Senter for fremragende forskning

Environmental Impacts from hypothetical accident scenarios involving the recovery of the dumped Russian submarine K-27

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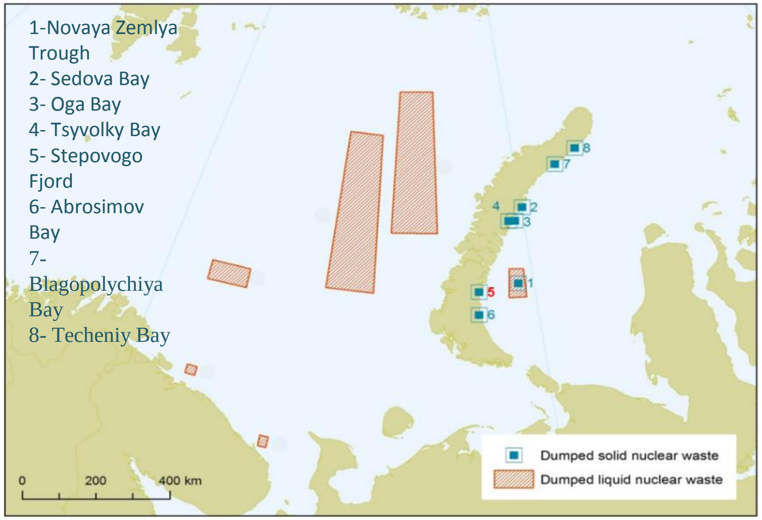
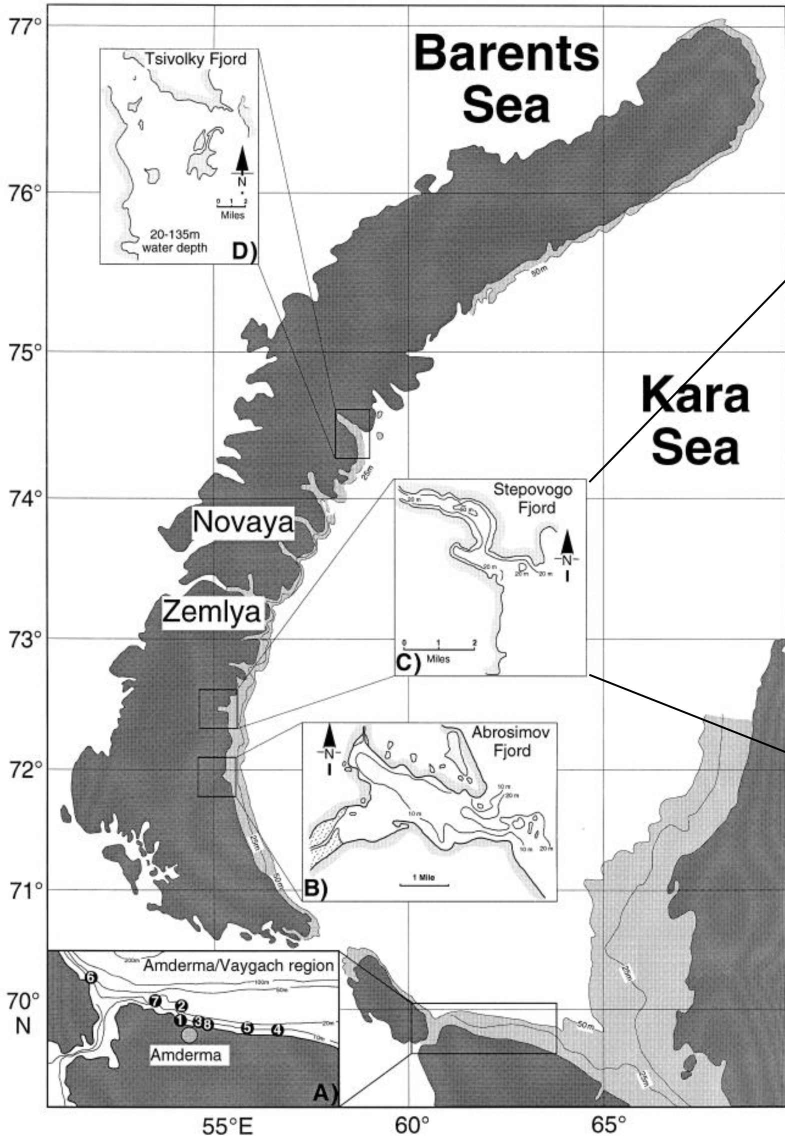
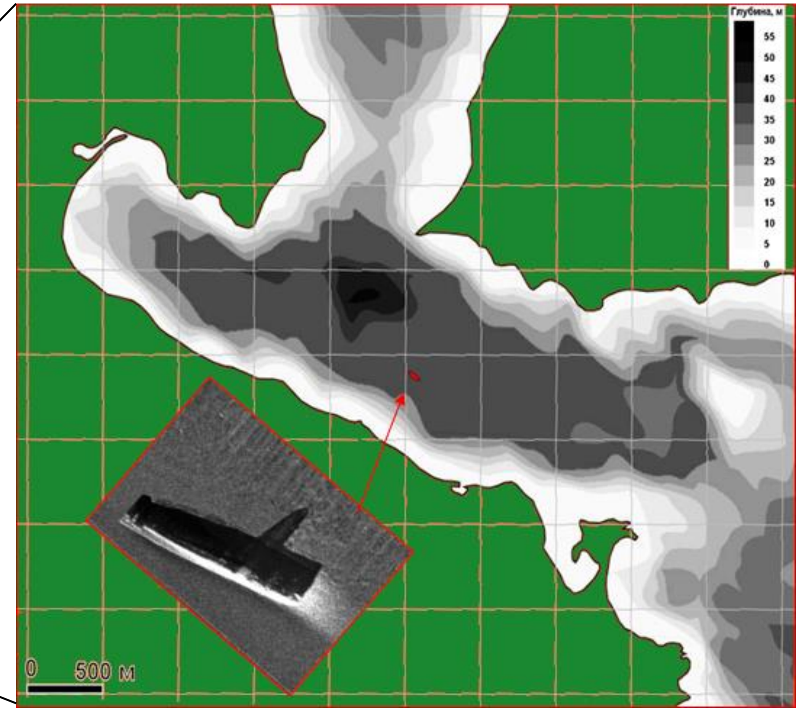
Background



- Concerns have been expressed by various parties regarding the issue of the dumped nuclear waste in the Kara Sea and in particular submarine K-27.
- Although work was conducted earlier (IASAP), an updated risk- and environmental impact assessment was deemed necessary.
- NRPA initiated collaboration with IBRAE (Institute for Nuclear Safety) OASys and Met.no to achieve this goal.
- The study has considered several release scenarios based on various management plans that have been envisaged for the submarine.

Location

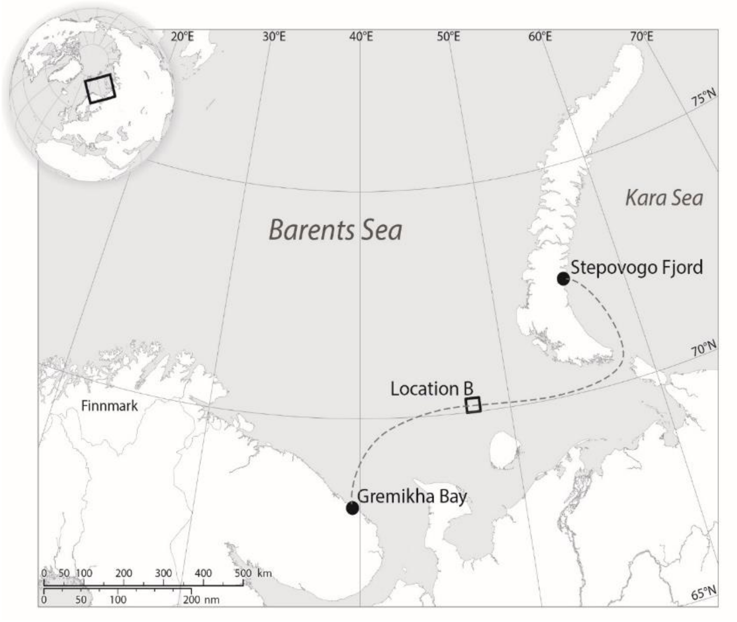




K-27 two reactors with highly enriched SNF and lies at a depth of about 30 m under water. The submarine was dumped in Stepovogo Fjord had an associated activity, at the time of dumping in 1981, slightly in excess of 2 PBq

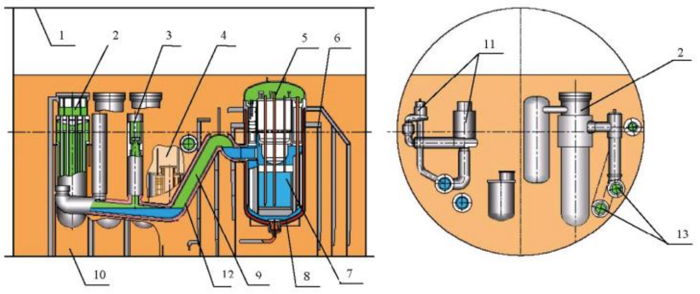
Scenario based EIA

- Different scenarios have been considered to estimate the potential dispersal and transfer of radionuclides within the environment.
  - "Zero- intervention", i.e. investigating the current radiological conditions thus assuming no interventions.
  - Raising of the submarine
  - Transport from Kara Sea to Kola Bay



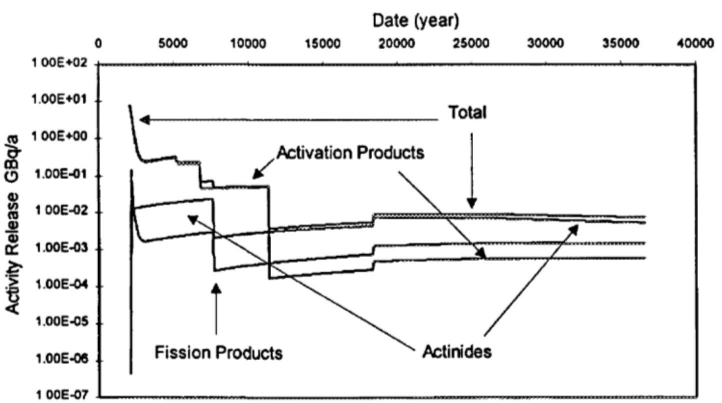
Source Term

- Inventory estimates
  - IASAP, White book and new analyses
- Possible consequences of long-term stay under water
  - state of the protective barriers (Factory Number 900)
  - Corrosion of reactor vessel and primary circuits
  - Long-term behaviour of bitumen and fufural
- Spontaneous Chain Reaction (SCR): initiation possibilities and development
- Release scenarios related to a potential raising and transporting of submarine
- Source term
  - Rads produced (Fission power),
  - Release fractions



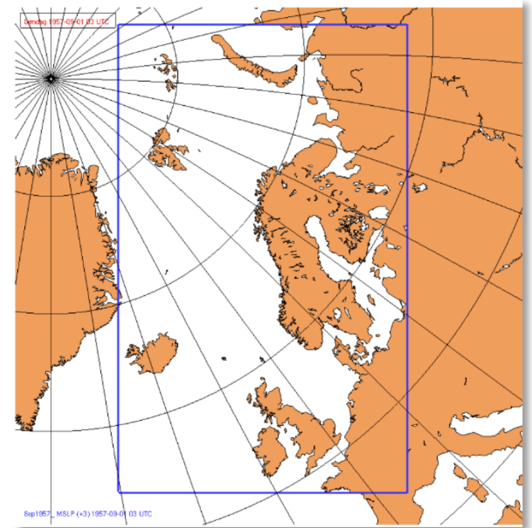
1 – Strong hull;
2 – steam generator;
3 – valve and bellows expansion joint;
4 – pump tank bay;
5 – reactor;
6 – lead-water shielding tank;
7 – solidifying Pb-Bi-alloy;
8 – furfural with cadmium nitrate;
9 - bitumen with orthoboric acid;
10 – bitumen;
11 – pumps;
12 – heat insulation;
13 – pipelines.

Figure 4.2. Schematic overview of measures taken at different parts of the reactor compartment of K-27 prior to its sinking.



Atmospheric dispersion modelling

- SNAP (Severe Nuclear Accident Program) – regional advection and dispersion.
  - A Lagrangian particle dispersion model developed and currently used at the Norwegian Meteorological Institute, MET, for emergency situations.
  - Capable of parametrization of particle properties (diameter, composition and density).
  - Well tested and evaluated
- Urban Dispersion Model (URD) was used to simulate local scale advection and dispersion.
  - URD is an integrated part of the ARGOS Decision Support System.
  - Can be used to model on a local level with high spatial (meters) and temporal (seconds) resolutions close to release point

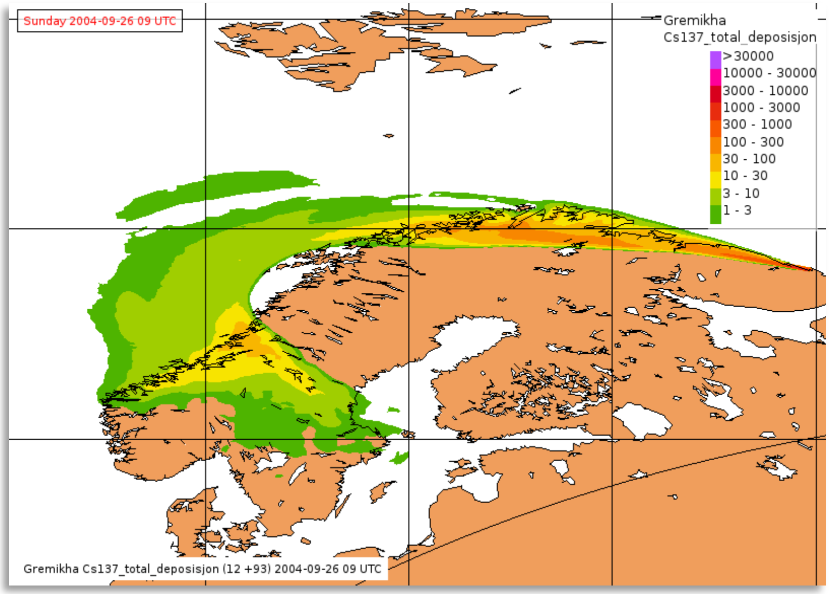


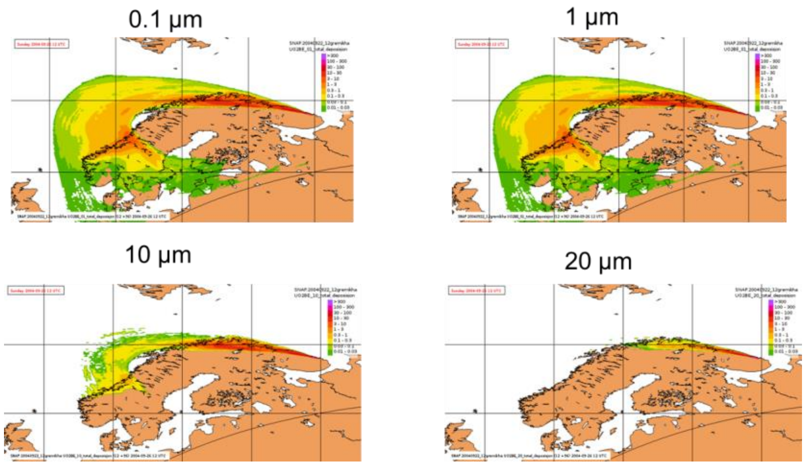
<table>
<tr><th rowspan="2">Group</th><th rowspan="2">Density g cm^{-3}</th><th colspan="8">Radius in um</th><th rowspan="2">Release Bq</th><th rowspan="2">Decay hrs</th></tr>
<tr><th>0.1</th><th>0.5</th><th>1.0</th><th>5.0</th><th>10</th><th>20</th><th>50</th><th>100</th></tr>
<tr><td>UO2-Be</td><td>2.1</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>1.35×10^{13}</td><td>No</td></tr>
<tr><td>Bitumen</td><td>1.0</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>9.8×10^{11}</td><td>No</td></tr>
<tr><td>Metal</td><td>10.5</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td></td><td></td><td>8.4×10^{11}</td><td>No</td></tr>
<tr><td>Ru-106</td><td>3.3</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td>●</td><td></td><td></td><td>1.9×10^{9}</td><td>No</td></tr>
<tr><td>I-131</td><td>0.0113</td><td colspan="8">●</td><td>1.4×10^{11}</td><td>192.96</td></tr>
<tr><td>I-133</td><td>0.0113</td><td colspan="8">●</td><td>5.2×10^{12}</td><td>20.04</td></tr>
</table>

Specification of the model particles representing the real particles and gases for the worst case SNAP model runs. The symbol " ●" indicates the type of the model particle used in the simulations. Decay means decay half-time.

Atmospheric simulations

- The distribution map for accumulated deposition of ^{137}Cs (following a 96 h simulation period) was used as input to food-chain models





Bartnicki, J., Amundsen, I., Brown, J., Hosseini, A., Hov, Ø., Haakenstad, H., Klein, H.,Lind, O.C., Salbu, B., Wendel, C., Ytre-Eide, M.A., 2016. Atmospheric transport of radioactive debris to Norway in case of a hypothetical accident related to the recovery of the Russian submarine K-27. J. Environ. Radioact. 151, 404-416.

- In earlier analyses the effects of particle sizes on advection and dispersion of contaminants had been investigated
  - Large heavy particles (>10 µm) had limited transport mainly affect a localised area in the vicinity of the accident location.

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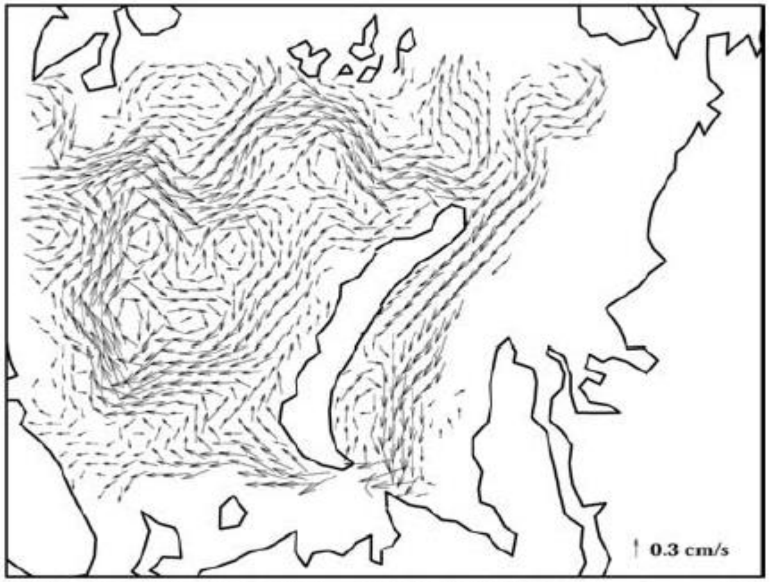
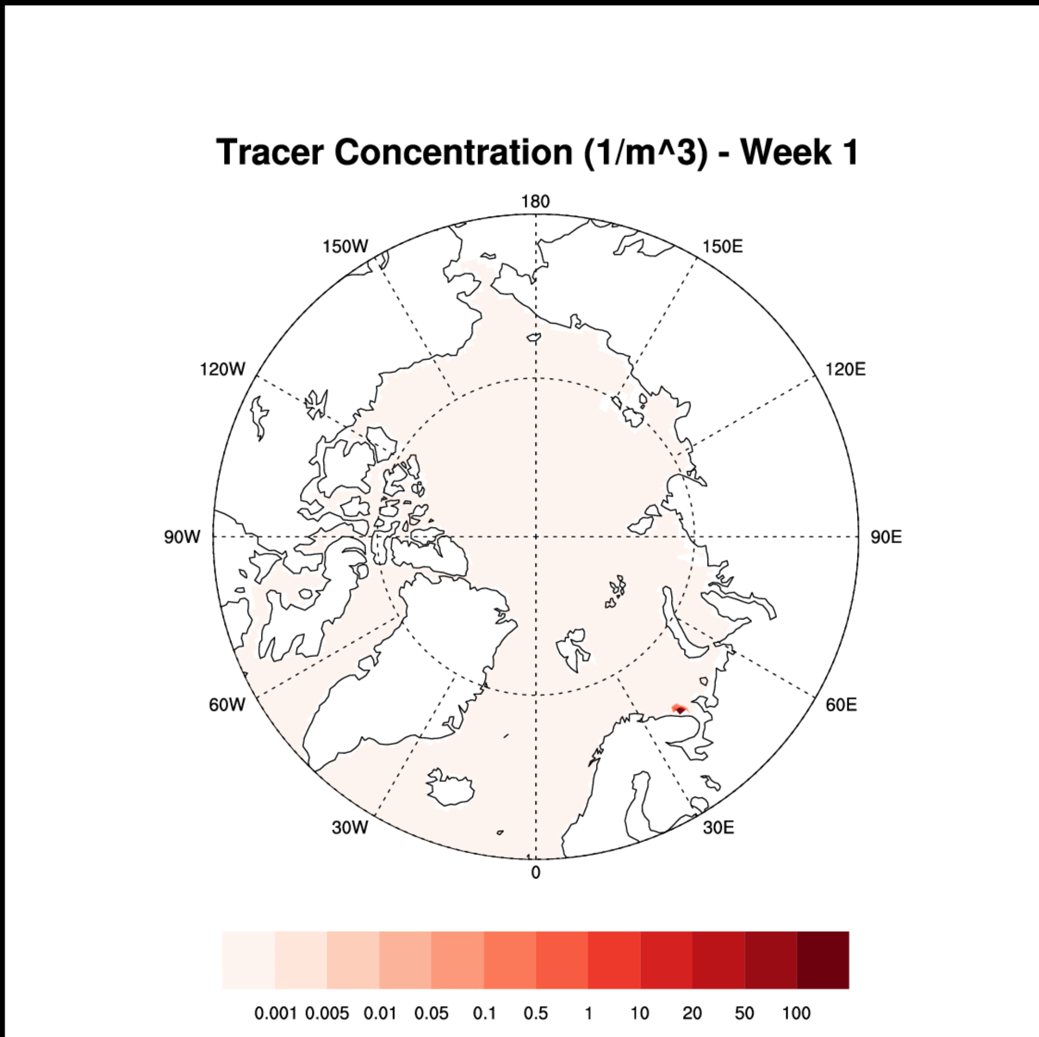
Marine dispersion modelling

- The numerical model used is a version of NAOSIM (North Atlantic/Arctic coupled Ocean Sea Ice Model).
- The model domain covers the Nordic Seas, the Arctic Ocean and the northern North Atlantic down to about 50ºN.
- The model is driven with daily atmospheric forcing from 1948 to 2010



Some of the assumptions:

- Soluble, conservative radionuclides
- Sediment interaction has not been considered,
- The half life has been assumed to be much larger than the dispersion period (10 years).



Instantaneous release 1998

Continuous releases also modelled

3 current regimes considered to be ‘extreme years’ : ‘83, ‘88, ‘98

Reverse flow through Kara Gate

In all cases the advection of the contaminants generally occurs eastward via the Kara Sea and Laptev Sea and subsequently into the central Arctic Ocean

Then, the dispersion occurs mostly via the Transpolar Drift to Fram Strait and further south with the East Greenland Current and into the Labrador Sea.

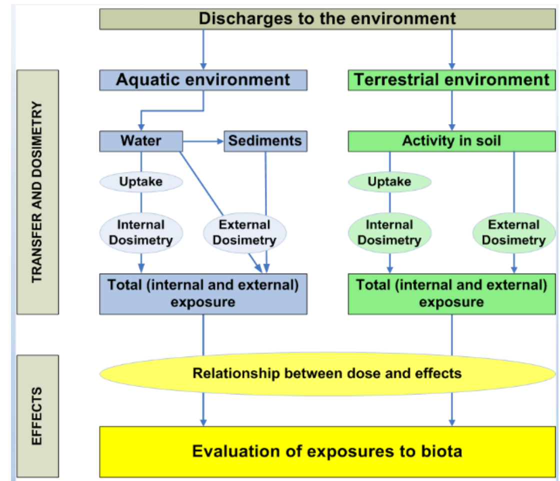
Part of the contaminants in the central Arctic, however, recirculates southward into the Barents Sea, dominantly on the east coast of Svalbard.

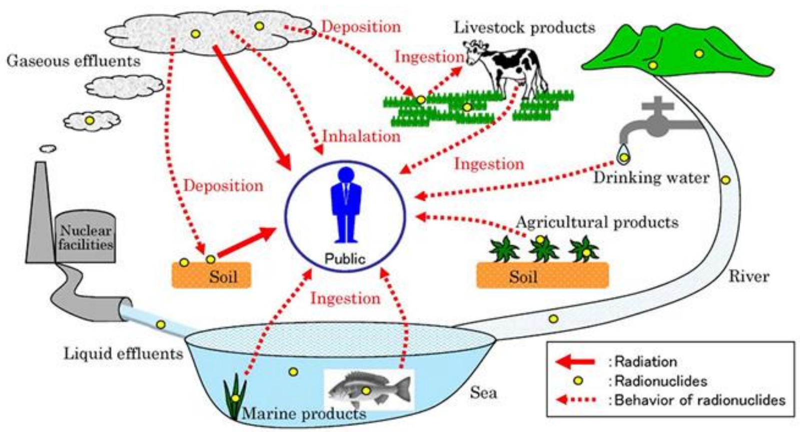
Food-chain transfer, doses to man and environment

Trophic level 3: Fish (uptake via water and food):

$$\frac{dC_f}{dt} = AE_f \cdot IR_f \cdot C_P + k_{uf} \cdot C_w - C_f \cdot k_{ef} \qquad [2]$$

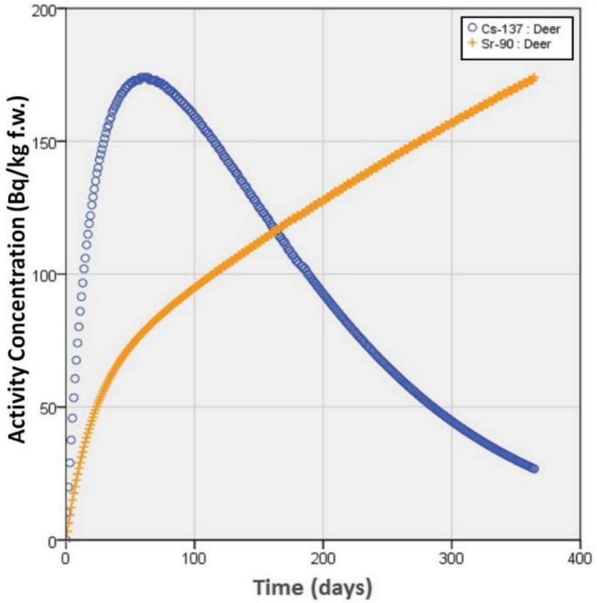
where AE_f is the assimilation efficiency (dimensionless) for fish;
IR_f is the ingestion rate per unit mass of fish (kg f.w. d^{-1} per kg f.w.);
k_{uf} is the uptake rate of radionuclide to fish directly from water column (d^{-1});
C_f is the activity concentration in fish (Bq kg^{-1} f.w.);
k_{ef} is the depuration rate from fish (d^{-1}).





- Internal from contamination of foodstuffs
- Internal via inhalation of contaminated gases
- External via irradiation from contaminated soil, sediment etc.

Terrestrial: doses to man and the environment



For Finnmark Norway:

- ^{137}Cs and ^{90}Sr levels highest in game animals; Deer (reindeer shown in Figure) still elevated but less so
- Over the 1st year, ingestion from foodstuffs would potentially dominate the doses to a representative person.
  - Doses could be as high as 0.25 mSv for the ingestion of terrestrial foodstuffs.
- Doses from all other pathways (table below) low by comparison
- Dose-rates for all representative organisms do not exceed 0.5 µGy/h

- For Stepovogo (military personnel): The dose from inhalation and cloud-shine would be in the region of 1 mSv. The dose from ground-shine would be more substantial at ca. 26 mSv,
  - but this is extremely conservative (occurs over a period of 1 year with no sheltering).

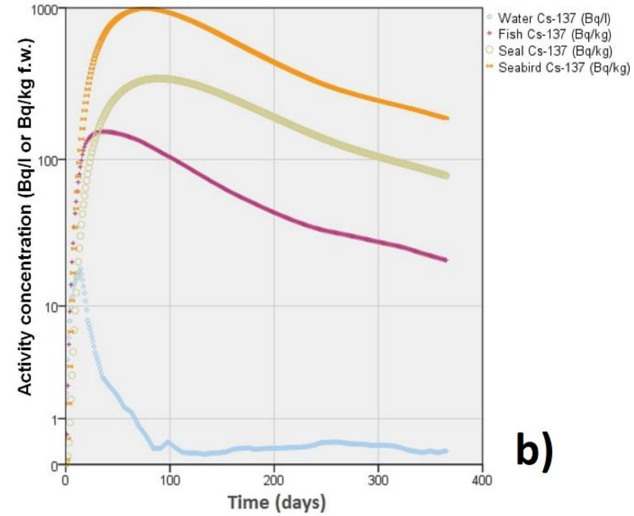
Table 7. Air concentrations. deposition levels and estimated effective doses (to a representative person in Norway) for various pathways (inhalation. cloud-shine and ground-shine) based on release scenario at Gremikha Bay.

Radionuclide	Time Integ. Air Conc. (Bq s/m^3)	Deposition (Bq/m^2)	Inhalation - Effective dose (mSv)	Cloud-shine - Effective dose (mSv)	Ground-shine - Annual effective dose (mSv)
Kr-85	6.7E+02	n.c.	n.c.	1.7E-10	n.c.
Sr-90	1.2E+04	2.2E+02	1.1E-04	5.3E-09	1.1E-05
Y-90	1.1E+04	7.8E+01	4.3E-06	8.9E-09	2.7E-04
Cs-137*	1.4E+04	2.5E+02	1.7E-05	3.6E-07	4.4E-03
TOTAL			**1.3E-04**	**3.7E-07**	**4.7E-03**

*includes Ba-137m; n.c. = not calculated

Marine: doses to man and the environment

- Activities in biota
  - Stepovogo release led to highest activities
  - Delay for maxima (weeks➔months)
  - Most Elevated in seabird (uncertain)
- Doses to humans
  - Highest for Yamal reference person from Stepovogo release
- Doses to marine biota
  - Maximum dose rates ca. 0.2 µGy/h for seabirds
  - Order of magnitude below, e.g. DCRL bands (ca. 4 µGy/h for RAP 'Duck')



At surface activity concentrations of ^{137}Cs in sea water (Bq/l) fish (Bq/kg f.w.) and seal (Bq/kg f.w.) based on releases to the marine environment for the Stepovogo scenario.

Table 1. Estimated Cs-137 annual effective doses from ingestion of marine food for release scenarios at Stepovogo Fjord, Barents Sea and Gremikha Bay based on maximum (surface) activity concentrations

Scenario	Cs-137 (Bq/l)	Dose contribution (mSv)				**Annual effective dose (*mSv*)**
	Water	Fish	Seal	Sea bird	Bird egg	
Stepovogo	18	3.6E-01	1.3E-01	9.4E-02	1.4E-02	**6.0E-01**
Barents Sea	13	1.7E-01	6.2E-02	4.5E-02	6.6E-03	**2.8E-01**
Gremikha	21	1.5E-01				**1.5E-01**

Conclusions

- Terrestrial :
  - Calculated human doses in Norwegian territory (from an accident in Gremikha) fell below 1 mSv even when all pathways were combined.
  - Human doses from ingestion have the potential to contribute substantially in the event that restrictions on specific local foodstuffs are not introduced (restriction for game = 3000 Bq/kg although predictions are substantially below this level).
  - Doses to (terrestrial) non-human biota (in Norway) would not be at a level to cause concern, falling within the range typical background dose rates from primordial radionuclides for terrestrial organisms.
  - Potential doses, primarily due to ground shine, to personnel on-site at Stepovogo could require preventative measures based on ICRP recommendations (20-100 mSv).
- Marine :
  - ^{137}Cs activity concentrations in marine organism for areas close to Norway were not at levels that would likely cause great concern from a regulatory perspective
  - For subsistence fishing communities Yamal/Northern Yenisey, it is not inconceivable that some restrictions on fishing/dietary advice would need to be introduced.
  - Doses to marine organisms insubstantial
  - Recovery of the marine system predicted to occur rapidly