INCO: International Scientific Cooperation Projects
(1998 - 2002)

Contract number: ICA-CT-2000-10037

FINAL SCIENTIFIC REPORT

COVERING THE PERIOD FROM
OCTOBER 1. 2001 TO FEBRUARY 28. 2003

Title: **Simulation Scenarios for Potential Radioactive Spreading in the 21st Century from Rivers and External Sources in the Russian Arctic Coastal Zone**

Project Acronym: **RADARC**

Project homepage: http://www.nersc.no/RADARC

Keywords: **Radioactive contamination, Arctic region, Climate change, modelling, 21st Century**

Contract number: ICA-CT-2000-10037

TITLE: Simulation Scenarios for Potential Radioactive Spreading in the 21st Century from Rivers and External Sources in the Russian Arctic Coastal Zone

Project Acronym: RADARC

COORDINATOR

NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTRE
EDVARD GRIEGSVEI, 3A
N 5059 BERGEN
NORWAY

PROF. JOHANNESSEN, OLA M.
E-M: ola.johannessen@nersc.no
TEL: +47 55 20 58 00
FAX: +47 55 20 58 01

Deputy coordinator: PETTERSSON, LASSE
E-M: lasse.pettersson@nersc.no

CONTRACTORS

RISOE NATIONAL LABORATORY (RISOE)
FREDERIKSBORGVEJ 399, POSTBOKS 49,
4000 ROSKILDE
DENMARK

DR. NIELSEN, SVEN P.
E-M: sven.nielsen@risoe.dk
TEL: +45 4677 5340
FAX: +45 4677 5347

NANSEN INTERNATIONAL ENVIRONMENTAL AND REMOTE SENSING CENTRE
26/28 BOLSHAYA MONETNAYA STR.
197101 ST.PETERSBURG
RUSSIA

DR. BOBYLEV, LEONID P.
E-M: adm@niersc.spb.ru
TEL: +7 (812) 234 38 65
FAX: + 7 (812) 234 38 65

V.G.KHLOPIN RADIUM INSTITUTE
2nd MURINSKI Av., 28
194021 St. PETERSBURG
RUSSIA

PROE. ANDERSON, EVGENIY B.
E-M: stepanov@atom.nw.ru
TEL: +7 812 247 5737
FAX: +7 812 247 8095

INSTITUTE OF MATHEMATICAL MACHINES AND SYSTEMS PROBLEMS
42 GLUSHKOV PR.
03187 KIEV
UKRAINE

DR. MADERICH, VLADIMIR S.
E-M: vlad@immsp.kiev.ua
TEL: (380-44) 2666187
FAX: (380-44) 2663615

NORWEGIAN RADIATION PROTECTION AGENCY
POSTBOKS 55
1332 ØSTERAAS
NORWAY

DR. PER STRAND
E-M : per.strand@nrpa.no
TEL : (+47) 67 16 25 00
FAX : (+47) 67 14 74 07

ARCTIC MONITORING AND ASSESSMENT PROGRAM
STRØMSVEIEN 96, P.O. BOX 8100 DEP.
0032 OSLO
NORWAY

MR. LARS OTTO REIERSEN
E-M: lars-otto.reiersen@amap.no
TEL: +47 22 57 34 00
FAX: +47 22 67 06

Nansen Environmental and Remote Sensing Center
Edvard Griegsvei 3a
N-5059 Bergen - NORWAY
Phone: +47 55 29 58 00 Fax: +47 55 20 58 01
E-mail: administrasjon@nersc.no Web.site: http://www.nersc.no

a non-profit environmental research center
affiliated with the university of Bergen

TECHNICAL REPORT

TITLE *Final Report*: Simulation Scenarios for Potential Radioactive Spreading in the 21st Century from Rivers and External Sources in the Russian Arctic Coastal Zone.	**REPORT No.** Technical report no. 249
CLIENT European Commission, DG Research INCO Programme	**CONTRACT No.** ICA2-CT-2000-10037
CONTACT PERSON Dr. George Neale Kelly (MO75 05/22)	**AVAILABILITY** Open
AUTHORS Ola M. Johannessen, Lasse H. Pettersson, Vladimir A. Volkov, Sven P. Nielsen, Vladimir S. Maderich, Andrey V. Stepanov, Morten Sickel, Yongqi Gao, Ivan A. Neelov, Leonid P. Bobylev, Mark Zheleznyak, Lars Otto Reiersen and Helge Drange	**DATE** December 10, 2003
APPROVAL Lasse H. Pettersson	 Ola M. Johannessen, Director

1 Table of Contents

2 Abstract

The Arctic Ocean and particularly the coastal zone of the Russian Arctic have been heavily exposed to technogeneous radioactivity. The main reason for this is the atmospheric fallout from the nuclear testing activities mainly on the Novaya Zemlya during the 1950s and 60s. Furthermore, radioactive wastes from European plants for reprocessing of nuclear fuel (Sellafield, Cap de la Hague, Dounreay) are transported into the region with the ocean currents system in the Norwegian and Barents Seas. However, the present level of radioactive contamination in these areas is relatively low. Nonetheless there exists a potential risk for radioactive contamination due to the fact that several waste deposits and reprocessing plants of solid and liquid nuclear waste are located on land and at the sea floor in the Kara and Barents Sea region and along the major Siberian rivers – Ob´ and Yenisey - ending up in the Kara Sea. Also potential radioactive pollution due to accidents with nuclear powered vessels and ship transportation of decommissioned reactors is a high risk in the regions. Accidents with the sunken submarines Kursk and K-159 are such examples, which have been studied within the RADARC project.

The overall objective of RADARC's research programme is to perform simulation scenarios for the 21st century, including global warming scenarios, of potential radioactive spreading from sources in the Russian Arctic coastal zone and its impact on Barents, Greenland and Norwegian Seas and the Arctic Ocean in order to support decision making for: risk prevention, forecasting and preparedness for probable crisis, alert and detection, relief and mitigation and damage assessment.

These studies were realised using hydrodynamic modelling of the rivers, estuaries, coastal Kara Sea and the open ocean aquatic systems of the northern Russia and the Arctic and a related comprehensive database that was organised in a Geographical Information System (GIS). Under the RADARC project a new modelling approach was implemented using Generic Model System, where the four types of models were integrated and merged.

The Generic Model System (GMS) that was created for the first time include the GIS and an interactive hydrodynamic models chain for simulations of radionuclide transport from relevant land-based sources through the river and estuary system to and in the Kara Sea as well as in the Arctic and North Atlantic Oceans. The GMS consist of four adopted and validated hydrodynamic models: a medium resolution (50 km) 3-D numerical ice-ocean model for the Arctic and North Atlantic Ocean; nested with a high resolution (5 km) model for the Kara Sea including a sediment module; nested with the river model system including a one-dimensional model of river dynamics and radionuclide transport and three-dimensional model of Ob´ and Yenisey estuarine and coastal areas hydrodynamics and radionuclide transport model.

The most probable release scenarios for radionuclides were developed and simulation studies for selected future scenarios of radionuclear contamination was carried-out, using atmospheric forcing scenarios, including global warming, likely consistent with a CO_2 doubling and control runs.

Thus a new tool for an assessment of the potential radioactive spreading in the Arctic was created and the assessment of the potential radioactive spreading from rivers and external sources in the Russian Arctic Coastal Zone was developed and assessed.

3 Final Summary Report

The main goal research objective of the RADARC research project is to perform simulation scenarios for the 21^{st} century, including global warming scenarios, of potential radioactive spreading from sources in the Russian Arctic coastal zone and its impact on Barents, Greenland and Norwegian Seas and the Arctic Ocean in order to support decision making for: risk prevention, forecasting and preparedness for probable crisis, alert and detection, relief and mitigation and damage assessment. In addition studies are made of the distribution and impact of marine radioactive pollution for sources in Europe (Sellafield) and potential accidental events with the sunken Russian submarines Kursk and K-159 in the Barents Sea.

During the two years project period, plus a three months extension, the project implementation of the work has developed in accordance with the agreed Description of Work (DoW) in general.

The main content of the work included;

- Development of an environmental information data base for modelling;
- Definition the most probable release scenarios for radionuclides to the aquatic environment;
- Improving, adaptation and validation of environmental models composing the model chain for simulations of radionuclide transport from relevant land-based sources, via the river system to or in the Kara Sea as well as in the Arctic and North Atlantic oceans;
- Developing a Generic Model System (GMS) including four hydrodynamic models and comprehensive Geographical Information System (GIS);
- Carrying-out simulation studies for the selected "release" scenarios of radionuclides, using atmospheric forcing scenarios, including global warming, likely consistent with a CO_2 doubling (ref. IPCC) and control runs.

The main scientific results, which have been achieved since the beginning of the project implementation, are:

- Data sets on radioactive pollution levels for the entire Russian Arctic, including the main sources of radioactivity in the Russian Arctic coastal zone, the land-based sources in the Ob’ and Yenisey rivers watersheds from different accessible sources were processed to perform model validation studies;
- The environmental parameters collected during the first year were prepared for integration in the AMAP database for the studied region; a dedicated project GIS was made for integration of model results and validation purposes;
- An archive of meteorological data was assembled; files of direct access for the period 1948-2000 for the Kara Sea region was set up based on global meteorological data from the NCEP/NCAR data base;
- A unique river discharge data set for 19 locations for a 50-60 years period was assembled and reconstructed;
- A long-time series of the Kara Sea sea-level and ocean currents was collected;

- Bottom sediment distributions for the key locations as well as temperature, salinity and water level data for key locations along Ob’ and Yenisey rivers were collected;
- The climatic relevant time series of oceanographic parameters, ice cover parameters, as well as data from quasi-synchronous observations outlining typical distribution of oceanographic parameters and water and ice circulation for the Kara Sea and Arctic Basin were collected;
- Various type of remote sensing satellite data (observations in the visible, infra-red and microwave, with focus on SAR data) needs for models validation were collected;
- The NIERSC’s regular digital Kara Sea bottom relief model (bathymetry) was acquired for use in the regional model simulations;
- The regular digital bottom relief model (bathymetry) for Ob and Yenisey estuaries was corrected;
- The most probable scenarios of accidental release of radionuclides influencing the Arctic environment and their transport from external sources to the Arctic Seas were specified and substantiated to a format relevant for initiation of the numerical models;
- The 3-dimensional, coupled ocean and sea ice North Atlantic-Arctic model was extended to include description of transport and dispersal of radionuclides, validated and integrated into the RADARC Generic Model System (GMS);
- The Kara Sea model was adapted for long-term simulations with constantly updating external meteorological and other forcing parameters. A simulation of the Kara Sea circulation has been carried out. The model uses source data from the nested river/estuary model and provide input data to the Arctic/North Atlantic large-scale ocean model (i.e. integrated in the GMS);
- The river model system includes a one-dimensional model of river dynamics and radionuclide transport (RIVTOX) and three-dimensional model of estuarine and coastal areas hydrodynamics and radionuclide transport (THREETOX). These models were validated against the available data on river discharge, water level, suspended sediment concentration and radionuclide concentration for the Ob’ and Yenisey rivers. The RIVTOX model was adapted to provide forcing data on the freshwater, sediments and radionuclide fluxes from the rivers to estuary model THREETOX. The THREETOX model input-output files were adapted to couple with the Kara Sea model of NIERSC;
- A concept of the Generic Model System (GMS) has been developed and implemented including formulation, testing and use of all format specifications for data exchange between nested models;
- A Generic Modelling System (GMS) has been created and used to perform simulation scenarios for the 21st century including global warming of potential radioactive spreading from sources in the Russian Arctic coastal zone using RADARC GMS.
- Model simulation studies of dispersion and transport of radionuclides (^{90}Sr and ^{137}Cs) from historical real sources and potential future accidental releases along the Russian rivers Ob′ and Yenisey, from the UK Sellafield

reprocessing plant and atmospheric fallout has been carried out with synoptic forcing and under a 2*CO_2 forcing scenarios.

- A radiological risk assessment has been carried out to evaluate the potential impact on man from hypothetical accidental releases of radioactive material from waste-disposal sites on the Russian rivers Ob’ and Yenisey and transported downstream to the Kara Sea in the Arctic Ocean. Furthermore, the potential impact of global warming (2*CO_2-scenario) on the radiological consequences has been evaluated.

Thus new tools for the assessment of the potential radioactive spreading in the Arctic has been created within the RADARC project.

The conclusion for a potential accidental discharge of ^{90}Sr through the Yenisey river follows that of the Ob discharge: The transport is quickest in the 2*CO_2 warming scenario run, and the transport into the Arctic Ocean is strongest in the 2*CO_2 warming scenario run.

For both the Ob and Yenisey releases, the peak value of surface ^{90}Sr concentration moves out of the Kara Sea in the 2*CO_2 warming scenario run, instead of being blocked in the Kara Sea under the present-day forcing. Consequently, the vulnerable regions for a potential accidental release of ^{90}Sr in the Ob and Yenisey rivers in a future climate are along the eastern coast of Greenland and the coast of the Siberia.

The reason for the obtained differences in the spatial distribution of the Ob and Yenisey releases of ^{90}Sr is the fact that the surface circulation is more energetic under the global warming scenario, leading to an intensified North Atlantic Drift, a stronger East Greenland Current, and to a shift in the circulation pattern in the Arctic Ocean. In fact, the difference between the present-day and the global warming simulations exceeds the difference between years with high and low North Atlantic Oscillation (NAO) forcing at the present-day climate.

The long-term concentration and surface circulation characteristics indicate that more of the released ^{90}Sr is confined to the Nordic Seas/Arctic Ocean in the global warming run, and that the distribution is different in the Arctic Ocean with a change in the location of the ^{90}Sr-enriched waters from the Kara Sea region at the present-day forcing to the coastal, non-European sector in the global warming run. It should be stressed that although large local differences in the spatial distribution of the tracers, the displayed concentration levels are very low.

Across all scenarios and locations the overall seasonal variation of doses is about 10% with doses higher in the high-flow season of the year, and the overall variation between years is about 20% with doses during 2084-2089 lower than in 1967. The impact from global warming on the radiological risks is thus estimated to be relatively minor and to have the effect of reducing the risks about 20% due to increased precipitation and reduced concentrations of radionuclides in the rivers.

The radiological risks from the estimated doses do not give rise to great concern, not even to the critical groups located near the points of discharge. The highest annual doses are predicted at 10-11 mSv at the Brodokalmak site with annual doses at all other sites below 1 mSv. The doses may be considered in the perspective of the Basic Safety Standards of the European Council (EC, 1996), which state that the annual dose limits for members of the public are 1 mSv, and that annual doses of 10 µSv and lower are below regulatory concern. These values may serve as reference points considering that they apply to on-going activities. Dose limits do not apply in case of accidents.

The research results of the RADARC project have been presented at several scientific conferences in St. Petersburg, Monaco, Hamburg and Archangelsk (Russia) and accepted in two referee publications. The book "*POLAR SEAS OCEANOGRAPHY: Simulation of a Radioactive Spreading in the Arctic*" by Ola M. Johannessen, Vladimir A. Volkov, Lasse H. Pettersson, Helge Drange, Yongqi Gao, Vladimir S. Maderich, Ivan A. Neelov, Sven P. Nielsen, Leonid P. Bobylev, Andrey V. Stepanov and Mark Zheleznyak is under preparation for publication by PRAXIS – Springer Publishing House in fall 2004.

Dr. Yongqi Gao defended his Ph.D. at the University of Bergen and Nansen Environmental and Remote Sensing Center in February 2003. Mr. V. Koshebutsky at IMMSP, Kiev and Mr. K.L. Bobylev and V. Plekov both at Khlopin Radium Institute, St. Petersburg will finish their Ph.D. thesis's partly under this project, both due for defence in 2004.

4 Consolidated Scientific Report

This section assesses each project WP according to the Description of Work (DoW) providing an assessment of compliancy of the work performed within RADARC project.

4.1 Objectives

According to the Description of Work the project the objectives were:

4.1.1 General objective of the research

The objective of RADARC's 2-years research programme is to perform simulation scenarios for the 21st century, including global warming scenarios, of potential radioactive spreading from sources in the Russian Arctic coastal zone and its impact on Barents, Greenland and Norwegian Seas and the Arctic Ocean in order to support decision making for:

- Risk prevention;
- Forecasting and preparedness for probable crisis;
- Alert and detection;
- Relief and mitigation;
- Damage assessment.

4.1.2 Specific scientific and technological objectives

The following specific objectives were scheduled and have been achieved within the implementation of the RADARC project.

1. To update the environmental (atmosphere-ice-ocean-rivers) and radioactive data base of the Arctic Monitoring and Assessment Program (AMAP) with new data sets available from the partners and their associates.
2. To assess, select and define the most probable release scenarios for radionuclides from relevant sources within the water shed of the river systems, sources along the coast and at the sea floor of the Kara and Barents Seas affecting the Arctic Ocean and the Barents, Greenland and Norwegian Seas, based on the AMAP and updated data base.
3. To implement a Generic Model System (GMS) with a validated medium resolution (50 km) 3 D numerical ice-ocean model for the Arctic and North Atlantic ocean nested with a validated high resolution (5 km) model for the Kara Sea including a sediment module nested with a validated river transport model to be used for simulation studies.
4. To carry out simulation studies for the selected "release" scenarios of radionuclides, using the following atmospheric forcing scenarios, including global warming, likely consistent with a CO_2 doubling and as result to assess the impact on potential radioactive spreading from sources located within the Russian Arctic coastal zone and rivers based on the simulation results, including global warming impact, as input to a risk management system.

4.2 The RADARC Scientific Activities and Achievements

During the two years and three months project period the project implementation of the work has developed in accordance with the Description of Work in general. The main content of the work included:

4.2.1 WP 1-3: Development of an environmental information base for modelling

Under WP 1-3 the extensive complex environmental data sets were developed using GIS technologies. The data-base includes atmosphere-ice-ocean and radiation pollution data yet not included in the AMAP database.

In particular, a dedicated Database of historical environmental (atmosphere-ice-ocean) *in situ* and remote sensing data for Russian Arctic coastal zone and other regions relevant for Project purposes (such as regions of chosen radioactivity sources, river systems etc.) was created. The data-base used for:

- Validation of the 3D numerical ice-ocean circulation models for the Arctic Seas and Arctic Ocean (WP5, WP6);
- Simulations of radionuclides transport through river systems from external sources to the Kara sea (WP7) and within the Arctic Ocean using GMS (WP9);
- Analysis and selection of the most probable scenarios of accidental hazardous radionuclides release (WP4);
- The Arctic radioactive risk management (WP10).

This database contains radionuclide data that previously were not present in the AMAP database and which are now included. These data were obtained from the partners and their associates from an existing open databases and new sources.

The participants of this work were NIERSC (responsible partner), NERSC, KRI and IMMSP.

The specific environmental and radionuclear data sets obtained within RADARC includes:

Oceanography data***:*** New NIERSC's regular digital Kara Sea bottom relief model (bathymetry) that was supplemented on the base of new collection of the bottom topography maps made by Russian hydrographical service, the climatic fields of oceanographic parameters, ice cover parameters, as well as data from quasi-synchronous observations outlining typical distribution of oceanographic parameters and water and ice circulation for the Kara Sea and Arctic Basin etc.;

Hydrological data***:*** An up to date Regular Digital Bottom Relief Model for Ob and Yenisey estuaries; a long time series of the river discharge parameters for the Ob and Yenisey watershed area as well temperature, salinity and level data for 19 points for the up to 50-60 years period have been created;

Ice cover distribution data: The Kara Sea ice distribution data for 1977-80 in the SIGRID format containing the information on the main ice cover parameters including stages of melting, snow concentration, cracks/fractures/polynyas/ hummock/ridge characteristics etc.;

Meteorological data*:* The NCAR reanalysis meteorological data for Arctic region including wind velocity, air temperature, cloudiness, humidity, and precipitation;

charts of atmospheric pressure and other meteorological parameters have been performed for the Kara Sea region and others;

Remote sensing data: Various types of remote sensing data - in the visible, infrared and microwave, with focus on SAR data - was used for the qualitative analysis of the numerical calculation results only;

Environmental data for radioactive sources: Geological, hydrological, meteorological, ecological and other parameters from archives of partners.

All data were organized as a Geographic Information System (GIS). The overall functionality of the GIS and corresponding database is to provide the input information for modelling initiation and validation. The potential source locations of radioactive contamination of the environment was originally in the DoW defined by three large-scale enterprises of the Russian Nuclear Complex: Production Association (PA) “Mayak”, Siberian Chemical Combine (SCC “Tomsk-7”) and Krasnoyarsk Mining and Chemical Combine (MCC “Krasnoyarsk-26”). The choice of sources of radioactivity for study was made by assessment of the following parameters:

- Type of industrial activity and its components in the past, present and future;
- Amount and isotopic composition of radionuclides accumulated at the sources;
- Accidental events that took place in the past and potential accidents in the future;
- Presence of technogenic and natural barriers on the Ob’ and Yenisey rivers hindering the release of radionuclides into environment;
- Geographical location of the facilities.

The RADARC Geographical Information System (GIS) is a customized application based both on ArcView GIS 3.x and MapInfo Professional 6.0 software for use on PC running Microsoft Windows. The GIS performs the collection, storage, generalization, analysis and preparation of spatial data for using in numerical modelling.

Several sources of the base cartographic data were used for generation of the GIS base maps. In particular, the sources for use with ArcView GIS are:

- The Digital Chart of the World (DCW, ESRI Inc.)- a comprehensive 1:1,000,000-scale vector base map of the world;
- ESRI Data and Maps. The basic mapping datasets of different scales delivered by ESRI with ArcView 3.2. Software;
- World Topography and Bathymetry (MrSID Image by ESRI) that represents a colour hill shaded Digital Elevation Model (DEM)-based image of the region under consideration;

The specific map sets compatible with MapInfo GIS Software have been chosen for more detailed representation of related information. The source of these cartographic data for use with is:

- Commercial digital maps of 1:200,000 scales from map bank of Nuclear Safety Institute, Russian Academy of Sciences, Moscow, Russia (IBRAE RAS). These map sets have been delivered under the treaty to the V. G. Khlopin Radium Institute, Ministry of Atomic Energy, St. Petersburg, Russia (KRI MINATOM).

These charts are used for more detailed representation of data and including the following major features: relief features, hydrography, inhabited locality, industrial objects (pipelines and power lines), main roads, railway lines network, landscape constituents, aerodromes, administrative boundaries (frontiers) and captioning data.

The data on results of numerical modelling and model validation obtained during implementation of the final part of the Project are also integrated into the Project Database. All environmental and radioactivity data have been distributed among partners of the project and for inclusion in the AMAP database.

4.2.2 WP 4: Definition the most probable release scenarios for radionuclides

WP4 is a key element of the RADARC project. The objectives of WP4 were to specify and substantiate the most probable scenarios of accidental release of radionuclides influencing the Arctic environment and their transport from external sources to the Arctic Sea in order to chose and evaluate various realistic scenarios for numerical modelling of hypothetical situations on the selected Russian industrial plants resulting in significant radioactivity release into the environment.

During the implementation of the RADARC project additional source locations such as the UK reprocessing plant in Sellafield (Irish Sea) and the sunken submarines Kursk and K-159 (post project completion) in the Barents Sea were included and defined.

KRI coordinated the WP4 activities of all partners (RISOE, AMAP, NRPA). The studies under this work package aimed to develop scenarios for accidental release of radionuclides from sources within the watershed of the river systems, along the coast and at the sea floor of the Kara and Barents Seas, and scenarios of dangerous environmental events affecting radionuclides release and transport. The scenarios were based on assessments of the character of industrial plants functioning under normal operating conditions in the past and present, potential changes of industrial activity due to conversion, and potential accidental conditions caused by natural and technogenic factors. Results of WP1, WP2 and WP3 provided necessary input data for this work package. Institute of Radiation Hygiene (IRH), under subcontract with KRI, also participated in the scenarios selection of radioactive release. We consider two scenarios of hypothetical accidental radionuclide release into the environment from two Russian radiochemical Combine: Krasnoyarsk Mining and Chemical Combine (MCC) and Tomsk Siberian Chemical Combine (SCC).

Hypothetical radionuclide release from the Mayak PA

In the Mayak PA accident scenario the flux of ^{90}Sr from the Ob' River to the Ob' Bay of the Kara Sea has been simulated. Scenario with the breakdown of the Reservoir-11 dam was used. This scenario assumes a sudden and uncontrollable break of the dam of reservoir-11 in a result, for example, strong flood, disastrous earthquake, falling on the dam of the aircraft etc. Description of the reservoir-11: volume is 200E+06 (m^3), ^{90}Sr content in water in 1997 is 8000 (Ci), ^{90}Sr content in water in 2084 - 1072 (Ci). Date of the accident: 5 April 2084. Simulations were implemented for the period of January 1 2084 –December 31 2086.

Hypothetical radionuclide release from the SCC - Tomsk

Due to the lack of necessary data for implementation of the given task, the assumption of hypothetical volley release (a worst case scenario) was accepted with the total radioactivity amount of 37 TBq (1000 Ci) of ^{137}Cs and 37 TBq (1000 Ci) of ^{90}Sr. This magnitude of release is similar to the release postulated by engineers at the Mining and Chemical Combine (MCC) for evaluation of consequences to the Yenisey River, although it is significantly smaller than the total inventory of the surface basins (ponds) at the SCC.

However, there are significant uncertainties regarding these ponds. The use of a unit release thus allows both the potential for scaling the release and a determination of the magnitude of release to the river system that is required for significant contamination of the river. These unit releases can be scaled to actual values, should such values be obtained in the future.

Similar to the analysis of the MCC, 50% of the radionuclides were assumed to be associated with silt sediments and 50% with clay sediments.

Discharges around 4000 m^3/sec provide the most significant redistribution of contamination downstream from the release point within the reach of interest. At this rate of discharge, approximately 70% of the silt is expected to retaine in the reach.

The highest levels of contamination are expected to occur at the lowest discharges and at locations nearest the discharge point. Contamination densities of over 400 Bq/g may be possible.

The highest doses resulting from a large and sudden release of radioactivity from the site into the river occur when the discharges are lowest, which is typically during the winter months. However, significant redistribution of contaminants would likely occur during such a high discharge conditions resulting from the spring snowmelt, when the trap efficiency of the reach for both silt and clay is low.

Because spring flooding would result in a significant redistribution of radionuclides released to the Tom′, a relatively fast response may be necessary to remediate or contain a release prior to this flooding. This potential need for a relatively quick response support the need for development of contingency plans prior to such a possible release events.

Hypothetical radionuclide release from the MCC - Krasnoyarsk

According to the above mentioned scenarios hypothetical failures at the MCC and SCC may result in release into Yenisey and Tom’ rivers of about 37 TBq of radioactivity. Based on radionuclides structure in releases and on the data the corresponding distribution coefficient of these radionuclides between a water phase and bottom sediments (flood-lands soils in case of the Yenisey River) these sediment formation can accumulate up to 90 % of released radioactivity, i.e. about 33 TBq for each river.

As one of potential sources of volley radioactive contamination of the Yenisey River we have considered the special open water storage reservoir (basin 365) in which the liquid radioactive waste products formed at MCC at various technological operations are accumulated. In these reservoirs the retention of effluent for decay of short-lived radionuclides and precipitations of radioactive suspensions is carried out. Basin 365 is an open water storage reservoir located on the first super-floodplain terrace of the Yenisey River, approximately 100 m from the right bank of the Yenisey River (approximately 0.5 km upstream from Atamanovo on the first super floodplain terrace) and 50 m above river level. It is designated for reception and interim storage of reactor emergency waters and off-grade non-process wastewaters from the radiochemical plant before they are sent to cleaning facilities. An anti-filtration shield of clay provides isolation from groundwater, two asphalt layers on the bottom and slopes, and bottom and bank drainage systems for interception and leak detection in case of damage to the liners.

In the RADARC project a methodology for reconstruction of the radionuclide supply to flood-plain soils and bottom sediments of the estuary of the Yenisey River and bottom sediments of the Kara Sea was developed. In the case of flood-plain soils and bottom sediments of the Yenisey River the method is based on the combination of data on the radionuclide vertical distribution in these deposits on the one hand and absolute age of the corresponding horizons and deposit formation rate, obtained from the ^{154}Eu/^{152}Eu activity ratios, on the other hand. In the case of bottom sediments of the Yenisey Bay and Kara Sea the data on the radionuclide vertical distribution are treated along with the chronology data obtained by the ^{210}Pb method. The methodology proposed allows assignment of the peaks in the radionuclide vertical profiles to certain periods of MCC operation. It is important also that the method provides a possibility to evaluate the integral inventory of radionuclides in the flood-plain soils and bottom sediments of the investigated system, which is necessary, in particular, for determination of the geochemical balance with respect to radionuclides in the system MCC → Yenisey River → Kara Sea. Initial data, which can be used for modelling of dissipation of radionuclide release from basin 365 into the Yenisey River, are the following:

- Suspension sedimentation rate [(1.7-2.6) x 10^{-3} cm/s] and sediment formation rate
  (1 cm/yr. on the average);
- Radionuclide distribution coefficients [(2-8) x 10^4 and (1-4) x 10^6 g/l for ^{137}Cs and ^{239,240}Pu, respectively];
- Radionuclide diffusion coefficients (1 x 10^{-8} cm^2/yr. for ^{137}Cs)
- Radionuclide migration forms. Suspended forms: ^{239,240}Pu, ^{241}Am, ^{152,154}Eu (> 90%), ^{137}Cs (> 80%). Soluble forms: ^{90}Sr (> 80%).
- Factor of radionuclide run-off from the catchments area [(0.01-0.03) % per yr].
- The rate of transfer of fixed forms of radionuclides due to regular sediment erosion/sedimentation is estimated to a distance up to 1500 km downstream from MCC to be 20-50 km/yr.

4.2.3 WP 5: 3-D numerical ice-ocean model for the Arctic and North Atlantic Ocean

The open ocean model system applied in this study is the OGCM MICOM, fully coupled ocean model to a sea-ice module consisting of the rheology in the implementation of, and the thermodynamics of Drange (1996). The model is set up in a Global mode coupled to and interacting with an atmospheric model in the Bergen Climate Model (BCM; Furevik et al. 2003), and for the RADARC applications simulations are performed for the North Atlantic and Arctic Oceans.

The model has 23 vertical layers with fixed potential densities, and an uppermost mixed layer (ML) with temporal and spatial varying density. The specified potential densities of the sub-surface layers were chosen to ensure a realistic representation of the major water masses in the North Atlantic-Nordic Sea region. The densities of the isopycnic layers (in sigma-0 units) are 24.12, 24.70, 25.28, 25.77, 26.18, 26.52, 26.80, 27.03, 27.22, 27.38, 27.52, 27.63, 27.71, 27.77, 27.82, 27.86, 27.90, 27.94, 27.98, 28.01, 28.04, 28.07 and 28.10. In the horizontal, the model is configured with a local orthogonal grid mesh with one pole over North America and one pole over western part of Asia, yielding a grid spacing of about 90-120 km in the North Atlantic-Nordic Seas region.

The vertically homogeneous mixed layer (ML) utilizes the bulk parameterization for the dissipation of turbulent kinetic energy, and has temperature, salinity and layer thickness as the prognostic variables. In the isopycnic layers below the ML, temperature and layer thickness are the prognostic variables, whereas salinity is diagnostically determined by means of the simplified equation of state. The bathymetry is computed as the arithmetic-mean value based on the ETOPO-5 data-base (Data Announcement 88-MGG-02, Digital relief of the Surface of the Earth, NOAA, National Geophysical Data Center, Boulder, Colorado, 1988).

The continuity, momentum and tracer equations are discredited on an Arakawa C-grid stencil. The diffusive velocities (diffusivities divided by the size of the grid cell) for layer interface diffusion, momentum dissipation, and tracer dispersion are used. A flux corrected transport scheme is used to advect the model layer thickness and the tracer quantities.

The diapycnal mixing coefficient is parameterized and the numerical implementation of the diapycnal mixing follows the scheme of McDougall and Dewar (1998).

The model was initialized by the Levitus climatological temperature and salinity fields for January, respectively, a 2~m thick sea-ice cover based on climatological sea-ice extent, and an ocean at rest. The model was first spun-up for 180 years with monthly-mean atmospheric forcing fields derived from the NCEP/NCAR reanalysis. In this spin-up, both sea surface salinity (SSS) and sea surface temperature (SST) was relaxed towards monthly mean surface climatology. The relaxation was carried out by applying fluxes of heat and salt proportional to the SSS and SST differences between model and climatology, respectively, with an *e*-folding time scale of 30 days for a ML of 50 m or less, decreasing linearly with thicker ML depths. The spin-up was then continued with daily NCEP/NCAR forcing, repeating the period 1974-1978 twice. Only salinity relaxation was applied in these two integrations, and the deduced salinity adjustment flux was stored from the latter integration to produce seasonal averaged restoring fluxes for salt. The period 1974-1978 was chosen because of the relatively neutral North Atlantic Oscillation (NAO) conditions of these years. Finally, the model was integrated with daily forcing for the period 1948-1999 with no relaxation but with the diagnosed restoring fluxes for salt.

4.2.4 WP 6: Kara Sea model

The modified 3D model of the water circulation in the Kara Sea and the transport of pollutants is based on the on the equations of movements of viscous and incompressible liquid in spherical co-ordinates in the approximations of Boussinesq and hydrostatics. The model is designed to include various types of information concerning the meteorological, oceanographic and hydrological processes that govern water circulation and transport in the Kara Sea, during both winter (ice cover) and summer conditions. The model consists of the main circulation module and additional modules: wind-wave interaction module and sediment module. A module for the ice evolution assessment on the base of a Hibler's viscous–plastic thermohydrodynamic model was improved.

The previous version of the model (with spatial resolution 5.5 km by longitude and 4.5 km by latitude) was successfully validated and used within the earlier INTAS

Kara Sea Project (INTAS 93-814) for simulation of radionuclides transport in the Kara Sea from river and bottom- and coast-based sources of radioactivity for period of up to 400 days. Environmental data set used for model parameterisation, run and validation covering the period from 1977 to 1980.

The model was adapted for long-term simulations with constantly updating external meteorological and other forcing parameters. Files of direct access for the period 1948-2000 for the Kara Sea region was set up on the base of the NCEP/NCAR global meteorological data sets (coming forcing data as for the North Atlantic and Arctic Oceans model).

A simulation of the Kara Sea circulation with the space resolution 20 minutes by longitude and 10 minutes by latitude for 1948-2000 was carried out. The time step was 45 minutes. The conditions on the fluid boundary were taken from the MICOM large-scale model of Arctic Ocean. The climatic fields of temperature, salinity, currents and thickness of the ice cover were obtained.

The model was prepared and used for the use of boundary data from nested river model and to provide input data to the Arctic/North Atlantic large-scale model (WP5).

4.2.5 WP 7: River modelling

The river model chain includes a one-dimensional model of river dynamics and radionuclide transport and a three-dimensional model of estuarine and coastal areas hydrodynamics and radionuclide transport.

The model validation and calibration studies were carried out on the basis of the Ob' and Yenisey river/estuarine environmental and radionuclide pollution data made available from WP1 and WP2. The integrated model system river-estuary development consisted of three stages:

(a) The 1-D model RIVTOX of river dynamics and radionuclide transport was adapted to the Ob' river path from the Mayak Plant and to the Yenisey River from Zheleznogorsk plant. For modelling purposes the river network was divided into a set of branches in compliance with the location of observation points and the main tributaries. For numerical simulations the monthly river discharge values and parameters of water cross-sections for observation points were used.

(b) The 3-D model THREETOX was adapted to the estuaries of the Ob' and Yenisey rivers using digitised maps of estuaries bottom, and meteorological forcing. In the rivers mouths the end points of the calculations by RIVTOX were river discharge, sediment concentration and radionuclide concentration in the solute, suspended sediments. In the estuary mouth the temperature and salinity distributions and level were computed by the Kara Sea model and used as outer boundary conditions.

(c) The model chain was validated against the available data on river discharge, level, suspended sediment concentration and radionuclide concentration in the Ob' and Yenisey rivers. The 1D model RIVTOX was validated using Mayak contamination data in the Techa River for 1949-1956 and Krasnoyarsk-27 in 1992. The model calculations are compared with ^{90}Sr field measurements at two sites along the Techa River. The measured concentrations of ^{90}Sr, ^{137}Cs and ^{60}Co compared quite well with the calculated concentrations. The 3D model was validated against available data of field oceanographic surveys in the estuaries.

4.2.6 WP 8-9: A Generic Model System

The Generic Modelling System (GMS) was created and used to perform simulation scenarios for the 21st century including global warming of potential radioactive spreading from sources in the Russian Arctic coastal zone using GMS. The task includes development of an GMS including the four hydrodynamic models and comprehensive Geographical Information System (GIS) as well as carrying-out simulation studies for the defined potential "release" scenarios of radionuclides, using the defined atmospheric forcing scenarios (climate change scenarios), including global warming, likely consistent with a CO_2 doubling. Thus a new tool for an assessment of the potential radioactive spreading in the Arctic has been created within the RADARC project implementation.

NERSC coordinated an activity of all partners under WP8 and WP9 (NIERSC, NRPA, IMMSP, KRI). Data streams between RADARC-GIS and all models were developed and implemented.

To ensure stable operation of the GMS for long simulation periods and with frequent update of external environmental data as forcing and boundary conditions the integration of river, estuary and Kara Sea models was done.

The 1D model RIVTOX was adapted to provide forcing data on the freshwater, sediments and radionuclide fluxes from the rivers to the estuary model THREETOX. The THREETOX model input-output files were adapted to couple with the Kara Sea model of NIERSC. In the rivers mouths the river discharge, sediment concentration and radionuclide concentration in the solute, suspended sediments calculated by RIVTOX provide input for THREETOX. In the estuary mouth the temperature and salinity distributions and level computed by Kara Sea model were used in the THREETOX model as outer boundary conditions.

The model chain was validated against the data available on river discharge, level, suspended sediment concentration and radionuclide concentration in the Ob' and Yenisey rivers. The 1D model RIVTOX was validated using Mayak contamination data in the Techa River in 1949-1993, and KMCC in 1975-1994. The calculations are compared with ^{90}Sr measurements at two sites along the Techa River and in the Ob' River (Salekhard). The measured concentrations of ^{90}Sr, ^{137}Cs and ^{60}Co calculations were compared with the calculations in the Yenisey River. The 3D model was validated against available data of field oceanographic surveys in the estuaries in 1993-1995.

To improve computational efficiency of GMS the possibility of two options were studied: direct use of radionuclide flux calculated by river model in the computation of the radionuclide transport (a) by Kara Sea model and (b) large-scale model. A comparative study, that was done with the river-estuary system, showed for both Ob' and Yenisey rivers that the discrepancies in the ^{137}Cs and ^{90}Sr concentrations in solute computed by both models are small. A difference around 10% in the concentration of ^{137}Cs in suspended sediments was found in the Yenisey estuary. Therefore, for most of the simulations direct input was used from the river model in the estuary mouth .

Kara Sea model simulations were carried out using data directly from the river models and boundary conditions from the NERSC Arctic Ocean model. As a result numeric calculations for radionuclides (^{90}Sr and ^{137}Cs) distributions for the Kara Sea were carried out:

- Two experiments - to reconstruct the situation for radionuclide pollution of Ob and Yenisey. Rivers discharge and add mixtures concentrations in rivers mouths, used as boundary conditions for the Kara Sea model, were obtained from river simulation model for pollutant transportation by the river flow. Add mixtures transfer was calculated as a full hydrodynamic model using atmosphere fields (data) NCEP/NCAR and boundary conditions on liquid (open) boundary from solution of the NERSC large-scale model. Transfer calculations for radionuclides discharges by Ob and Yenisey were made for two time periods: 1949-1993 and 1958 –1994.

- Five different situations (scenarios) with radionuclide pollutions to the rivers were simulated to preview (forecast) their distribution. Radionuclide distributions for the Kara Sea water area and their variations (evolution) in time were calculated. Boundary conditions for rivers discharge and radionuclide concentrations used in calculations were obtained from river models for pollutant transportation.

Two major simulation setups were performed using the global MICOM model covering the North Atlantic and Arctic Oceans. Historical simulations using realistic data on radioactive contamination of the marine environment including the historical discharges due to atmospheric fall out, known discharges through Ob´ and Yenisey and additional to the original project plan the discharges from the UK re-processing plant in Sellafield.

Simulations of historical releases

The spatial and temporal distributions of the anthropogenic radionuclides ^{137}Cs and ^{90}Sr, originating from nuclear bomb testing, atmospheric fallout due to Chernobyl and the Sellafield reprocessing plants in the Irish Sea, are simulated using a global version of the Miami Isopycnic Coordinate Ocean Model (MICOM). The physical model is forced with daily atmospheric re-analyzed fields for the period 1950 to present. Comparison of temporal evolution of observed and simulated concentrations of ^{137}Cs have been conducted for the regions east of Scotland, west of central Norway and at the entrance of the Barents Sea. It follows that the radionuclides from the Sellafield discharge reach the Barents Sea region after 4–5 years, in accordance with observations. The simulation provides a detailed distribution and evolution of the radionuclides over the integration time.

Kershaw and Baxter (1995) summarize the pathways of the soluble radionuclides ^{137}Cs and ^{90}Sr from Sellafield to the Arctic Ocean. Initially the tracer is carried northward from the Irish Sea as a plume-like structure via the North Channel, and it then flows along the coast of Scotland into the North Sea. The tracer is transported northward before branching off northern Norway: One branch passes eastwards into the Barents Sea; the other passes through the Fram Strait with the West Spitzbergen Current. The main surface water return flow occurs with the East Greenland Current. In case the tracer is mixed into sub-surface waters, the return flow will also include the Denmark Strait overflow, the overflow across the Iceland-Faroe Ridge and the Faroe-Bank Channel overflow (Hansen and Østerhus, 2000).

For the Atlantic waters off the coast of Norway and in the southern Barents Sea, the atmospheric fallout dominates over the Sellafield release up to the mid 1960s and from the early 1990s, whereas Sellafield is the main source for the two radionuclides in the 1970s and 1980s.

To qualitatively and quantitatively evaluate the simulated transport and mixing of the Sellafield discharge, time series of the observed and simulated surface ^{137}Cs concentration east of Scotland (57.0–57.5°N, 1.5–2.0°W), west of Norway (59–61°N, 3.5–5.0°E) and in the south-western Barents Sea region (71–72°N, 20–30°E) have been analyzed. The temporal and spatial evolution of the surface ^{137}Cs concentration is in broad agreement with observations. However, the simulated surface ^{137}Cs concentrations are generally lower than the observed values. For instance, the maximum concentration in the Barents Sea is about 75% of the observed value. This finding, at least up to the Chernobyl accident in 1986, may indicate that the applied model resolution is too coarse.

This validated model systems will be used for future prediction of radioactive contaminations in the Nordic Seas and the Arctic Ocean, for instance under various global warming scenarios.

Simulations of future potential contamination under climate change scenarios

Accidental releases of ^{90}Sr through the Ob River were defined in WP4. For both the present-day and the 2*CO_2 global warming scenario runs, ^{90}Sr spreads eastwards following the coast of Siberia and thereafter north- and westwards heading towards the Fram Strait. At the Fram Strait, a branch of ^{90}Sr-enriched water flows southward along the coast of Greenland, whereas another branch enters the Arctic Ocean north of Greenland and the Canadian Archipelago.

The difference between the present-day and the 2*CO_2 global warming scenario runs are in general that the transport is accelerated in the warming scenario run. Whereas the difference between the two integrations is small in the Nordic Seas, substantial differences are evident in the Arctic Ocean. In the 2*CO_2 warming scenario run, ^{90}Sr-enriched water enters the basin along the coasts of Siberia and Greenland/the Canadian Archipelago. This finding indicates that the high latitude circulation pattern is quite different between the two forcing situations.

The conclusion for a potential accidental discharge of ^{90}Sr through the Yenisey river follows that of the Ob discharge: The transport is quickest in the 2*CO_2 warming scenario run, and the transport into the Arctic Ocean is strongest in the 2*CO_2 warming scenario run.

For both the Ob and Yenisey releases, the peak value of surface ^{90}Sr concentration moves out of the Kara Sea in the 2*CO_2 warming scenario run, instead of being blocked in the Kara Sea under the present-day forcing. Consequently, the vulnerable regions for a potential accidental release of ^{90}Sr in the Ob and Yenisey rivers in a future climate are along the eastern coast of Greenland and the coast of the Siberia.

The reason for the obtained differences in the spatial distribution of the Ob and Yenisey releases of ^{90}Sr is the fact that the surface circulation is more energetic under the global warming scenario, leading to an intensified North Atlantic Drift, a stronger East Greenland Current, and to a shift in the circulation pattern in the Arctic Ocean. In fact, the difference between the present-day and the global warming simulations exceeds the difference between years with high and low North Atlantic Oscillation (NAO) forcing at the present-day climate.

The long-term concentration and surface circulation characteristics indicate that more of the released ^{90}Sr is confined to the Nordic Seas/Arctic Ocean in the global warming run, and that the distribution is different in the Arctic Ocean with a change in the location of the ^{90}Sr-enriched waters from the Kara Sea region at the present-day forcing to the coastal, non-European sector in the global warming run. It should be stressed that although large local differences in the spatial distribution of the tracers, the displayed concentration levels are very low.

4.2.7 WP 10: Assessment – input to risk management

The purpose of the assessment is 1) to evaluate the radiological impact on man from potential accidental releases of large amounts of radioactive material located at sites on the Russian rivers Ob' and Yenisey and transported to the Arctic Ocean and 2) to estimate the impact of global warming on the radiological consequences. The assessment is focusing on maximum annual radiation doses received by individuals affected by hypothetical releases of radioactivity from the nuclear-waste sites.

The methodology used for assessing radiation doses to individuals is based on predicted concentrations of radionuclides (^{90}Sr and/or ^{137}Cs) in water and sediments, transfer of radionuclides through food chains and human habits. The assessment has focused on annual average individual doses to adults, with focus on the most exposed - critical groups, and the dose models are therefore based on assumptions and parameter values that provide annual average doses across season. Thus annual average concentrations in water and sediment have been used as input for the dose assessment. The models used for predicting the environmental transfer and dispersion are capable of providing data with a much higher time resolution, but this has not been considered of relevance for the dose assessment. The dose calculations were based on both low-flow (fall) and high-flow (melting) conditions in the rivers and locations near the potential release sources, in the mouth river and in the estuary.

The accident scenarios at the Mayak PA are predicted to give rise to radiation doses of 10-11 mSv at Brodokalmak, 4-8 μSv at the Ob' River delta, and 4-6 μSv at the Ob' estuary. The most important exposure pathway at Brodokalmak is ingestion of ^{90}Sr in freshwater fish. The most important pathways at the Ob' delta and estuary are ingestion of ^{90}Sr in fish, grain products and green vegetables. Variations of the doses due to time of season of the accident are small, in the range of 2-7% with doses higher in April than in November. The variation of doses between years is significant for the Ob delta only, with doses in 2084 some 30% lower than in 1967.

The accident scenarios at the Tomsk SCC are predicted to cause radiation doses in the range 0.09-0.13 mSv at Tomsk-7, of 9-38 μSv at the Ob' delta and of 3-4 μSv at the Ob' estuary. Caesium-137 is the dominating radionuclide at the Tomsk-7 location. At the Ob' delta ^{137}Cs is the dominating radionuclide in most cases, and at the Ob' estuary ^{90}Sr is dominating. Ingestion of fish is the dominating exposure pathway for all locations and accident scenarios. The variations of the doses due to time of season of the accident are zero for the Tomsk-7 site, 29% for the Ob' delta and 10% for the Ob' estuary with doses higher in June than in January. The variation of doses between years is 33% for Tomsk, 45% for the Ob delta and insignificant for the Ob estuary with doses lower in 2084 than in 1967.

The accident scenarios at the Krasnoyarsk MCC are predicted to cause radiation doses in the range 0.4-0.7 mSv at Krasnoyarsk-26, of 6-13 μSv at the Yenisey delta and of 3-9 μSv at the Yenisey estuary. Caesium-137 is the dominating radionuclide at the Krasnoyarsk-26 location where external exposure is the dominating exposure pathway. At the Yenisey delta and estuary locations the results show that ^{90}Sr dominates for the scenarios in 1967 while ^{137}Cs dominates in 2089; ingestion of fish is the dominating exposure pathway. The variations of the doses due to time of season of the accident are zero for the Krasnoyarsk-26 site, 12% for the Yenisey delta and 8% for the Yenisey estuary with doses higher in June than in January. The variation of doses between years is 40% at Krasnoyarsk-26, nil at the Yenisey delta and 40% at the Yenisey estuary with doses lower in 2089 than in 1967.

Across all scenarios and locations the overall seasonal variation of doses is about 10% with doses higher in the high-flow season of the year, and the overall variation between years is about 20% with doses during 2084-2089 lower than in 1967. The impact from global warming on the radiological risks is thus estimated to be relatively minor and to have the effect of reducing the risks about 20% due to increased precipitation and reduced concentrations of radionuclides in the rivers.

The radiological risks from the estimated doses do not give rise to great concern, not even to the critical groups located near the points of discharge. The highest annual doses are predicted at 10-11 mSv at the Brodokalmak site with annual doses at all other sites below 1 mSv. The doses may be considered in the perspective of the Basic Safety Standards of the European Council (EC, 1996), which state that the annual dose limits for members of the public are 1 mSv, and that annual doses of 10 µSv and lower are below regulatory concern. These values may serve as reference points considering that they apply to on-going activities. Dose limits do not apply in case of accidents.

4.3 Problems Encountered

Some delays have occurred in the time schedule for the definitions of the release scenarios (more difficult and complex task than envisaged in the DoW) and accordingly a three months extension of the project duration was applied for and granted. The final assessment and conclusions were further delayed due to late completion of the large-scale Arctic Ocean model simulations, pending on input data from rivers and regional models.

4.4 Technology Implementation Plan

The RADARC project has contributed to the further development of existing model and information tools among the partners. The different tools have also been further developed for new applications as well as developed for communication and exchange of data between the various elements of the model simulation processes in the different aquatic elements (summarized in Table 1).

This integrated approach encourages further cooperation among the various partners. The applications of the project tools and methodology are fore seen to be applicable in a both impact assessment and combat actions for future potential and real radioactive contamination accidents or regular discharges to the aquatic environment.

The models tools developed and the simulations performed have clearly applications beyond those completed in the project. Post project completion the NERSC Atlantic and Arctic Ocean MICOM model has been used for the simulations of potential spreading of a possible radioactive leakage from the Russian submarine K-159 that sunk north of Murmansk in August 2004. The results of the simulations and the relevant public press release material made by NERSC have been submitted to the EC Scientific Officer and published at the RADARC project web-site (http://www.nersc.no/Projects/RADARC).

Table 1: Overview of results.

No.	Title of exploitable result	Category[1] A, B or C	Partners of the project involved (result owners) or third parties to exploit results	Exploitation/dissemination intention	Type of IPR[2]
1	The RADARC Geographical Information System	A	NIERS, KRI, NERSC	The developed system and its data are intended for use in the assessment of the radionuclear loading (current and future) to aquatic environment. It will be offered to the appropriate agencies and used in further research and impact assessment studies by the RADARC partners.	Copyright
2	RIVTOX river and TREETOX estuary models	A	IMMSP	The model tools will be used and further developed within new related research projects and applied in impact assessment studies.	Copyright
3	The Kara Sea ocean circulation and radionuclide trace model	A	NIERSC	The model tools will be used and further developed within new related research projects and applied in impact assessment studies.	Copyright
4	Atlantic and Arctic MICOM ocean circulation and radionuclide trace model	A	NERSC	The model tools will be used and further developed within new related research projects and applied in impact assessment studies.	Copyright

The research results of the RADARC project have been presented at several scientific conferences in St. Petersburg, Monaco, Hamburg and Archangelsk (Russia) and accepted in two referee publications. In order to make public available the data collected and results achieved in the RADARC project at least four scientific publications are accepted or under preparation (see Table 2). The totality of the project will be published in a dedicated monograph "*POLAR SEAS OCEANOGRAPHY: Simulation of a Radioactive Spreading in the Arctic*" by Ola M. Johannessen, Vladimir A. Volkov, Lasse H. Pettersson, Helge Drange, Youngi Gao, Vladimir S. Maderich, Ivan A. Neelov, Sven P. Nielsen, Leonid P. Bobylev, Andrey V. Stepanov and Mark Zheleznyak under preparation for publication by PRAXIS – Springer Publishing House during late fall 2004 (post-project completion).

Table 2: Timetable for exploitation and dissemination activities.

Activity	Partners involved (including third parties)	start date	end date
Preparation of the monograph entitled "*POLAR SEAS OCEANOGRAPHY: Simulation of a Radioactive Spreading in the Arctic*"	All partners of the RADARC project: Ola M. Johannessen, Vladimir A. Volkov, Lasse H. Pettersson, Helge Drange, Youngi Gao, Vladimir S. Maderich, Ivan A. Neelov, Sven P. Nielsen, Leonid P. Bobylev, Andrey V. Stepanov and Mark Zheleznyak plus Mr. Clive Harwood of the Springer-Praxis Publishing House.	Jan. 2003	Dec. 2004
A series of papers are to be submitted to international journal	All partners of the RADRAC project	Aug. 2003	June. 2004
Delivery of seminars for decision and at scientific conferences	NERSC, NIERSC, IMMSP et al.	April 2003	June 2004

[1] see explanation on page 1 (in TiP guidlines for INCO)

[2] the following categories should be used: patent applied for, patent search carried out, patent obtained, registered design, trademark applications, copyrights, secret know-how, other (please specify)

4.5 Publications and papers

Summary of the RADARC project reports as submitted to EC during the project implementation:

WP/ D#	Deliverable Title	Institution	Authors
WP1/ D.1	Historical in situ and remote sensing environmental data sets.	NIERSC	V.A Volkov, L.P. Bobylev S. Kuzmina A. Kouraev K. Zemeszirks O. Rozanova K. Khorostovsky
WP2/ D.2	Annual report of RADARC WP2 - Arctic region radioactive contamination data set.	KRI	V.S. Plekhov K.L. Bobylev A.A. Osokina V.P. Tishkov, O.S. Tsvetkov
WP3/ D.4	GIS for Russian Arctic coastal zone and Ob and Yenisey watershed areas.	NIERSC	K. Bobylev
WP4/ D.5	Scenarios of accidental radionuclide release and their transport from external sources to the Arctic Seas – Report.	KRI	Y. V. Kuznetsov A. V. Stepanov Y. A. Panteleev
WP5/ D.6	Description of model for simulation of transport of radionuclieds in the North Atlantic and Arctic ocean.	NERSC	Y. Gao H. Drange M. Bentson O.M. Johannessen L.H. Pettersson
WP6/ D.7	Description of model for simulation of transport of radionuclides in the Kara Sea.	NIERSC	I.A. Neelov
WP7/ D.8	Description of model for simulation of transport of radionuclides from external sources via Ob and Yenisey river systems to the Kara Sea.	IMMSP	I. Brovchenko G. Donchits N. Dziuba V. Koshebutsky A. Nesterov V. Maderich M. Zeleznyak
WP8/ D.9	Description and validation of the Generic Model System for the merged models.	NIERSC/ NERSC/ IMMSP	L.H. Pettersson Y. Gao I. A. Neelov V.S. Maderich V.A. Volkov M. Zheleznyak
WP9/ D.10a	Arctic Ocean simulation results using the GSM	NERSC	Y. Gao H. Drange O.M. Johannessen L. H. Pettersson
10b	River model simulation under quasi-normal meteorological conditions.	IMMSP	N. Dziuba V. Koshebutsky V. Maderich M. Zheleznyak
10c	River model simulation for 2000-2100 period using CO_2 doubling forcing data to study the impact from global warming on radioactive spreading.	IMMSP	N. Dziuba V. Koshebutsky V. Maderich M. Zheleznyak
10d	The Kara Sea Model simulation results using the GSM.	NIERSC	I. A. Neelov V. A. Volkov
WP10/ D.11	Report on the assessment of impact of radioactive pollution from sources located in the Russian Arctic coastal zone and rivers of the Arctic ocean in the 21st century.	RISØ + all	S.P. Nilsen et al
WP0/ D.12	Final report.	NERSC	O.M. Johannessen, L.H. Pettersson et al.
2* Ann. Rep	Annual Scientific Progress Report for the RADARC Project, including institutional Annexes (1st and 2nd year)	NERSC/ NIERSC	L.H. Pettersson et al.

The status of other RADARC publications and communications:

Peer review papers:

1. Yongqi Gao, Helge Drange, Mats Bentsen and Ola M. Johannessen, 2004: Simulating transport of non-Chernobyl 137-Cs and 90-Sr in the North Atlantic-Arctic region. Journal of Environmental Radioactivity Vol. 71 2004, pp. 1-16.

Submitted papers:

2. Dziuba N.N., V. Koshebutsky, V.S Maderich, V.A Volkov, and M. Zheleznyak: Modelling of the seasonal dynamics of the water masses, ice and radionuclide transport in the large Siberian river estuaries**.** Submitted to J. Env. Radioactivity in 2003.
3. Maderich V.S., O. Nesterov, S. Zilitinkevich: The influence of different parameterisations of meteorological forcing and turbulence schemes on modelling of eutrophication processes in a 3D model of estuary. Submitted to Estuarine Coastal and Shelf Sciences in 2003.

Monograph/book:

4. Johannessen, Ola M., Vladimir A. Volkov, Lasse H. Pettersson, Helge Drange, Youngi Gao, Vladimir S. Maderich, Ivan A. Neelov, Sven P. Nielsen, Leonid P. Bobylev, Andrey V. Stepanov and Mark Zheleznyak : *POLAR SEAS OCEANOGRAPHY: Simulation of a Radioactive Spreading in the Arctic*. PRAXIS – Springer Verlag (under preparation for publication during fall 2004).

Presentations, proceedings:

5. Bobylev, K.L., V.A. Volkov, O.M. Johannessen, L.H. Pettersson, A.V. Stepanov: Geographic Information system (GIS) and its application for study, assessment and forecasting of the radioactive spreading processes in the Kara Sea from land-base sources. Proceedings of VIII St. Petersburg’s International conference: “Regional informatics – 2002”. St.Petersburg, 26-28 November 2002. Part II: Information technologies in ecology. UNESCO, 2002.
6. Bobylev K.L., Plekhov V., Kuznetsov Yu. V., Tishkov V.P., Stepanov A.V.: The influence of the land-based sources of radionuclides on radioactive contamination of the Kara Sea. 3rd Russian Conference on Radiochemistry, Radiochemistry-2000, Thesis of Reports, Saint-Petersburg, 2000.
7. Johannessen, O.M., L.H. Pettersson, Y. Gao, L.P. Boylev, V.A. Volkov, I.A. Neelov, M.J. Zheleznyak, V.S. Maderich, S.P. Nielsen, P. Strand, A.M. Borghuis, L.O. Reiersen, A.V. Stepanov, K.L. Bobylev, Y.V. Kouznetsov and V.P. Tishkov: Study of a potential radioactive spreading in the Russian Arctic coastal zone from rivers and external sources in the 21st century. International conference: “Ecology of the Northern Territories. Problems, Prognosis of the Situations, Ways of the Development, the Solutions”. Archangelsk, 17-22 June, 2002.
8. Johannessen, O.M., L.H. Pettersson, S.P. Nielsen, V.S. Maderich, M.J. Zheleznyak, L.P. Bobylev, V.A. Volkov, A.V. Stepanov and K.L. Bobylev: Study of influence of land-based sources of radionuclides on radioactive contamination of Kara Sea through Ob and Yenisey river systems. International conference on radioactivity in the environment. Monaco, 1-5 September, 2002.
9. Johannesen, O. M., L. H. Pettersson, Y. Gao, S.P. Nielsen, S. Borghuis, P. Strand, L.O. Reiersen, L.P. Bobylev, V.A. Volkov, I.A. Neelov, A.V. Stepanov, K.L. Bobylev, M.J. Zheleznyak, V.S. Maderich: Simulation for potential radioactive spreading in the 21 century from rivers and external sources in the Russian arctic coastal zone-RADARC, in The 5th Int. Conf. on Environmental Radioactivity in the Arctic & Antarctic, edited by P. Strand, T. Jølle and Å. Sand, Norway Radiation Protection Authority, Norway, 2002.
10. Maderich, V.S., N.N. Dziuba, V. Koshebutsky, M.J. Zheleznyak, V.A. Volkov. Modelling of the seasonal dynamics of the water masses, ice and radionuclide transport in the large Siberian river estuaries: Book of Extended Abstracts of the 11th International Biennial Conference on Physics of Estuaries and Coastal Seas (PECS'02), Hamburg, Germany, 17-20 September 2002.
11. Maderich V.S., Nesterov O., and Zilitinkevich S.: The influence of different parameterisations of meteorological forcing and turbulence schemes on modelling of eutrophication processes in a 3D model of estuary. Book of Extended Abstracts of 11th International Biennial Conference on Physics of Estuaries and Coastal Seas in Hamburg, September 17-20, 2002

4.6 Conclusions

The main scientific results, which have been achieved during the contract period, are:

- Data sets on radioactive pollution levels of the whole Russian Arctic, including main sources of radioactivity in the Russian Arctic coastal zone, including the land-based sources in the Ob’ and Yenisey rivers watersheds from different accessible sources were processed to perform the RADARC validation studies;
- The environmental parameters collected during the first year were prepared for integration in the AMAP database; a dedicated project GIS for the studied region has been prepared with inclusion of model simulation and validation;
- The archive of meteorological data was formed; files of direct access for the period 1948-2000 for the Kara Sea region was set up on the base of the NCEP/NCAR global meteorological data sets;
- The unique river discharge data set for 19 points for the 50-60 years period was assembled and reconstructed;
- A long-time series of the Kara Sea sea-level and currents was collected;
- Bottom sediment distributions for the key points along the river flow temperature, salinity and level data of Ob’ and Yenisey rivers were collected and analysed;
- Climatic fields of oceanographic parameters, ice cover parameters, as well as data from quasi-synchronous observations outlining typical distribution of oceanographic parameters and water and ice circulation for the Kara Sea and Arctic Basin were collected and analysed; various types of remote sensing satellite data (observations in the visible, infra-red and microwave, with focus on SAR data) needs for models validation were collected and analysed;
- The NIERSC’s regular digital Kara Sea bottom relief model (bathymetry) was acquired for use in ocean model setup;
- The regular digital bottom relief model (bathymetry) for Ob and Yenisey estuaries was corrected;
- The most probable scenarios of accidental release of radionuclides influencing the Arctic environment and their transport from external sources to the Arctic Seas were specified and substantiated;
- The 3-dimensional, coupled ocean and sea ice North Atlantic-Arctic model was extended to include description of transport and dispersal of radionuclides, validated and implemented in RADARC Generic Model System (GMS);
- The Kara Sea ocean circulation model was adapted for long-term simulations with constantly updating external meteorological and other forcing parameters. A simulation of the Kara Sea circulation with the space resolution 20 minutes by longitude and 10 minutes by latitude for 1948-2000 was carrying out. The model were prepared for the inclusion of data from the nested river/estuary model and provide input data to the Arctic/North Atlantic large-scale ocean model as a part of the RADARC GMS;
- The river model system includes a one-dimensional model of river dynamics and radionuclide transport (RIVTOX) and a three-dimensional model of estuarine and coastal areas hydrodynamics and radionuclide transport

(THREETOX). These models has been validated against the available data on river discharge, level, suspended sediment concentration and radionuclide concentration in the Ob' and Yenisey rivers. The RIVTOX model was adapted to provide forcing data on the freshwater, sediments and radionuclide fluxes from the rivers to estuary model THREETOX. The THREETOX model input-output files were adapted to couple with the Kara Sea model as a part of the RADARC GMS;

- A concept of the Generic Model System (GMS) has been developed and implemented including formulation, testing and use of all format specifications for data exchange between nested models;
- A Generic Modelling System (GMS) has been created and used to perform simulation scenarios for the 21st century including global warming of potential radioactive spreading from sources in the Russian Arctic coastal zone using GMS.
- Model simulation studies of dispersion and transport of radionuclides (^{90}Sr and ^{137}Cs) from historical real sources and potential future accidental releases along the Russian rivers Ob´ and Yenisey, from the UK Sellafield reprocessing plant and atmospheric fallout has been carried out with synoptic forcing and under a 2*CO_2 forcing scenarios.
- The model simulations have been validated against available field data records resolving a statistical match between the data and model of about 30%.
- A radiological risk assessment has been carried out to evaluate the potential impact on man from hypothetical accidental releases of radioactive material from waste-disposal sites on the Russian rivers Ob' and Yenisey and transported downstream to the Kara Sea in the Arctic Ocean. Furthermore, the potential impact of global warming (2*CO_2-scenario) on the radiological consequences has been evaluated.

5 Management report

5.1 Organisation of the collaboration

A close cooperation has been established between all European and NIS project partners, partly based on good relations established within earlier cooperative projects and efforts. NERSC has been the overall coordinator facilitating the communications between the partners, through the efforts of the Project coordinator Prof. Ola M. Johannessen and the deputy coordinator Lasse H. Pettersson. For the joint project responsibilities between the NIS partners the NIERSC partner has been responsible for the coordination, primarily due to facilitation of the full understanding of the project issues in Russian language and to minimize travel and communication expenses. NERSC and NIERSC have jointly planned and monitored these activities, with the overall responsibility for the co-ordinator.

Seven project progress meetings have been conducted during the project implementation of which during two EC Scientific officers Drs. Ernst H. Schulte and Michele Genovese participated. Their participation both facilitated the communication of the EC expectations and the project status and expected final results.

Results of the project have been presented at seven conferences and in their proceedings. One peer review manuscript will be published in Journal of Environmental Radioactivity in January 2004. In preparations of proceedings manuscripts and presentations (PowerPoint etc.) to be given at conferences the project partners have submitted individual contributions reviewed and assembled by the co-ordinator.

5.2 Meetings

Cumulative overview of all project meeting, during the two years and three months project period:

Meeting	***1. Kick-off meeting***
Date	24 November, 2000
Place	Nansen International Environmental and Remote Sensing Centre, St. Petersburg, Russia
Outcome	• Data provision/delivery scheme and principles of its logistic implementation • Financial management • Future regular meetings schedule (time, place, specific emphasis, participants) • Action plan for the next few months
Participants	Representatives of all partners, 16 pers.

Meeting	***2. Model specification design Workshop***
Date	8-9 February, 2001
Place	Nansen Environmental and Remote Sensing Center, Bergen, Norway
Outcome	• Status and Plans for WP activities – Data and Data base (WP´s 1-3) • Presentations of the three model tools in RADARC, including data requirements (The Arctic and North Atlantic Model - WP 5, The Kara Sea Regional Model - WP 6, River model - WP7) • Discussion - Integrated Modelling Strategy and Implementation (WP8) • Interaction and communications between partners • Drafting of an implementation Plan document • Possible release scenario definitions and data input (WP4) • Assessment and Input to risk management (WP10) • List of Actions • Management issues (Matching funding, Schedule, Milestones, Payment, Reporting, etc.)
Participants	Representatives of all partners, 12 pers.

Meeting	***3. Project Progress Meeting***
Date	19 –20 June, 2001
Place	The Odessa Hydrometeorological Institute, Odessa, Ukraine
Outcome	• Information base of the RADARC Project - Radiation pollution data (WP2) • New Ob/Yenisey rivers data base (WP1) • Setting up a dedicated Database and GIS for the Ob’ and Yenisey river systems (WP 1, 2, 3) • Update and status of AMAP Database (RADARC WP 2, 3) • Summary of data status for assessment and modelling use • Development and implementation of numerical models for simulation of radionuclides transport from land-based sources to the Kara Sea, validation and simulations (WP7) • The Kara Sea Model implementation and validation (RADARC WP6) • Implementation of the MICOM model for the Arctic and its validation with respect CFC-11 (WP5) • The scenarios for numerical modelling of radionuclides migration from land-based sources to the Kara Sea (WP 4) • Assessment – input to risk management (RADARC WP 10) • Group Discussions: (Data exchange &Analysis, Modelling integration, Scenarios definitions) • Management (6 & 12 months Reports, Financial reporting, List of activity)
Participants	Representatives of all partners, 14 pers.

Meeting	***4. Project Progress Meeting***
Date	23. January, 2002
Place	Nansen International Environmental and Remote Sensing Centre, St. Petersburg, Russia
Outcome	• RADARC 's Deliverables and Data Sets • GIS for Russian Arctic coastal zone and Ob and Yenisey watershed areas (D.4) • Status on Data provision to the AMAP data base (D.3) • Scenarios of accidental radionuclide release and their transport from external sources to the Arctic Seas (D5) • Description of model for simulation of transport of radionuclides in the North Atlantic and Arctic ocean and results of modelling (D6) - WP5 • Description of model for simulation of transport of radionuclides in the Kara Sea (D7) and results of modelling - WP6 • Description of model for simulation of transport of radionuclides from external sources via Ob and Yenisey river systems to the Kara Sea (D8) and results of modelling - WP7 • Integrated modelling – Generic Model System (GMS) - WP8 and Plan of simulations using GMS - WP9 • Assessment of impact of radioactive pollution from sources located in the Russian Arctic coastal zone and rivers of the Arctic Ocean in the 21st century (WP10). • Project management
Participants	Representatives of all partners, 14 pers.

Meeting	***5. Project Progress Meeting***
Date	19 June, 2002
Place	Nansen International Environmental and Remote Sensing Centre, St. Petersburg, Russia
Outcome	• Scenarios of accidental radionuclide release and their transport from external sources to the Arctic Seas &Status on Data provision • Discussion: Integrated modelling – Generic Model System (GMS) - and Plan of simulations using GMS • Status and problems of the modelling • Project management (Data provision/delivery scheme and principles of its logistic implementation, Financial management) • Action plan for the finishing months
Participants	Representatives of all partners, 18 pers. including Dr. Ernst H. SCHULTE (European Commission, Brussels, Belgium)

Meeting	***6. Project Progress Meeting***
Date	25 September 2002
Place	Nansen International Environmental and Remote Sensing Center, St. Petersburg, Russia
Outcome	• General status of the RADARC Project – Deliverables and Data Sets • Status of river modelling and final choice of scenarios • Results of the Kara Sea modelling • Results of the Arctic Ocean modelling • Assessment of Doses • RADARC Final Report preparation • Project management
Participants	Representatives of all partners, 14 pers. including Dr. Michele GENOVESE (INCO programme, European Commission, Brussels, Belgium)

Meeting	***7. RADARC Final Meeting***
Date	22 January, 2003
Place	Nansen International Environmental and Remote Sensing Center, St. Petersburg, Russian
Purpose	• Individual partner final reports • General status of the RADARC Project – Deliverables and Data Sets • Status of GMS modelling, assessment of doses • Consolidated scientific Final report • Project management report • Review of Project publications and presentation • Plan of publications (papers and monograph) • Table of contents and distribution of responsibility for monograph (post project writing)
Participants	Representatives of all partners, 10 participants

5.3 Scientific Exchange Visits

Both Russian scientific staff and Ph.D. students working on the project have under taken scientific exchange visits to the other project partners of up to three months duration.

In order to prepare for the Generic model System and the exchange of data and information between the various model components Dr. Ivan Neelov (NIERSC) visited the Nansen Center in Bergen during the two months period February 6. to April 6. 2001.

During the 2nd project year Ph.D. student Mr. K. Bobylev visited the Nansen Center during January to March 2003, funded under an INTAS Young Scientist Grant. Additionally, in connection with the project meetings the participating scientists have also arranged separate working sessions or meetings (additional days) in order to progress the work within the shared tasks of the project. Between the Russian partners in St. Petersburg a high project co-operation was developed, including frequent staff exchange visits.

5.4 Problems Encountered

A significant delay in the final approval and transfer of the 1st year payment has caused problems in the cash flow available for the NIS partners to implement the project. No, other managerial problems have been reported from the coordinator and the partners.

6 Completed Catalogue Page

Contract Number: ICA2-CT-2000-10037

Title: **Simulation scenarios for potential radioactive spreading in the 21st century from rivers and external sources in the Russian arctic coastal zone - RADARC**

Keywords: radioactivity, global change, climate predictions, Russia, Arctic

6.1 Introduction

Though the present level of technogenic radioactive contamination in the coastal zone of the Russian Arctic is relatively low, there nonetheless exist a potential risk for radioactive contamination from several sources in the coastal zone and on the watersheds of the Siberian rivers.

Potential changes in the climate system under global warming will undoubtedly affect various meteorological, hydrological and oceanographic processes governing also transport and spreading of radioactive pollution. However, assessment of such influence has not yet been performed.

Existing numerical models for simulation of transport and spreading of radionuclides in the Arctic region have coarse resolution or are restricted to selected regions or processes or the time span of simulation was limited to shorter periods. No existing simulation addresses the influence of global change on the behaviour of radionuclides in the Arctic basin.

6.2 Objectives

- To perform simulation scenarios for the 21st century, including global warming scenarios, of potential radioactive spreading from sources in the Russian Arctic coastal zone and its impact on Barents, Greenland and Norwegian Seas and the Arctic Ocean;
- To update the environmental and pollution data base of the Arctic Monitoring and Assessment Program (AMAP);
- To assess, select and define the most probable simulation scenarios for accidental releases of radionuclides;
- To implement a Generic Model System (GMS) consisting of several nested models designed to simulate radionuclides transport through rivers, in the Kara sea and in the Arctic ocean / North Atlantic;
- To carry out simulation studies for the selected "release" scenarios of radionuclides, using various atmospheric forcing scenarios;
- Assess the impact on potential radioactive spreading from sources as input to risk management.

6.3 Foreseen results and deliverables

- Creation of a dedicated Database of historical environmental and radioactivity data for Russian Arctic coastal zone and used in update of AMAP database;
- Specification and substantiation of the most probable scenarios of accidental radionuclide releases;

- Implementation of Generic Model System (GMS) with a validated medium resolution (50 km) 3D numerical ice-ocean model for the Arctic and North Atlantic ocean nested with a validated high resolution (5 km) model for the Kara Sea including a sediment module nested with a validated river transport model to be used for simulation studies;
- Simulation studies for the selected "release" scenarios of radionuclides, using various atmospheric forcing scenarios, including global warming, likely consistent with a CO_2 doubling
- Assessment of impact on potential radioactive spreading from sources located within the Russian Arctic coastal zone and rivers based on the simulation results, including global warming impact, as input to a risk management decision making system.

6.4 Results achieved

Under the RADARC project a new Generic Modelling System (GMS) including information exchange between hydrodynamic models for the rivers, estuaries, coastal Kara Sea and the open ocean aquatic systems of the northern Russia and the Arctic were set up.

The most probable future release scenarios for radionuclides were developed and simulation studies for selected future scenarios of radionuclear contamination was carried-out, using atmospheric forcing scenarios, including global warming, likely consistent with a CO_2 doubling and control runs.

Thus a new tool for an assessment of the potential radioactive spreading in the Arctic was created and the assessment of the potential radioactive spreading from rivers and external sources in the Russian Arctic Coastal Zone was developed and assessed.

7 Final data sheet

Contract number: ICA2-CT-2000-10037 **Year**: 2003

Data sheet
for final report

(to be completed by the co-ordinator at 12-monthly intervals from start of contract. Figures to be up-dated cumulatively throughout project lifetime)

	Totals (cumulative)
1. Dissemination activities	
Number of communications in conferences (published)	9
Number of communications in other media (internet, video, …)	2
Number of publications in refereed journals (published)	1 (1)
Number of articles/books (published)	(1)
Number of other publications	7 (2)
2. Training	
Number of PhDs	4
Number of MScs	0
Number of visiting scientists	4
Number of exchanges of scientists (stays longer than 3 months)	0
3. Achieved results	
Number of patent applications	0
Number of patents granted	0
Number of companies created	0
Number of new prototypes/products developed	0
Number of new tests/methods developed	3
Number of new norms/standards developed	0
Number of new softwares/codes developed	3
Number of production processes	0

4. Industrial aspects

	yes	no
Industrial contacts	☐	☒
Financial contribution by industry	☐	☒
Industrial partners : - Large	☐	☒
- SME[1]	☐	☒

5. Comments

Other achievements (use separate page if necessary)

[1] Less than 500 employees.