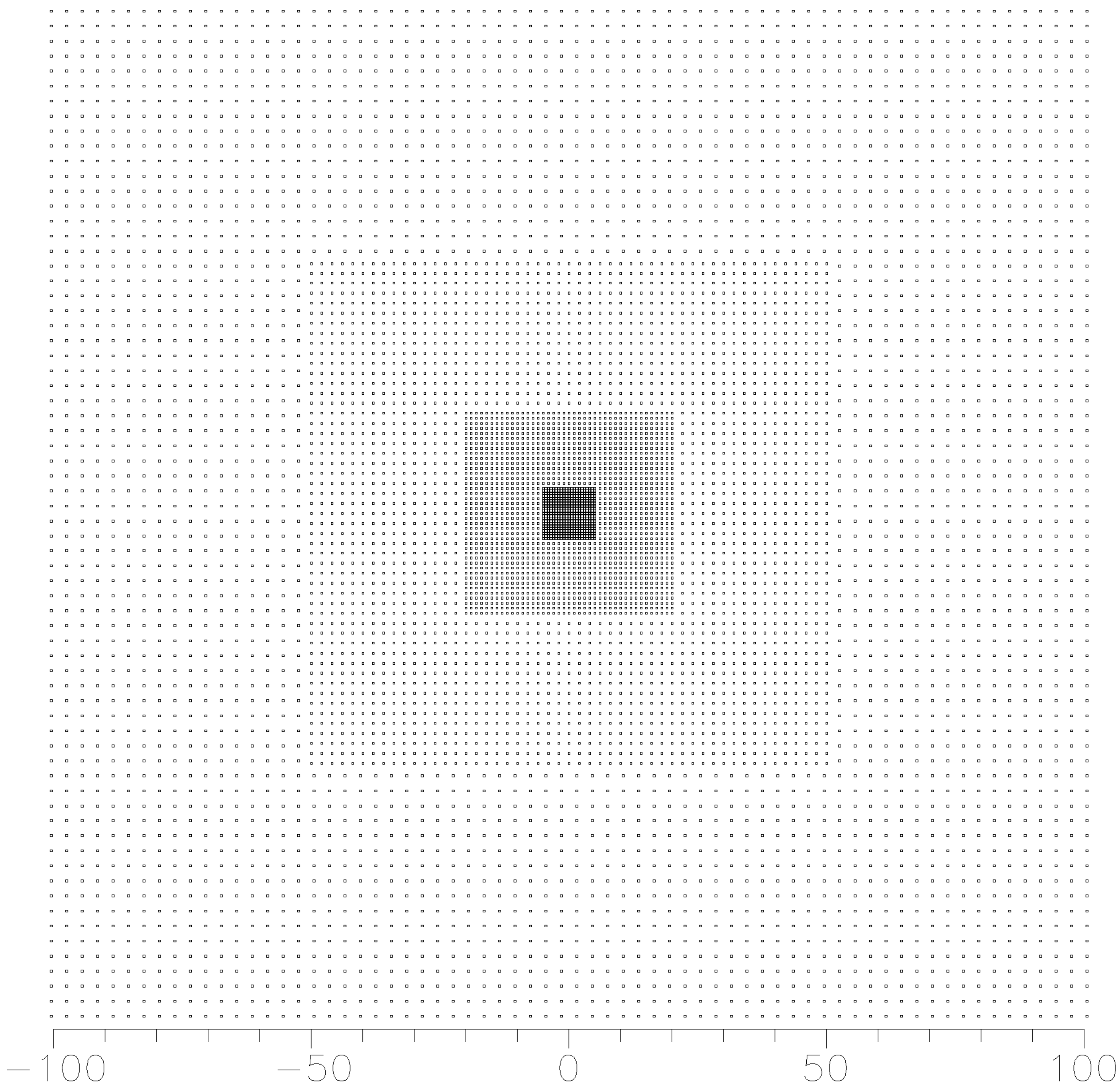


Figure 3 Telescopic detector point grid used for short range gamma dose rate calculations.

Radiation threat database

The binary output of each dispersion calculation is post processed to give a single ascii file holding for every grid point the total dose [Sv] received during the calculation time, i.e. sum of doses from airborne and ground deposited activity, the maximum dose rate [Sv/h] received, and the first time [seconds after start of release] the dose rate reaches 100 nSv/h. These files are stored in directories named by the release site/power plant and each named with the release start time, e.g. "Asco\2007010100.dat", and for each case zipped into long and short range zip-files, e.g. "Asco_long_data.zip" and "Asco_short_data_zip" for results from the Asco cases. These zip files

additionally contain a file named "Points_UTM.dat" holding the grid point coordinates for the actual case.
Due to difficulties for the optimization program (work package WP2) to simultaneously handle results given for coordinates in different UTM zones and thereby in different projections, the long range calculations have been further reprocessed to refer to the same coordinate system in a Lambert Azimuthal Equal Area projection, and given so as GeoTIFF files/images covering all of Europe. This work has been carried out by Jan Erik Dyve, NRPA, Norway. Figure 4a shows the treated area in this projection with a frame showing the long range calculation area for the release site named Golfech, and figure 4b shows a result picture for this case. Like the ascii files also the GeoTIFF files for each release site are zipped, e.g. for the Asco case into "Asco_GeoTIFF.zip". The collection of zip-files for all cases constitute the radiation threat database.

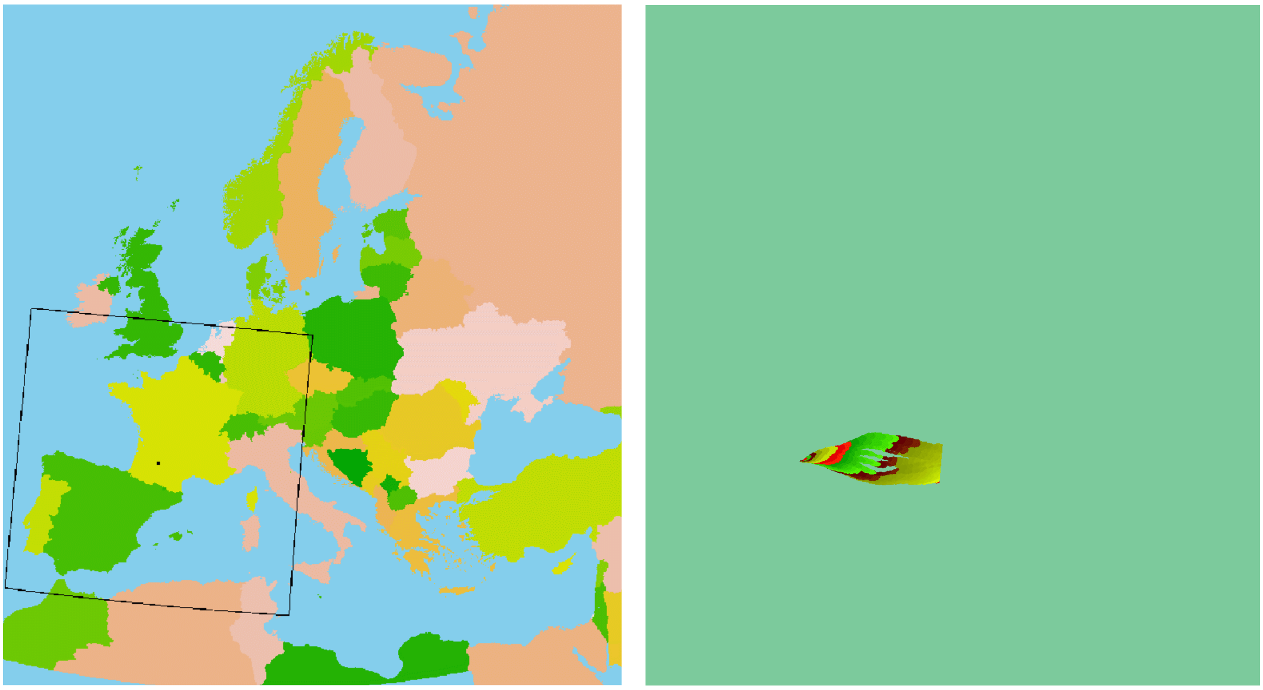


Figure 4: a) Common area and projection for all long range results with Golfech site calculation area framed. b) A result picture for a Golfech release.

Influence of rain

Wet deposition is a major contributor to the deposition of radio nuclides. For the calculations leading to the radiation threat database, the rain calculated by the used numerical weather prediction and analysis model - WRF - has been used, i.e. rain given at the WRF grid with approximately 45 km resolution.
To better illustrate the patchy nature of rain and thereby of wet deposition, a few extra calculations have been made with measured rain data overwriting the WRF rain. These rain data are from May 2011, not 2007 as the WRF results, and they cover an area not coinciding with any of the calculation areas used for DETECT. The data are radar based, has a spatial resolution of 1 km, a time resolution of 10 minutes, a duration of two and a half days in mid May 2011, and cover most of Denmark plus the southern part of Sweden, and so are typical to the northern part of Europe. They hold many spikes close to the radar probably located at the island of Bornholm just outside the covered area, spurious data up to 650 mm/h are observed, see figure 5.

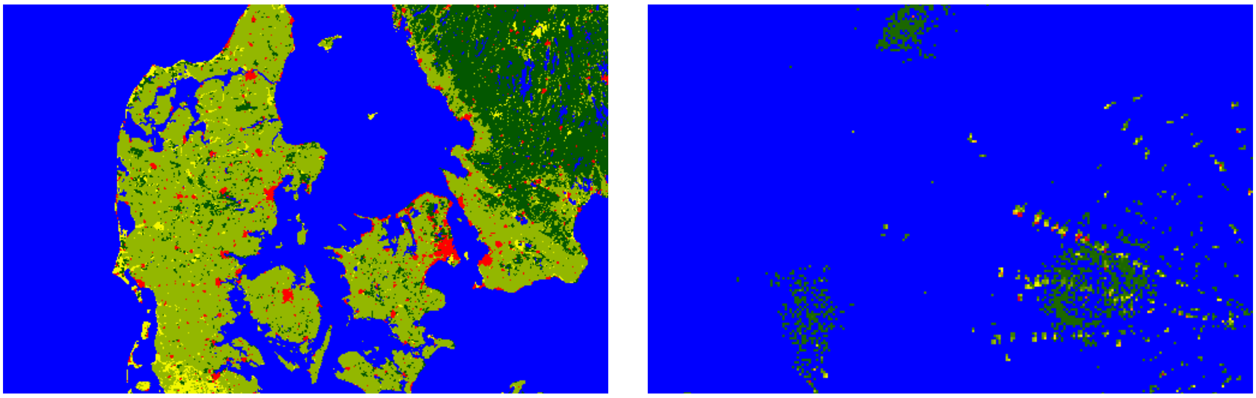


Figure 5: Left: The area covered by the actual rain radar data includes most of Denmark, the south western part of Sweden plus tiny bits of northern Germany.
Right: typical picture of spurious data. Blue means no rain, rain rate then increasing through dark and lighter green, yellow and red to dark red for maximum.

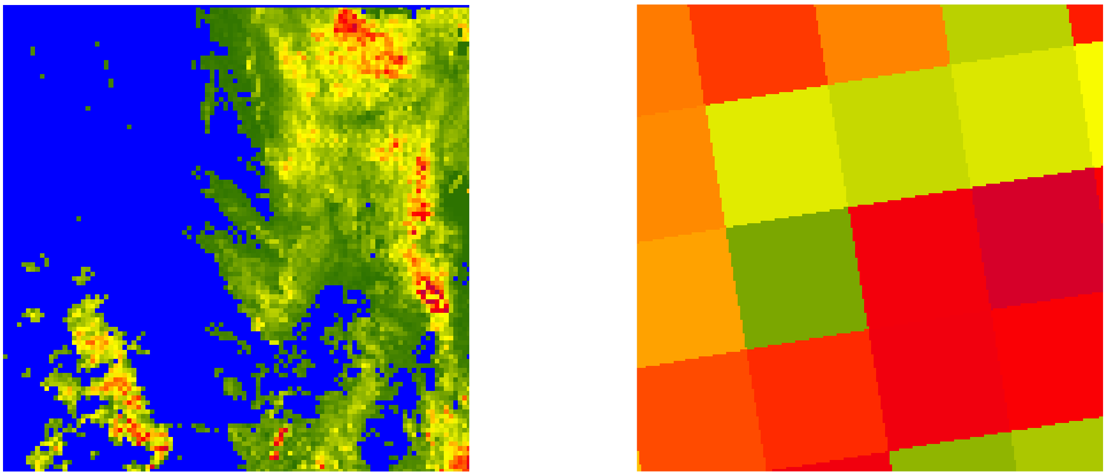


Figure 6. Radar rain pattern (left) and WRF rain pattern (right). Blue = no, dark red = max rain.

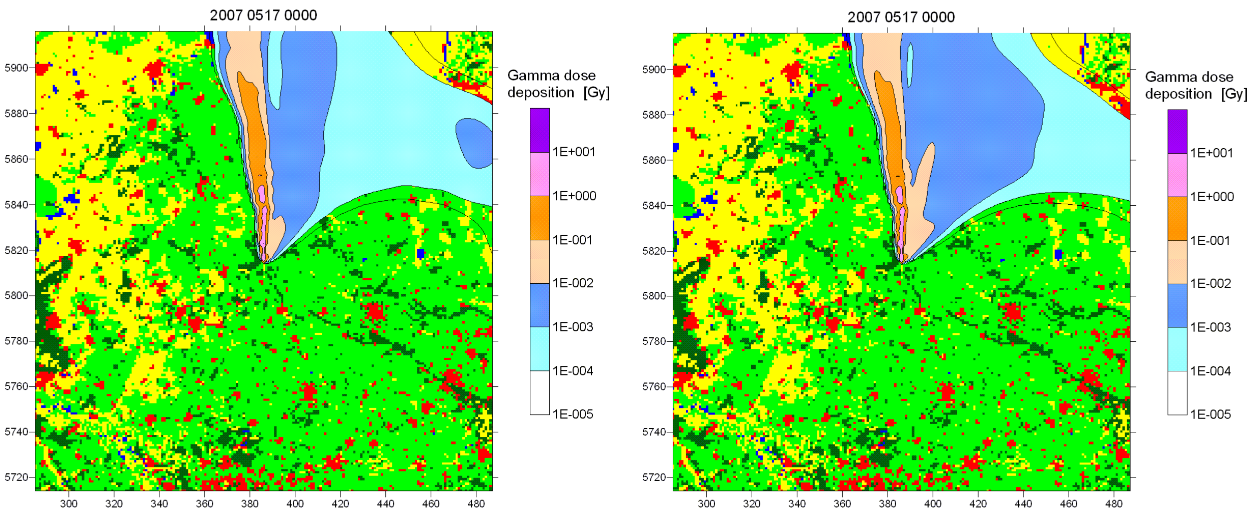


Figure 7: Gamma dose from deposition with radar rain (left) and with WRF rain (right).

For the calculation tests with the radar rain an area of 202*202 km corresponding to the short range calculation area has therefore been extracted from the northwest corner of the radar rain information area, see figure 5 right. Calculations with the spatially highly resolved radar rain provide a correspondingly more detailed instant picture than those using the 45 km resolution WRF rain, see figure 6. To see the influence of radar rain replacing WRF rain, the calculation for the Emsland power plant starting 14th May 2007 was chosen. It has been run with WRF calculated rain for 14th May 2007 and with radar rain of 16th May 2011. Both rain field sequences show a front passing the area from between southwest and west. As the weather except for the rain is the same and the puffs therefore follow the same paths in the two calculations, the area of wet deposition shall be approximately the same. Here it turns out that the wet deposition and so also the final gamma doses from deposition becomes almost the same, see figure 7. For days with summer showers the picture can be expected to be rather different, i.e. rather more patchy (in stripes) with radar rain than with WRF rain.
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Conclusion

The goals set for work package 1 has been achieved:
One year, 2007, of met-data covering Europe with a time resolution of 1 hour has been created and uploaded to the DETECT web server.
A common release profile have been agrees upon and 68 nuclear power plants have been selected by the end users as possible threats to their respective countries.
292 long range and 292 short range dispersion calculations from each of the 68 nuclear power plants have been carried out, a new release scenario starting every 30 hours. So the whole year have been covered and statistically most meteorological conditions. The output has been post processed, and the end results which form the radiation threat database have been uploaded to the DETECT web server.
Radar measured rain has been obtained and tested for a few cases using Emsland in Germany as source point. With a high resolved radar rain front passing the calculation area, the found deposition pattern was almost the same as with a low resolution NWP-rain front passing and so the inherited gamma dose rates also got almost equal. Greater differences can be expected for summer-thunder-rain, but for a project like DETECT, the numerical weather predicted rain seems fully sufficient plus that radar rain for all of Europe for a whole year is hardly obtainable.
A program allowing extraction of a time series of gamma dose rate data from a movable detector has been written for the former style output. It was never found needed nor applicable for the DETECT web-program and so has not been updated to use the latest output format.

References

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APPENDIX A

The below describes the work on WP1 carried out before the Plitvice meeting 4th to 6th April 2011 the results of which is not in use in the final DETECT web-model.

Release site selection
Three European areas were selected for potential long range cross border threats: Norway, which has no nuclear power plants really close, the Balkan area which has a number of plants along the northern borders, and Spain which may be potentially threatened by the French Golfech plant. Spain itself has 8 reactors.

Release sites selected potentially threatening Norway:
Ringhals, Sweden; Forsmark, Sweden; Kola, Russia; Torness_PT, Scotland: and a point in the Antlantic outside the island of Andoya, Norway, this being a place of naval exercises including nuclear driven vessels.
Release sites selected potentially threatening the Balkan area:
Chernavoda, Romania; emelin, Czech Republic; Kozloduy, Bulgaria; Krsko, Slovenia; and Paks, Hungary.
Release site selected for potentially threatening Spain: Golfech, France.
Emsland, Germany, was also selected as release site for long range dispersion calculations.

A further three sites were selected for short range calculations, i.e. out to 100 km from the release site: Chooz in France but almost in the centre of Belgium and featuring hilly terrain, Leibstadt in Switzerland in complex terrain, and again Emsland in Germany in flat terrain.

Release scenario, long range
The release scenario for the long range cases was fixed as a 12 hour constant release of Kr-88, Sr-91, I-131, Xe-133, Xe-135, and Cs-137, 1.0E+12 Bq/s of each, release height 50 m and 1550 m, no added heat.

Dispersion calculations, long range
To cover the different meteorological conditions though a year, a high number of RIMPUFF dispersion calculations have been performed. For each long range case, i.e. each selected site and release scenario, a run is started every 84 hours, i.e. 2 runs per week, a total of 104 runs for 2007 per case, the maximum simulation time set being 168 hours, i.e. one week, otherwise till all puffs have left the calculation grid. Grid resolution is 4 km, calculation area depends on case, the size being up to 2000*2000 km.

The saved RIMPUFF output files for each run are three binary files:
"Out_GamDoserateDep.DAT", "Out_GamDoseratePuff.DAT", and "Out_GamDoseTot.DAT".
The "Out_GamDoseratePuff.DAT" file holds for each output time step gamma dose rate fields at ground level due to irradiation from the passing puffs/plume, a field for each nuclide plus one for the sum over the nuclides. "Out_GamDoserateDep.DAT" similarly holds the gamma dose rate fields due to irradiation from the deposited material. The "Out_GamDoseTot.DAT" holds the sum of gamma doses from puffs and deposition., i.e. the sum of the time integrated gamma dose rates, at every output time, for each nuclide and for the sum of nuclides. The time between outputs has been 30 minutes.

Radiation threat database, long range
For the further processing within DETECT only the sum over nuclides of gamma dose rates from airborne and deposited activity separately are needed, and only once an hour. The so requested fields are extracted from the above mentioned binary files and written in the GRD ascii format specified by Golden Software for their presentation program Surfer, a single field per file for which reason the filename includes the time of validity of the field, while the path includes the time of initial release, e.g.
"2007010318\Gratedep_TOTAL_20070103210000.grd"
for the sum of gamma dose rates from all nuclides in the deposited material, valid 3rd January 2007 at 2100 UTC, release start same day at 1800 UTC, and
"2007010318\Gratepuf_TOTAL_20070103210000.grd"
for the corresponding gamma dose rate field from airborne activity.
Finally all GRD files from the 104 runs for a case is zipped into a single file maintaining the release time directory structure and named with the site, the type (always Grate for gamma dose rate) and the release height, e.g. "Golfech_Grate_1550.zip".

The long range radiation threat database consists of the following zip files:

```
Release height 50 m                       File size
-------------------                     -------------
  Andoya_Grate_50.zip                   1,494,178,846
  Forsmark_Grate_50.zip                 1,618,269,093
  Kola_Grate_50.zip                       684,740,819
  Ringhals_Grate_50.zip                 1,503,058,279
  Torness_PT_Grate_50.zip               2,143,580,816

  Chernavoda_Grate_50.zip               2,453,875,045
  Kozloduy_Grate_50.zip                 2,863,503,703
  Krsko_Grate_50.zip                    2,692,009,625
  Paks_Grate_50.zip                     2,638,130,772
  Temelin_Grate_50.zip                  1,741,967,290

  Golfech_Grate_50.zip                  3,266,343,676
  Emsland_long_Grate_50.zip             2,049,681,685

Release height 1550 m
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  Andoya_Grate_1550.zip                 1,191,318,639
  Forsmark_Grate_1550.zip                 956,542,579
  Kola_Grate_1550.zip                     550,129,689
  Ringhals_Grate_1550.zip                 977,348,308
  Torness_PT_Grate_1550.zip             1,670,392,611

  Chernavoda_Grate_1550.zip             1,509,478,155
  Kozloduy_Grate_1550.zip               2,244,429,168
  Krsko_Grate_1550.zip                  1,998,782,193
  Paks_Grate_1550.zip                   1,838,693,318
  Temelin_Grate_1550.zip                1,417,433,372

  Golfech_Grate_1550.zip                2,101,276,979
  Emsland_long_Grate_1550.zip           1,283,490,458
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Release scenario, short range
For the short range calculations two scenario's have been considered: 1) a constant 1 hour release of the same nuclides and with the same release rate as for the long range cases (see above), 50 m release height, no heat input; and 2) a more realistic release profile taken from the source term database of RODOS, Raskob and Erhardt (1999):

Period	0-0.5 h	0.5-1 h	1-12 h
Release height	100 m	100 m	100 m
Heat input	225 MW	225 MW	0 MW
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Nuclide	[Bq/s]	[Bq/s]	[Bq/s]
Kr- 85m	1.29444E+14	1.29444E+14	2.69444E+12
Kr- 85	0.00000E+00	0.00000E+00	0.00000E+00
Kr- 88	4.02778E+14	4.02778E+14	8.38889E-04
Xe-133	1.25000E+15	1.25000E+15	2.59444E+13
Xe-135	2.65556E+13	2.65556E+13	2.72222E+13
I -131	6.11111E+14	6.11111E+14	1.27222E+13
I -132	8.83333E+14	8.83333E+14	1.83889E+13
I -133	1.24444E+15	1.24444E+15	2.57778E+13
I -135	1.16667E+15	1.16667E+15	2.42778E+13
Rb- 88	0.00000E+00	0.00000E+00	0.00000E+00
Sr- 89	3.80556E+13	3.80556E+13	0.00000E+00
Sr- 90	4.08333E+12	4.08333E+12	0.00000E+00
Zr- 95	2.83333E+12	0.00000E+00	0.00000E+00
Ru-103	5.09444E+14	5.09444E+14	0.00000E+00
Ru-106	1.70556E+14	1.70556E+14	0.00000E+00
Te-131m	0.00000E+00	0.00000E+00	0.00000E+00
Te-132	3.61111E+14	3.61111E+14	4.59444E+12
Cs-134	6.55556E+13	6.55556E+13	1.31111E+11
Cs-136	1.57222E+13	1.57222E+13	3.18333E+10
Cs-137	4.11667E+13	4.11667E+13	8.11111E+10
Ba-140	9.27778E+13	9.27778E+13	0.00000E+00

The Kr-88 release of 8.38889E-04 Bq/s from 1 to 12 hours is probably and error, but used so.

Dispersion calculations, short range
For the short range cases, a new release is started every 30 hours, so having releases start at four different times of the day. Covering 2007 this makes 292 calculations per case. Simulation time is 24 hours, and grid resolution is 1 km. The output is however not on the calculation grid but on a grid with varying spatial resolution: 0.5 km out to 5 km from the release point or rather within a 10*10 km square centred at the release point, then 1 km out to 20 km, 2 km out to 50 km, and 3 km resolution out to 101 km from the release point, i.e. within a 202*202 km square, see figure 3. The positions of these 7629 so called detector points are input to RIMPUFF which calculates the gamma dose rates to these directly and not by interpolating in the 1 km grid point values. The time between outputs has here been 10 minutes.

The saved RIMPUFF output files for each run are the ascii detector point files:
"<releasesite>\yyyymmddhh\OUTP_GamRateDep.DAT"
"<releasesite>\yyyymmddhh\OUTP_GamRatePuff.DAT"
and the binary file

"<releasesite>\yyyymmddhh\Out_GamDoseTot.DAT"
where again "yyyymmddhh" is the date and time for start of release/start of calculation.

Radiation threat database, short range

Extraction of the needed data is carried out with a program "outp" which for each output time writes an ascii file holding point position, gamma rate for each nuclide plus the sum or only the sum, but only for points with nonzero gamma dose rate. The files are named with data type and time of validity and stored in subdirectories giving release site and start time, e.g.
"...\Chooz_short\2007010206\Det_GratePuff_200701020750.dat" and
"...\Chooz_short\2007010206\Det_GratePuff_200701020750.tot"
where the first with extension "dat" holds gamma dose rates for each nuclide plus the sum of these while the latter with extension "tot" just has the sum. Finally all such files for a site are zipped, maintaining the release time directory structure and name by the site and the "dat" or "tot", e.g. "Chooz_short_tot.zip".

The short range radiation threat database consists of the zip files described above, a list of the release site dependent UTM zones used in the calculations plus the lists of detector point positions.