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Radiological impact assessment including data, models and techniques

UAV plume measurements for reconstructing radiological source terms, and field trials at the BR-1 reactor

James Carr[1], *Luke Lebel*[1], *Marta Kocemba*[1], *Johan Camps*[2], *Johan Paridaens*[2], *Geert Olyslaegers*[2]

[1]*Canadian Nuclear Laboratories, CNL, Canada*

[2]*Belgian Nuclear Research Centre, SCK-CEN, Belgium*

Management of a nuclear incident is typically a very complex process. It requires background knowledge in multiple technological areas and relies on timely and accurate information. At present, emergency responders rely quite heavily on forward models in order to make predictions about how an accident will progress. Here, an assumption is made on the state of the plant and the type of accident that is taking place, and a pre-calculated source term (i.e., radioactivity release) is then applied along with an atmospheric dispersion calculation to project the likely dose consequences in regions around the plant. However, this relies on a number of assumptions that may or may not be known reliably as an emergency unfolds. Estimates of radiological releases can be greatly improved if it can be coupled with environmental measurements. The avenue of research being pursued in this study leverages the emerging Uncrewed Aerial Vehicle (UAV, sometimes referred to as a drone) technologies and mathematical plume inversion algorithms to directly estimate the source term.

The overarching concept would be to mount a gamma-spectrometry sensor package, known as GEOREDAQ (Georeferenced Radiological and Environmental Data Acquisition), to a UAV. The system would then be deployed into the area of interest, specifically focusing on surveying airborne radioactive plumes. The UAV would take a flight path under the plume or near ground level, and use a small upward-facing shielded and collimated gamma spectrometer (CsI and / or CZT). The flight path transects the plume from below, allowing a concentration cross section to be inferred from the gamma flux measurements (or more precisely, the vertical integral of the concentrations, given the viewing angle of the collimator). The data allows Gaussian plume parameters to be estimated directly, including the lateral dispersion coefficient, source term, and plume centerline angle. As part of this project, CNL's UAV team collaborated with SCK CEN to deploy the GEOREDAQ system at the BR-1 reactor's releases of Ar-41 during field trials in October 2022. Follow up field trials are planned for August 2023.

The purpose of the presentation would be to describe the actions undertaken by the team to develop the UAV deployable gamma spectrometry sensor package and collimator, field deployments of GEOREDAQ (e.g. Onsite commissioning flights, October 2022's twenty BR-1 deployments, and August 2023's collaborative field deployments with SCK CEN at their BR-1 reactor, insight into CNL's deployment methodology, and post data analysis efforts. The October 2022 measurements were able to successfully reconstruct the BR-1 reactor's release rate, consistent with its known release rate of 50-150 GBq/h [1-3].

1. G. Bijloos et al., "Parametrization of homogeneous forested areas and effect on simulated dose rates near a nuclear research reactor," Journal of Environmental Radioactivity, 2020.
2. J. Pauly et al., "Source term estimation based on in-situ gamma spectrometry using a high purity germanium detector," Centre de l'Etude de l'Energie Nucleaire, Mol, Belgium, 1997.
3. C. Rojas-Palmas et al., "Experimental evaluation of gamma fluence-rate predictions from argon-41 releases to the atmosphere over a nuclear research reactor site," Radiation Protection Dosimetry, pp. 161-168, 2004.

Clustering and selection of relevant meteorological scenarios for short-range atmospheric dispersion in the case of nuclear accidents

Youness El-Ouartassy[1], Matthieu Plu[1], Laurent Descamps [1], Laure Raynaud[1], Irène Korsakissok[2], Olivier Connan [3]

[1] *Centre National de Recherches Météorologiques, CNRM/Météo-France, Toulouse, France.*
[2] *Nuclear Safety and Radiation Protection Authority (ASNR), BMCA, France.*
[3] *Nuclear Safety and Radiation Protection Authority (ASNR), LRC, France.*

Atmospheric dispersion models are used during a nuclear accident to assist in crisis management, for example to predict the dose likely to be received by the population during a nuclear accident and infer appropriate countermeasures. However, it is essential to take into account the uncertainties inherent to these simulations, in particular the meteorology used to feed the dispersion models. For this purpose, we used the fine-scale meteorological ensembles AROME-EPS from Météo-France coupled to the dispersion model pX developed by IRSN (the French Institute for Radiation Protection and Nuclear Safety) (El-Ouartassy et al., 2022).

The presented work focuses on the computational time constraints that limit the use of all members of a meteorological ensemble in a crisis situation. To address this issue, one of the approaches is to reduce the number of simulations composing the meteorological ensemble used as input to the dispersion model, by selecting representative members ("clustering") which are supposed to represent a large part of the uncertainty of the global ensemble. Several Machine Learning algorithms are used in meteorology to optimize ensemble forecasting systems. In this study, we compare the statistical performance of three clustering methods: K-means, Agglomerative Hierarchical and Ward.

Since the wind is one of the most sensitive meteorological variables for atmospheric dispersion, the three clustering methods are applied to the wind fields in order to classify the meteorological members of AROME-EPS into similar subgroups (or clusters). Then, a representativeness index is calculated for the members of each cluster to select the representative member to be used for the atmospheric dispersion calculation. The performance of the dispersion sub-ensembles thus constructed is compared to the absolute AROME-EPS-pX ensemble using the Figure of Merit in Space (FMS) score. The results show a good performance of the clustering algorithms.

Atmospheric Plume Modelling and Source Reconstruction of Radioactive Argon-41 from the NRU Reactor

Lucian Ivan [a]; F. Forgues [a], S. Pfeiffer [a], J.G. McDonald [a, b], P. Leeson [a], L. Lebel [a]
[a] Canadian Nuclear Laboratories, CNL, Canada
[b] University of Ottawa, UOttawa, Canada

The potential of data assimilation (DA) methods to improve the forecast capability of any predictive model has long been recognized since the inception of numerical weather prediction. Given that a stand-alone model will divert from reality due to the impact of many approximations, uncertain initial conditions, and unidentified processes, the primary objective of DA is to improve the model capability of forecasting the future state of a system by incorporating information from the observations of the system.

In a nuclear emergency response to an accidental environmental release of hazardous radionuclides, the application of inverse modelling and DA techniques represents a viable way to reduce the uncertainties in the emission rate estimate, meteorological data, and other factors impacting the atmospheric transport and dispersion model of radioactive pollution. Hence, an active research area is the improvement of prediction accuracy of the dispersion model by making efficient use of gamma dose measurements which, although sparse, are typically available around every nuclear power plant.

This study considers the evaluation of DA techniques for the atmospheric Argon-41 (41Ar) emissions from the stack of the National Research Universal (NRU) reactor, a multipurpose science facility that operated for over 60 years. At the 41Ar released rate of approximately 2.1x1014 Bq/week, NRU was the main source of radioactive emissions at the Chalk River Laboratories (CRL) site. The CRL site is located about 160 km northwest of Ottawa, Ontario, on the south shore of the Ottawa River, which locally flows from northwest to southeast parallel to a large bedrock ridge.

The local topography features the lowest elevation of around 100 m above sea level along the river surface, and hills of gradual and steep elevation changes of up to 350 m on the south and north banks of the river, respectively. The atmospheric wind fields, predominantly oriented along the riverbed, are described in this work using the diagnostic (i.e., measurement based) wind field generator within the California Meteorological Model (CALMET) package, which contains objective analysis and parameterized treatments of slope flows, kinematic terrain effects, a divergence minimization procedure, and a micro-meteorological model for overland and overwater boundary layers.

The hourly wind-prediction model makes use of high-resolution digital elevation data and meteorological information that includes time-averaged measurements from the ground (i.e., 10 m, 30 m, and 60 m height) and SODAR (up to 150 m height) CRL stations, a few neighbouring regional weather stations, and the nearest upper air station in Maniwaki, Quebec.

The application of the four-dimensional variational assimilation (4D-Var) is considered here for improving the prediction capabilities of a three-dimensional Lagrangian puff dispersion model, implemented in an in-house code, with cloudshine measurements (i.e., radiation from the radioactive aerosol plume). In this approach, the forecast model parameters are computed so as to minimize discrepancies between monitoring radiation-dose observations distributed over time and model outputs. The gamma dosimetry measurements used for DA were collected by the ambient radiological monitoring system (ARMS) stations at CRL site.

ARMS comprises 22 gamma detectors spaced relatively uniformly in a semicircular region around the NRU stack at a radial distance between zero and 10 km and an average of about 2.5 km. The accuracy of the approach is determined by comparing the 41Ar activity emission rate predicted by the 4D-Var model at the source against the stack activity measured by the reactor stack effluent monitoring system. Furthermore, the gamma dose predictions from the optimized plume are compared against those reported by several national radiation surveillance monitors located around the CRL site at distances ranging from about 7 km to 45 km from the stack.

The final presentation will provide details about the devised algorithm to perform variational DA, the process of data acquisition, and the collected meteorological and radiological measurements. Results to illustrate how the data-enhanced dispersion model performs in the short and medium range will be shown along with sensitivity parameter studies, including the impact of the number of DA detectors, which are instrumental when considering the approach for emergency nuclear planning.

Protective actions, decision support and disaster informatics

Dose and risk calculation tool for simulation of countermeasures, aimed for training of, for example, decision makers not specialized in radiation protection

Jonathan Sundström[a], Mats Isaksson[a], Christopher Rääf[b]

[a] Department of Medical Radiation Sciences, University of Gothenburg, Gothenburg, Sweden

[b] Medical Radiation Physics, Department of Translational Medicine, Lund University, Malmö, Sweden

1. Introduction

In the case of a large-scale nuclear power plant (NPP) accident, radionuclides will be dispersed over large areas. Depending on the countermeasures taken both before and after the fallout, the radiation dose and risk to humans may vary heavily. To help with the training of decision-makers in planning and assessing countermeasures, the software LARcalc has been developed – a tool that calculates age- and gender-specific lifetime risk of cancer (LAR, Lifetime Attributable Risk) or radiation dose following fallout (Sundström et.al., 2023, Rääf et.al., 2020).

LARcalc is mainly intended to be used as a pedagogical strategic tool for training and education, not as a real time decision-tool during an on-going accident. However, it has been verified to some extent with real data from Nordic experiences of the Chornobyl fallout in 1986 (Andersson et al., 2000, Jönsson et al., 2017) and experience from the global nuclear weapons fallout (UNSCEAR, 1972).

2. What the tool does

LARcalc (seen in Fig 1) is a tool to estimate the dose and risk based on a known local and regional fallout deposition. Input to the tool is the nuclide vector, and the activity concentration of 137Cs (Bq/m2). The tool will calculate estimated: cumulative effective dose (CED), organ absorbed dose or Lifetime Attributable Risk, to either an individual (representative of a certain age cohort residing in the area of interest) or to a whole population. Thus, the tool can give an estimate of the expected increase in cancer cases for a population.

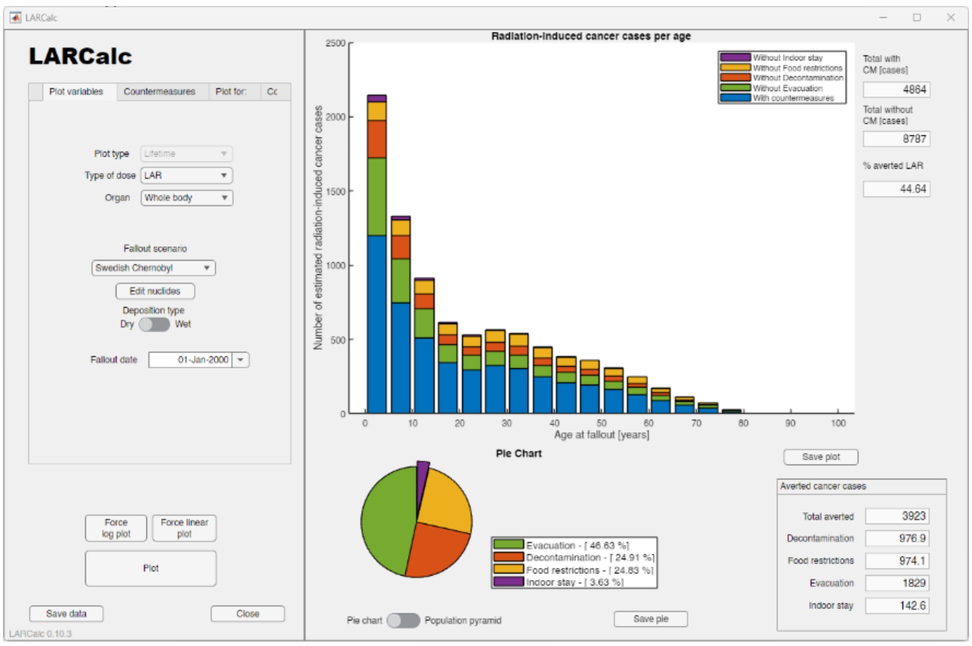
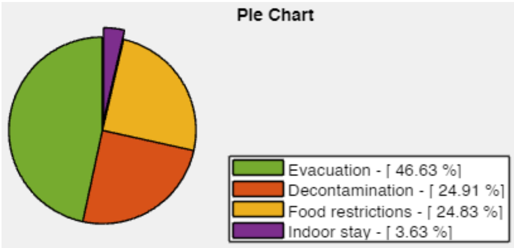


Figure 1. Main window of LARcalc, with an estimation of LAR for a population, with countermeasures.

The tool can also include the countermeasures; indoor stay (sheltering), evacuation/relocation, food restrictions and/or decontamination of the local area. From this the effects of the countermeasures can be presented directly as both reduced dose or LAR as well as how effective the different countermeasures are relative to each other (e.g. Fig 2).



Averted cancer cases

Total averted	3923
Decontamination	976.9
Food restrictions	974.1
Evacuation	1829
Indoor stay	142.6

Figure 2. Example of the effects of countermeasures for a population.

3. Models included in LARcalc

The calculations are based on previous published models and dose coefficients on both internal and external exposure for males and females with the age-groups; 3-months, 1-year, 5-years, 10-years, 15-years and adults. To make an estimate for all ages, LARcalc uses a Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) to estimate dose coefficients for ages between the ones defined by the ICRP.

Included pathways for exposure are:

- Ground- and cloudshine, using dose coefficients from ICRP Publication 144 (ICRP, 2020)
- Inhalation, using dose coefficients from ICRP Publication 71 (ICRP, 1995)
- Ingestion of 137,134Cs and 131I, based on consumption rates (Rääf et.al., 2006, Isaksson et.al., 2019, and Isaksson et.al., 2021), and dose coefficients from ICRP Publication 56 (ICRP, 1990)

4. User interface – step by step

Choose a fallout scenario by either choosing one of the pre-defined scenarios (Chornobyl, Fukushima, Theoretical Swedish NPP), or define one of you own by open the "Edit Nuclides" window. Change the Plot type, Dose type and Dose place to for example: Cumulative or Rate; Effective dose or LAR; and Whole body or Lungs. Lastly, decide if it should be a Dry or Wet deposition. It is possible for the user to choose a date for the fallout; else it will be set to 1 January 2000.

Choose Countermeasures by changing to the Countermeasures tab, where you can choose the time of onset for your countermeasures. It is possible to have overlapping dates, but in that case, evacuation will have priority and thus pause all dose contribution during that time. For food restrictions and decontamination, it is possible to set the efficiency of the countermeasure.

Choose a population or individual by going to "Plot for:"-tab. There you can either choose to estimate for an individual by deciding age and sex, or you can choose to calculate for a population where populations are defined as a population pyramid (population data taken for Swedish inhabitants from Statistics Sweden, 2021 and the rest of the world from PopulationPyramid.net, 2021). Populations are pre-defined for all counties and municipalities in Sweden and for some countries. It is also possible to define an own population pyramid.

Change constants by going to the "Constants"-tab. LARcalc uses some constants that changes based on the fallout scenario. In the constants-tab it is possible to change Mean life expectancy, Local- and Regional 137Cs deposition, Snow covering factor, Outdoor time factor, and more.

Choose Pathways by going to the "Pathways"-tab. Here it is possible to choose all or some of the pathways.

5. Examples

1) LAR for the whole population of the municipality Gävle, Sweden (102 892 inhabitants). Chornobyl-fallout vector with a 137Cs areal activity concentration of 250 kBq/m2 both locally and regionally, wet deposition. The results, with, and without the countermeasures given in table 1 can be seen in Figure 3.

With countermeasures   Without any countermeasures

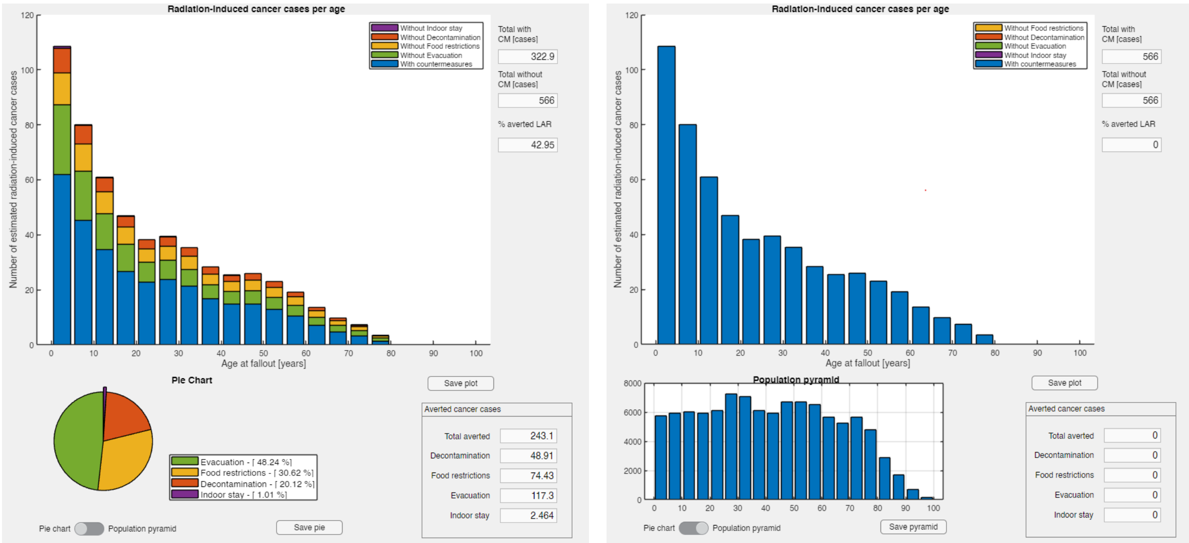


Figure 3. Left: LAR for all inhabitants in Gävle with countermeasures. Right: without any countermeasures. Blue bars are LAR, green are the LAR averted from evacuation, yellow are averted LAR form food restrictions, orange are averted LAR from decontamination, and purple are averted LAR from indoor stay.

2) Cumulative effective dose for a 30-year-old male, Fukushima-fallout vector with a 137Cs areal activity concentration of 2000 kBq/m2 locally and 300 kBq/m2 regionally, dry deposition. The results, with, and without the countermeasures given in table 1 can be seen in figure 4.

With countermeasures Without any countermeasures

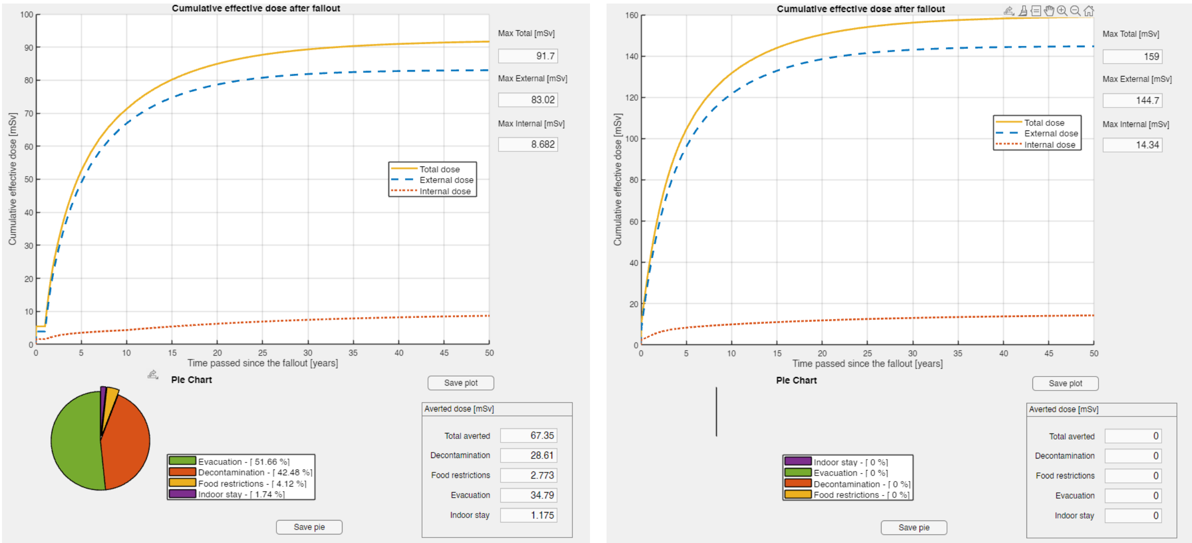


Figure 4: Left: LAR for a 30-year-old male with countermeasures. Right: without any countermeasures. Yellow line is total CED, blue line is external CED, and orange line is the internal CED.

Table 1: Countermeasures used in examples above.

Indoor stay	Evacuation	Food restrictions	Decontamination
First 7 days	Day 8 – day 365	First 10 years 50 % reduction	Started day 365, done day 730, 30 % reduction

6. Technical details

LARcalc is written in MATLAB and is a freeware. Both the source code and a compiled executable version (.exe file) are available on request and at GitHub: https://github.com/JSundstroem/LARCalc. LARCalc is planned to be updated with ICRP's new dose coefficients to members of the public when they are released.

7. Conclusion

The LARCalc tool has been developed for Swedish conditions. For use in other countries, it is recommended that the radioecological transfer parameter, governing the average whole-body burden of radiocaesium per unit regional ground deposition (e.g. Rääf et al., 2006) and its related time parameters (presented in Table 1 in Sundström et al., 2023) be adapted to better match locally or regionally recorded body burdens of radiocaesium. The indoor sheltering factor and occupancy factor may also need to be adjusted in other countries.

8. Acknowledgement

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A novel method to estimate the radiological effects of fallout from nuclear detonation

Jasper Thomas[1], Arjan van Dijk[1], Michiel de Bode[1], Astrid Kloosterman[1], Marte van der Linden[1]
[1]National Institute for Public Health and the Environment, RIVM

The need for methods to accurately simulate the consequences of nuclear detonation has increased. For a near-surface detonation the effects of blast, heat, direct radiation and electromagnetic pulse are local, albeit severe, depending on the yield of the explosion. However, the fallout that is generated by nuclear detonation can travel larger distances due to atmospheric transport. The goal of this study is to provide both a fast and accurate method to assess the radiological effects of fallout.

One of the challenges is how to deal with the large number of radionuclides that are released, including their progeny. A known method is taking into account only that part of the decay chains of radionuclides that contribute most to the considered exposure pathways [1].

However, this approach has two major drawbacks. Firstly, the selection of relevant radionuclides depends on the considered exposure interval, because the relative contribution of radionuclides and their progeny changes over time due to radioactive decay and ingrowth. Secondly, this selection depends also on the endpoint and it may not be known a priori which endpoint is of interest (e.g. an exposure pathway or level of contamination).

In case measurements indicate the detection of certain (daughter) radionuclides, one would like to compare these measurements with model results. The comparison will be unclear if the modelled source term did not include these detected (daughter) radionuclides.

To avoid the beforementioned drawbacks a novel method was developed that takes into account all decay and progeny ingrowth from an arbitrary mixture of initially released radionuclides. This is achieved by numerically solving the Bateman equation [2] for the considered radionuclide mixture for pinpoints in time over an interval up to 2 million years, thereby taking into account all 1252 radionuclides listed in ICRP Publication 107.

Under de assumptions that the mixture is released instantaneously and that the total mixture does not unmix, the calculation of radioactive decay, ingrowth, and dose can be separated from the dispersion calculation. Therefore, at the considered pinpoints in time the nuclide composition is multiplied with corresponding dose conversion coefficients for multiple exposure pathways using ICRP Publications 144 and 119 and [3].

The results are time-dependent activity-dose conversion coefficients for the specific mixture of instantaneously released radionuclides. Subsequently, a dispersion model is used to compute the atmospheric transport and deposition of a passive and stable tracer material with deposition characteristics resembling the nuclide mixture at hand.

The dose rates corresponding with the considered exposure pathways are retrieved by multiplying the resulting thinning coefficients for air concentration and ground concentration with the time-dependent activity-dose conversion coefficients (and multiplying with the breathing rate, in case of the inhalation pathway).

The method is applied to a hypothetical case of fallout emitted from a nuclear detonation. The dispersion model NPK-Puff is used while the initial stabilized cloud geometry, particle size distribution, and vertical distribution of radioactivity over the stabilized cloud geometry are based on available literature. Results will be presented that highlight the advantages of the method in terms of computational time, accuracy, and ease of use. Concluding, it is worth mentioning that the method is not only applicable to nuclear detonation scenarios, but to any instantaneous emission of radionuclides that do not unmix.

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New challenges for emergency preparedness, response and recovery

Investigations on Small Modular Reactor Emergency Preparedness and Response Planning Basis at Canadian Nuclear Laboratories

David Hummel [a], Luke Lebel [a]

[a]Canadian Nuclear Laboratories

The deployment of small modular reactors (SMRs), including advanced reactors (that is, not water-cooled technologies), is being actively supported by multiple levels of Canadian Government and industry. Fundamental to the safety of these SMRs and advanced reactors, as with the contemporary operating nuclear power plants (NPPs), is the concept of defence in depth. The fifth and final level of defence in depth is composed of the emergency preparedness and response (EPR) measures implemented off the licensed plant site that mitigate the consequences of significant radiological releases.

The components of the offsite EPR planning basis are broadly: i) the basis for protective action decision making (for example, generic criteria), ii) the radiological hazards (selected from reactor facility accidents and source terms), iii) the postulated effects of the accident on public health and safety (from dose assessment based on the selected accident scenarios), and iv) the geographical extent of the accident consequences that define the necessary extent of emergency planning zones (EPZ). Whereas the generic criteria for protective actions are independent of the reactor technology, the other three components can be affected by the proposed SMRs in ways that deserve closer consideration.

No regulatory barrier has been identified in Canada that would prevent EPZs from being sized commensurately with the reduced risks claimed for SMRs as compared to contemporary large NPPs. An aspirational goal for some SMR stakeholders is to eliminate the need for offsite urgent protective actions, which in some districts is equivalent to eliminating the EPZ.

These claims have engendered questions such as: i) what accident sequences must be considered in the EPR planning basis and what can be practically eliminated, ii) what are the regional authorities with the mandate to implement nuclear EPR willing to accept, and iii) what constitutes the final level of defence in depth when no EPZ is defined.

Canadian Nuclear Laboratories (CNL) is investigating the technical criteria for identifying events that can inform the necessary size of the EPZ within Canada's Federal Nuclear Science and Technology (FNST) program and in a research project coordinated by the International Atomic Energy Agency (IAEA). A decision-making framework has been developed to establish which events need to be considered in the off-site planning basis and what is the necessary extent of the urgent protective action planning zone (effectively the size of the EPZ).

The proposed method is based on Level 3 probabilistic safety assessment as well as an evaluation of the public health risks associated with protective actions in units of adjusted life years. The framework is intended to provide technology- and deployment-neutral justification for when the EPZ around a SMR can be reduced or eliminated.

It has been noted, however, that reduced off-site preparation for urgent protective actions may increase the onus on field monitoring in the extended planning distances (including contingency planning areas) and the longer-term focussed ingestion and commodities planning distance. EPR measures in these farther distances are still a fundamental part of defence in depth. Critical to this monitoring is the concept of operational intervention levels (OILs) – specific practical field measurements that indicate a generic criterion for intervention is likely to be exceeded.

OILs are precisely defined, but they are based on assumptions of the reactor accident source term composition, environmental transport, and food consumption behaviours that may not be applicable to all SMR technologies in every environment. This is especially true for some of the advanced reactor technologies and remote or northern deployments being considered for Canada. These challenges, and the research CNL is performing to address these challenges, are discussed.

On the needs for updates of European nuclear/radiological emergency management tools to address warfare fallout scenarios

Kasper Gran Andersson[1]
[1] Technical University of Denmark (DTU SUSTAIN), Denmark

The nuclear and radiological threats that our society is facing have changed a lot over time, and surely will continue to do so. Naturally, this requires that our preparedness tools and plans are continuously developed to enable adequate emergency and recovery response. With respect to nuclear incidents, the focus has traditionally been on large nuclear power plant accidents, whereas some relatively limited attention has been given to the possible deployment of malicious radiological dispersion devices ('dirty bombs').

In the European standard decision support models for radiological consequence assessment and planning of countermeasure options, ARGOS and RODOS and in the European recovery handbooks, the focus has also mainly been on nuclear power plant accidents. However, modern warfare could include a number of weapons that have previously not attracted much attention, probably since their use has been believed to be of very little likelihood (but in some cases potentially very high impact). Heated discussions between state leaders, and associated more or less trustworthy rumors have recently increased the awareness of an international lack of crucial response knowledge and tools that can be used in decision support for management of radioactive land contamination after explosions of radiological or nuclear weapons. The radiological dispersion devices actually have a history that is slightly longer than that of the nuclear bombs, since a 'dirty bomb' was essentially first deployed to study fallout effects in connection with the Trinity nuclear test series in the summer of 1945. Since then, the 'dirty bomb' concept was again discussed during the cold war era, possibly to limit access paths in enemy terrain, but has over the most recent few decades been regarded as a potential weapon of terror.

According to leaked diplomatic documents, Al-Qaeda has been capable of producing 'dirty bombs'. The production of 'dirty bombs' with potential to cause much damage if for example detonated in a densely populated city area has always been believed to be limited by factors such as availability, physicochemical forms, transportability and guarding of existing strong sources. However, if the producer is not a terrorist but a state with nuclear reactors and facilities, the traditional list of 'suspects' (mainly 137Cs, 90Sr, 60Co, 192Ir, 241Am, 252Cf and 238Pu) with their 'normal' physicochemical properties would be much too short, as demonstrated by the Litvinenko assassination in 2006 with 210Po. Depending on the contaminant, doses from a 'dirty bomb' could be dominated by other types of dose contributions than those from a nuclear power plant accident (e.g., deposition on humans, smearing and resuspension could have more prominence). The European preparedness tools need to be extended to reflect such differences.

Nuclear weapons of different sizes might be applied, also in a battlefield to deny access to certain land areas. The fallout from nuclear weapons would have different characteristics than those that would typically be dispersed in other incident scenarios. There would be great differences between characteristics of particles originating from a ground and an air nuclear bomb blast, and also for example the bomb yield has great impact on particle size. It should be ascertained that we are adequately prepared for this type of incidents with different contaminants.

Resilience and sustainable development following a nuclear accident: lessons from the Fukushima Daiichi NPP accident

Thierry Schneider[a], Pascal Croüail[a], Jacques Lochard[b], Deborah Oughton[c], Friedo Zölzer[d]
a Nuclear Protection Evaluation Centre (CEPN), Fontenay-aux-Roses, France
b Department of Health Risk Control, Atomic Bomb Disease Institute, Nagasaki University, Nagasaki, Japan
c Norwegian University of Life Science (NMBU), As, Norway
d Faculty of Health and Social Sciences, University of South Bohemia in České Budějovice, Czech Republic

Abstract
After a short presentation of the difficulties for restoring the socio-economic activities following a nuclear accident, this paper highlights the main challenges for radiological protection with regard to the objective of resilience, based on the lessons from the Fukushima Daiichi accident. On this basis, some future developments are identified, including the need to develop a multi-hazards approach to preparedness in connection with the Sendai Framework and tools for evaluating the concept of well-being.

Introduction
Lessons from the Fukushima Daiichi nuclear power plant accident emphasize the difficulties for restoring the socio-economic activities in the affected areas, including the challenges of the policy of lifting evacuation orders. The conditions for the return of populations to the territories evacuated after the accident highlight the complexity of the individual and collective decision-making process and show that the radiological situation of the affected territories is only one dimension of the problem faced by the individual and communities (Croüail et al., 2020). The managers of business activities have been and are still confronted with several radiological challenges, in particular for the protection of their employees, for securing their production and providing guarantee to consumers by the radiological control of the products to restore their confidence (Schneider et al., 2021). Municipalities have difficulties predicting their future and sizing infrastructure to accommodate the potential number of residents. The decision whether or not to return is a matter of choice and preference for each individual or family, and these choices must be respected. Municipalities are seeking to modernize infrastructure and develop economic activities in order to increase their attractiveness to their former residents but also to potential new residents in full mutation. Today, the recovery process is shifting towards the economic revitalization of the affected territories through the implementation of the Fukushima Innovation Coast Framework aimed at encouraging people to return and attracting newcomers.

Fukushima Innovation Coast Framework

In the Hamadori region, and more broadly in the Fukushima Prefecture, future socio-economic development relies heavily on the Fukushima Innovation Coast Framework, which combines financial support and incentives for the development of a series of innovative projects. The "Fukushima Innovation Coast Framework" (FICF) was established in January 2014 by the national government and the Fukushima Prefecture with the aim of promoting research and development in the field of robotics, decommissioning, energy, environment, etc. in the Hamadori region along the Pacific coast, most affected by the nuclear accident, but also by the earthquake and the tsunami (FICF, 2018).

By focusing on innovation, this framework aims to rebuild the region's industrial base and, in addition, to encourage the return of evacuees to their places of residence, as well as the establishment of new residents in the region with the hope of promoting the rebirth of an attractive and dynamic society. Among the various projects under development, it is worth mentioning (FIPO):

- the establishment of the Fukushima Robot Test Field for verification test, performance evaluation and operation training of robots and drones that are expected to be utilized for logistic, infrastructure inspection and large-scale disaster (Fukushima Hamadori Robot demonstration zone);
- the establishment of a hydrogen production unit in Namie, using renewable energies and aimed at contributing to the objective of the Fukushima Prefecture of reaching 100% renewable energies by 2040;
- the establishment of a Japan Atomic Energy Agency (JAEA) research centre for the development of technologies for the decommissioning of the Fukushima-Daiichi nuclear power plant.
- The Great East Japan Earthquake and Nuclear Disaster Memorial Museum [Futaba Town], which aims to show the world how the people of Fukushima are resolutely working towards reconstruction, and to communicate appreciation for the support received from across Japan and throughout the world.

The objective of the framework is to create industrial clusters, to foster human resources, and to increase the number of visitors in the region. Particular attention has been devoted to the governance of this socioeconomic development, steered by a council at the ministerial level and mobilizing public organisations and private companies (Nii, 2020). The overall goal of the Innovation Coast Framework is "to become a symbol of hope and to be a pioneer in using innovation to solve social issues" for the Hamadori region (Hope Tourism, 2020).

Challenges for business activities facing the consequences of a nuclear accident

The feedback experience of Chornobyl and Fukushima accidents highlights two major radiological protection issues that business activities had to face to maintain or develop in the recovery process (Schneider et al., 2020; ICRP 2021):

- the protection of employees and their families against radiation, and;
- the implementation of a radiological quality assurance process for the products and at the same time actions to restore the image of the products.

Preservation of economic activities and protection of personnel

The first issue for business activities following the accident is to evaluate the capacity to maintain or not the production in affected areas taking into account the radiological situation and the availability of personnel. In this perspective, the following actions have to be performed:

- Identify sources of information, means of measurement, access to expertise, effectiveness of decontamination actions, and planning for their implementation;
- Identification of radiological criteria relevant for making decisions in the context of post-accident situation;
- Consider the possibility to maintain the business activity taking into account the decisions made by the authorities in relation to the affected territories with due consideration on their possible evolution in the future;
- Identify the employer's responsibility related to exposure of their employees to ionizing radiation; this issue is not necessarily developed prior to the accident and all occupational activities in the affected territories are far to be classified as radiation occupationally exposed;

- Implement actions to maintain exposures of employees as low as reasonably achievable;
- Promote the development of radiation protection culture
- Guarantee working conditions to people working in affected areas that contribute to the "well-being" of staff, beyond the management of radiation exposure;
- Involve staff in evaluating and monitoring the radiological situation to ensure a good confidence in the radiological characterisation of the situation and in the implementation of protective actions.

Guarantee the quality of production for consumers

For ensuring the radiological quality of their products before placing them on the market; managers of businesses located in affected territories have to organize a quality assurance and surveillance system for monitoring the products as well as providing the market with transparent information on their radiological quality.

For organizing and implementing the quality assurance process, several options are possible, ranging from good quality assurance practices directly developed by companies to formal certification provided by an authoritative third-party organization. However, for large scale nuclear accident, it is necessary to Identify available technical resources and access to expertise.

Beyond the quality assurance process, to restore trust with consumers and costumers, managers of business activities must organize dialogue and communication with them. This relies notably on:

- Promoting transparent and pluralistic information on the radiological situation;
- Promoting direct contacts and organizing "open days" allowing consumers and customers to better understand the reality of the situation and the conditions of production.

Experience shows the importance of being able to react quickly to guarantee the radiological quality of the products and to ensure the future of their business activities. In this perspective, developing operational guides in advance for the implementation of quality processes for manufacturers is a key component for the success of the recovery process. It is also necessary to adopt dynamic, scalable and flexible processes to take into account the specific situation of each installation and its evolution. Finally, the cooperation between economic actors performing their activities in affected areas is essential to deal with the situation and require to set up or rely on existing cooperation mechanisms to share experience, concern and identify common protective strategies to cope with the radiological protection challenges.

Organisation of the socio-economic recovery

Following a nuclear accident, the main challenge for the recovery process is to restore the socio-economic development to support local communities in the affected areas where the radiological conditions have been deemed by the authorities to be sufficiently secured to allow people to reside and work (Lee and Kubota, 2016). In this perspective, cooperation between local, regional and national authorities aims to develop and adopt a common project for local communities to ensure their future including the different facets of sustainable development (WCED, 1987; Hammer and Pivo, 2017). In practice, such a common project relies notably on the selection of areas in which to re-establish production and to organise support for the establishment and maintenance of agricultural, industrial and commercial activities.

Resilience is generally defined in the literature as the return to an "equilibrium" after an event (Norris et al., 2008; Paton, 2009). However, the experience of the Chernobyl and Fukushima post-accidental situations reveals that the return to the ante-situation is generally not achievable in itself. Therefore, the socio-economic resilience at territorial level relies notably on:

- The identification and adoption of a contract of objectives shared between the different stakeholders in the territory to enable the development of decent living and working conditions, with a long-term vision for the people and the territories;
- The capacity of maintaining the integrity of the local community and having a monitoring process involving the different stakeholders.

Sendai Framework for disaster risk reduction (2015-2030)

The objectives of the Sendai Framework for Disaster Risk Reduction 2015–2030 adopted at the 3rd UN World Conference on Disaster Risk Reduction held in Sendai, Japan, on March 18, 2015 (UNDRR, 2015) is to prevent new risks, reducing existing risks and strengthening resilience. 4 priorities have been adopted (UNDRR, 2015):

- Priority 1: Understanding disaster risk
  - The aim is to have a shared "understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment."

- Priority 2: Strengthening disaster risk governance to manage disaster risk
  - Risk governance mechanisms dedicated to disaster risk have to be set up and reinforced at the national, regional and global levels for prevention, mitigation, preparedness, response, recovery, and rehabilitation, fostering collaboration and partnership.

- Priority 3: Investing in disaster risk reduction for resilience
  - Public and private investment in disaster risk reduction must be encouraged through structural and non-structural measures to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment.

- Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction
  - The focus on preparedness aims to improve the capacity and efficiency of response in case of disaster, "take action in anticipation of events, and ensure capacities are in place for effective response and recovery at all levels."
  - "Building Back Better" is a key driver in recovery, rehabilitation and reconstruction to achieve efficient disaster risk reduction.

If these priorities could be considered for managing nuclear disasters, their integration has been rather limited in the Sendai Framework. The dynamics provided by this framework and its link with the UN Sustainable Development Goals could enrich the reflection on the management of nuclear disasters. Particularly, the fourth priority emphasizing the objective of "Building Back Better" opens the debate on its meaning in case of nuclear accidents at the various levels: local, national and global.

In this perspective, it is interesting to mention the Roadmap 2021-2030 of the European Forum for Disaster Risk Reduction (EFDRR, 2021). For the Priority 4, the following actions have been selected:

- Invest in accessible multi-hazard early-warning systems;

- Strengthen gender-responsive, age-sensitive and inclusive preparedness for complex emergencies at all levels;
- Apply lessons identified from the Covid-19 pandemic response for future preparedness and recovery planning and approaches;
- Develop new accessible and inclusive disaster-resilience tools for building back better that address existing, emerging and future risks.

Considerations for the resilience of affected territories

Calling for the resilience of affected territories following a nuclear accident raise inevitably some key ethical challenges both for the process of recovery and for preparedness. It is interesting to highlight the approach developed in the TERRITORIES project aiming at promoting decent living and working conditions for people affected by a nuclear accident (TERRTORIES, 2020). Similarly, as mentioned above, the UN Sendai Framework for disaster risk reduction calls in its priority 4 for resilience and sustainable development with the objective to "build back better in recovery, rehabilitation and reconstruction".

Several radiological protection challenges and ethical considerations can be highlighted when addressing the resilience of affected territories following a nuclear accident:

- Organising the vigilance with regard to possible future health effects
- Developing the radiological protection culture to allow local stakeholders to contribute to the decision-making process regarding the future of their territories;
- Promoting the approach in terms of well-being and quality of life where radiological effects are only one dimension of the issues at stake;
- Developing an inclusive approach with a central role of local stakeholders directly concerned by building a vision for the future of their life in the territories;
- Promoting socio-economic sustainability combining economic, environment and health objectives and respecting the ethical core values of radiological protection.

Conclusion: some ways forward for preparedness

The Fukushima Daichi Nuclear Power Plant accident has clearly highlighted the complexity of the socio-economic consequences of large-scale nuclear accidents. To foster the resilience and address the possible sustainable future of the life and activities in affected territories, preparedness is crucial to avoid or at least reduce some of the additional consequences beyond the direct radiological consequences (NEA, 2022). The reflections developed on these issues within several European research projects, mainly by NERIS partners, emphasize the need to further address the following issues (CONFIDENCE, 2020; ENGAGE, 2020; TERRITORIES, 2020):

- Integration of nuclear risk, alongside natural and technological risks, in the development of business continuity plans for industrial activities;
- Organization of a dialogue between local socio-economic actors as part of post-accident management preparedness;
- Analysis of vulnerabilities and challenges to ensure radiological protection of people and the environment taking into account ethical considerations;
- Analysis of the possible contribution of support mechanisms aimed at improving the well-being of affected people;
- Implementation of an expert training plan, as well as raising awareness among local communities.

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Analysing radiological consequences from fallout after nuclear explosions with ARGOS

Anna Maria Blixt Buhr [a], *Jonas Lindgren*[a], *Peder Kock*[a], *Anders Axelsson*[a], *Jan Johansson*[a], *Jonas Boson*[a], *Simon Karlsson*[a]

[a]*Swedish Radiation Safety Authority, SSM, Sweden*

The Swedish Radiation Safety Authority (SSM) has analysed radiological consequences from fallout after a nuclear explosion. In the analysis, the decision support tool ARGOS has been used in batch mode to run an external dispersion model with a number of historical weather cases.

For each run, a number of criteria were studied, for example, at which greatest distance a pre-defined level of dose or deposition level was exceeded. The methodology of using a number of weather cases thereby enabling a statistical analysis of possible consequences is in line with the methodology used in previous work to review emergency planning zones and distances surrounding the nuclear facilities placed in emergency preparedness category I and II in Sweden.

A number of assumptions were made within the analysis such as the selected scenario, the particle distributions in the initial stabilized cloud, the activity associated with the explosion, and the selection of radionuclides in the corresponding source term.

Moreover, choices were made for different input data for the dispersion and dose calculation in ARGOS as well as the endpoints in the analysis, e.g. total effective dose to a representative person for the public. In addition to doses, both the greatest deposition levels at fixed distances and greatest distances for fixed deposition levels were studied. In the latter analyses, a pseudo-nuclide representing the overall activity one hour after detonation (H+1) was used.

With the knowledge what dose a particular ground deposition level from a mix of radionuclides, including in-growth, would give at a certain time, the deposition level of the pseudo-nuclide can be recalculated to dose. The conversion was made in the post-processing of the ARGOS batch results using in-house software, enabling both effective and absorbed dose for different age groups to be calculated.

When running ARGOS in the newly introduced operative mode, a rapid analysis can also be made with the pseudo-nuclide alone. To estimate the effective dose from the external exposure pathway from ground deposition in operative mode, the pseudo-nuclide is subject to exponential decay and an overall ground dose factor is applied.

The analysis in ARGOS was a help to investigate possible radiological consequences from fallout after nuclear explosions, the dominant exposure pathways and the effectiveness in possible combinations of protective actions. Moreover, the results have been used to better understand possible recommendations to people outside the blast zone that warrant urgent or early protective actions such as sheltering, with different shielding factors, and relocation. The gained knowledge also serves as a basis for improving the emergency response for a nuclear explosion scenario and to identify gaps to investigate further.

The NERIS roadmap: research challenges in emergency preparedness, response and recovery

A. Bexon[a], S. Andronopoulos[b], P. Croüail[c], M. Montero Prieto[d], D. Oughton[e], W. Raskob[f], C. Turcanu[g] and on behalf of the NERIS platform R&D committee

[a]UK Health Security Agency (UKHSA), United Kingdom, [b]National Centre for Scientific Research "Demokritos" (NCSR), [c]Nuclear Protection Evaluation Centre (CEPN), [d]Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), [e]Norwegian University of Life Sciences (NMBU), [f]Karlsruher Institut für Technologie (KIT). [g]Belgian Nuclear Research Centre (SCK CEN)

NERIS as the European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery (EPR&R) initially developed a roadmap as part of the CONCERT European Joint Programme for the Integration of Radiation Protection Research. The roadmap sets out the key research challenges for radiation emergency preparedness, response and recovery and needs to be regularly reviewed to ensure that it continues to evolve to meet societal demands, but also to keep pace with scientific and technological developments and opportunities.

The NERIS community builds upon the knowledge gained from a wide range of research projects undertaken in this field. A selection of the most relevant is summarised to demonstrate how important areas for research and development have been identified and addressed.

The current research priorities for NERIS are published in the Strategic Research Agenda (SRA) which is under review. Three challenge areas have been identified as part of the SRA covering the topics of:

- radiological impact assessment,
- protective action strategies and,
- establishing a transdisciplinary and inclusive framework for emergency preparedness, response and recovery.

The roadmap considers the importance of these challenge areas and the underlying key topics for NERIS and has mapped these across to the Joint Radiation Protection Roadmap developed by the consortium of European radiation research platforms known as MEENAS.

On the basis of this cross-cutting analysis, and taking into account the new challenges posed by the war in Ukraine, four lines of action have been identified, bringing together the main research priorities and revisiting and updating NERIS's challenges for the coming years.

These updated challenges are:

(1) optimisation of management strategies for the transition and recovery phase,
(2) uncertainty quantification, data assimilation and monitoring strategies,
(3) inverse modelling and,
(4) lessons identified from Ukraine and implications for emergency preparedness.

These challenges are expected to make a decisive contribution to significantly advance the holistic design and development of EPR&R in the coming years, in line with the joint game changers for radiation protection. This presentation provide details on the development and contents of the roadmap linking with NERIS Strategic Research Agenda and the role of NERIS in identifying emerging research challenges.

Holistic and inclusive framework for preparedness for emergency response and recovery

Review of the management of non-food goods in Japan after the Fukushima accident

Eymeric Lafranque[a], Pascal Croüail[a], Anne Mathieu[b], Natalia Bastrikova[b]
[a] Nuclear Protection Evaluation Centre, CEPN, France
[b] Nuclear Safety and Radiation Protection Authority, ASNR, France

1. Objectives

This paper describes the work carried out by CEPN for ASNR (ex-IRSN) in 2022 to respond to a request from the French Ministry of Economy concerning the management of non-food manufactured products in a post-accidental situation. This work focused on identifying management issues of goods in recovery phase, specifically levels or thresholds for the use of materials, products, and raw materials. This paper gives a focus on the feedback from post-accident Fukushima experience and reflections of international organisations on this issue.

2. Methodology

CEPN contacted international organisations (ICRP, AEN-OCDE, IAEA…) and radiological protection authorities to gather information on strategies for managing radiological contamination of non-food goods. The findings of the European research project PREPARE[1] were also considered, and additional interviews were conducted with Japanese experts who were involved in discussions on setting control levels for contaminated goods. Two questionnaires were also shared with CEPN's contacts regarding the management of manufactured goods in Japan. A review of the available online literature on this topic was carried out to supplement the information collected.

The following sections provide an overview of how different industries—ranging from wood and paper to construction materials and automotive manufacturing—responded to this situation. These responses included the implementation of regulatory and operational radiological criteria, often shaped by public concern, international trade requirements, and the need to restore consumer confidence. This analysis also explores the measures taken for imports and exports, the circulation of potentially contaminated goods within Japan, and the recycling of low-level contaminated materials. By examining these sector-specific experiences, this paper aims to highlight the diversity of approaches, and the lessons learned in managing non-food goods in a post-accidental context.

3. Post-Fukushima feedback

Following the Fukushima Nuclear Power Plant (FNPP) accident in 2011, some industrial sectors, including the wood, paper and manufacturing industries, were subject to regulations with specific radiological criteria. These sectors were occasionally subject to special attention both by authorities and producers themselves, with radiological criteria mostly established in response to consumers or importers concerns. In this context, these radiological criteria were either regulatory criteria or operational.

[1] PREPARE (2013-2016) Work Package 3: Management of contaminated goods.

3.1. Industry

3.1.1. Wood sector

In the wood industry, Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF) set maximum levels of cesium in firewood (40 Bq/kg) and charcoal (280 Bq/kg) in 2011 to prevent exposure above 10 µSv/year under any circumstances when used for cooking[2]. A level for firewood (≤ 8,000 Bq/kg) has also been set to allow conventional ash landfilling. The Fukushima Prefecture has also decided to restrict trade in wood from forests with air dose rates above 0.5 µSv/h.

3.1.2. Paper Industry

Marusan Manufacturing (in Minamisoma city), which had been closed right after the earthquake, reopened 3 months after evacuation orders were put in place. As a consequence, some media claimed potential danger of Fukushima paper, due to the use of contaminated wood chips in the mabufacturing process . Marusan indeed struggled processing bark to bring contamination levels below detection thresholds, which were lower than regulatory standards[3]. Daio Paper also stopped operations in its factory, partly due to concerns about contamination in the Prefecture[4].

3.1.3. Construction materials and civil engineering

While this sector was not initially identified as a priority for radiological monitoring, practical developments soon brought it to the forefront. The detection of contamination in a residential building in Nihonmatsu in December 2011 prompted the Japan's Ministry of Industry to establish a specific criteria for the shipment of crushed stone and aggregates from quarries: 100 Bq/kg total cesium for use in construction projects for public use, with a maximum dose rate of 0.23 µSv/h[5].

3.1.4. Automotive industry (new and used vehicles)

According to the Japan Used Motor Vehicle Exporters' Association (JUMVEA), controls were carried out with a threshold of 0.3 µSv/h[6], since following the accident, several companies sought to reassure car buyers[7]. JUMVEA noted that the number of vehicles exceeding the 0.3 µSv/h threshold, required to remain in Japan, had fallen from 6 544 in 2012 to 48 in 2018 (out of a total 1 326 597 exported used vehicles)[8].

3.1.5. Electronic components

Alpine, an electronic components manufacturer based in Iwaki city, implemented several actions in 2011 to answer concerns from employees and customers[9] such as dose rate and contamination controls in production areas, checking potential contamination of products[Erreur ! Signet non défini.]. The contractor, TÜV Rheinland, did not disclose the certification criteria.

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[2] Q&A on setting guide values for firewood and charcoal used for cooking and heating. MAFF, December 2011 (last accessed in April 2025)
[3] Masaharu Tsubokura (Fukushima Medical University), interviewed by CEPN
[4] Zero Coupon Convertible Bonds due 2020 – Investment Considerations. Daio Paper Corporation, 2015
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[6] CarShopReport, November 2013 (https://www.goonews.jp/carshop_detail.php?id=163 , last accessed in April 2025)
[7] CRN March 2011 (last accessed in April 2025).
[8] Radiation Testing. Integrity exports, 2018 (last accessed in April 2025)
[9] T. Yoshioka, Alpine, NEA Workshop on Preparedness for Post-Accident Recovery Process: Lessons from Experience, February 2020

Kikuchi Prototyping and Electronics Co, located in Iitate, is one of the few companies to have maintained operations in the Special Decontamination Area (SDA) after the evacuation of the village, carrying out radiological monitoring to reassure staff and customers. Communications don't have details on the inspection procedures[10].

3.2. Imports and exports

3.2.1. Control of exports by Japanese authorities

Radiological controls of port and airport containers are carried out in accordance with government guidelines[11]: decontamination is only implemented if air dose rate exceeds three times the measured background radiation (IAEA-TECDOC-1162)[12]. If dose rates exceed 5 μSv/h, port authorities report to the Ministry and inform the owner before any decontamination is carried out (International Maritime Dangerous Goods Code IMDG § 7.1.14.12).

3.2.2. International control of imports of Japanese goods

For maritime transport, the following summarizes information from the White Paper on international economics and markets published in 2011[12], completed with insights from interviews[13].

- Controls are carried out on containers and ships, with surface contamination criteria generally already used in normal international transport conventions (4 Bq/cm^2 **βγ**, 0.4 Bq/cm^2 **α** - IAEA TS-R-1).
- In Europe, controls were only carried out on ships and containers. Member states were requested[14] to report dose rates of ships and containers above 0.2 μSv/h and details of any detected contamination.
- In China, maritime containers were controlled with lower levels than in Europe: 0.04 Bq/cm^2 **α**, 0.4 Bq/cm^2 **β**,**γ**.
- Internationally, significant variability is observed for dose rate criteria used (variability of an order of magnitude). The controls and thresholds used indicate that their main objective was to detect hotspots rather than contaminated product lines.

For air transport, some countries have conducted controls on products transported by air from Japan[13]:

- In Hong Kong, a surface contamination inspection was implemented for all airfreight from Japan.
- The International Aviation Civil Organization issued guidelines in 2011 for transporting contaminated people and their goods[15], with decontamination thresholds of 0.4 Bq/cm^2 **β**, **γ** and 0.04 Bq/cm^2
- In China, air containers were controlled with maritime containers levels (0.04 Bq/cm^2 **α**, 0.4 Bq/cm^2 **β**,**γ**);
- USA customs performed controls on air cargo with alert thresholds at 0.4 Bq/cm^2 or 4 Bq/cm^2.

[10] Business continuity […] at Kikuchi Manufacturing. Reconstruction Agency, 2013 (, accessed in December 2021)
[11] Guideline on Radiation Measurement for Export Containers in Port. MLIT, August 2011
[12] White Paper on International Economy and Trade 2011, Chapter 4 Section 3. METI, August 2011
[13] Haruyuki Ogino, CRIEPI, PREPARE Workshop (WP3), November 2015
[14] ECURIE messages from April 14 and 15, 2011
[15] Dangerous goods panel (DGP). DGP-IAC, DGP-IAC Workshop 4-8 April 2011

3.3. Circulation of potentially contaminated non-food manufactured goods in Japan

Some companies contracted High Tech Plaza (HTP) technical centers in Iwaki and Tsukuba, to carry out radiological controls on manufactured goods in order to exclude the presence of any contamination and reassure customers, based on transport criteria. The technical centers established their own protocols based on the ISO 7503-1 standard. Commissioning companies decided on themselves whether to sell or dispose their goods based on the results.

The Fukushima Prefecture purchased measurement equipment for citizens to verify the safety of local goods, deployed in April 2011 and loaned to companies upon request via HTP. Some goods were controlled by HTP at the request of owners[13], to verify their safety compared to radioactive materials transport criteria.

There is too few information on governing arrangements for the circulation of non-food products in Japan after the Fukushima Nuclear Power Plant accident: potentially affected companies in evacuation zones had to stop activities for several months or years, often relocated outside the Fukushima Prefecture. There are also no examples of circulation restrictions of potentially contaminated goods outside evacuation zones or radiological controls at borders between regulated and non-regulated zones. Contaminated items such as vehicles and goods could have moved from one zone to another the first months after the accident[16].

3.4. Recycling of low-level contaminated materials

3.4.1. Recycling of disaster debris and decontamination wastes

The Japan Nuclear Regulation Authority (NRA) developed a recycling strategy in 2011 to allow recycling of disaster debris for civil works, if use or occupation of works does not expose the public above 10 µSv/year. This led to a calculated guideline of 3,000 Bq/kg for recycling concrete in road foundation works, found by simulating impact on road users and nearby residents, considering use of a protective layer (30cm) [17].

To reduce the volume of soil coming from remediation, the Ministry of Environment allowed its recycling in civil engineering works in a directive, by sorting soil with a radiological criterion[18]:

- The soil mass activity must be less than 8,000 Bq/kg, adaptable to some conditions. This criterion was calculated to keep exposure bellow 1 mSv/year during construction and 10 µSv/year thereafter[19,18].
- Use of such soil is limited to civil engineering projects: embankments, landfilling, resource crops soil.

[16] Communication between M. T. Homma (JAEA) and CEPN
[17] Landfill Disposal Plan of Specified Waste Utilizing the Controlled Disposal Site. MOE, February 2018 (last accessed April 2025)
[18] "Basic policy for the safe use of land removed and transformed into recycled materials". MOE, 2016 (last accessed April 2025)
[19] "Dose Assessment for Use of Reclaimed Land", MOE, June 2016 (last accessed April 2025)

The main objections from societies such as Friends of the Earth Japan to recycling contaminated soils have focused on[20, 21, 22]:

- The inadequacy of the selected criterion with the clearance threshold of 100 Bq/kg applied in Japan to radioactive materials deemed "harmless", eligible for 'release' without control by the authorities (the so-called clearance level);
- Their use in structures with a lifespan or operation period not exceeding 70 years, which could potentially lead to the return of materials still contaminated at more than 10 times current release thresholds,
- The risk of structure degradation after natural disasters and contamination of the environment by contaminated soils that have lost protective layers and isolating structures.

In 2015, CRIEPI (Central Research Institute of Electric Power Industry) proposed an unconditional release level to limit the additional dose to 10 µSv/year in accordance with National Security Council (NSC) regulations[23], with a contamination criterion of 10 Bq/cm2 for releasing contaminated materials. JAEA also proposed a set of criteria to release FNPP materials, for use in asphalt or concrete roads, respectively 13,000 Bq/kg and 100,000 Bq/kg, limiting dose rates to 1 µSv/h at 1m from the structures[24].

4. International reflections on management of non-food goods

4.1. PREPARE Project

The PREPARE project (2013–2016), funded by the European Commission, aimed to improve preparedness and response to nuclear and radiological emergencies in Europe. It was initiated in the aftermath of the Fukushima accident to address identified gaps in emergency management. A specific area of PREPARE's work addressed the management of non-food, and non-manufactured goods (e.g., raw materials, construction materials, natural products) in post-accident contexts. Key findings were the following[25]:

- The absence of a consistent international regulatory framework for these goods: while food products benefit from established standards such as those provided by the Codex Alimentarius, non-manufactured or non-food goods would often fall into a regulatory grey area, leaving authorities uncertain about appropriate handling procedures after contamination. Cases studies on existing guidelines from the International Civil Aviation Organization and U.S. airport authorities illustrated the practical complexities involved in applying such standards across different contexts.
- The influence of public perception and market dynamics on decision-making: the acceptability of using or selling contaminated goods would be shaped by how the public perceives the risk, the level of market confidence, and broader economic considerations.
- The need for context-sensitive criteria to guide decisions on the clearance and reuse of non-food goods.
- The importance of improving communication strategies, to better address public concerns and foster trust, and to foster dialogue among stakeholders for achieving a balanced approach.

[20] https://foejapan.wordpress.com/2018/09/02/0102/ September 2018, FOE Japan (last accessed April 2025)
[21] https://www.foejapan.org/energy/fukushima/200131.html January 2020, FOE Japan (last accessed April 2025)
[22] https://webronza.asahi.com/national/articles/2019022800005.html February 2019, (last accessed April 2025)
[23] Operational level for unconditional release of contaminated property from affected areas around FNPP. Haruyuki Ogino, CRIEPI, 2013
[24] Study on restricted use of contaminated rubble on Fukushima Daiichi NPS site, JAEA, 2019
[25] Overview of the PREPARE WP3: management of contaminated goods in post-accidental situation – Synthesis of European stakeholders' panels. S. Charron et al., Radioprotection 51(HS2), S83-S91, DOI: 10.1051/radiopro/2016038, 2016

4.2. RIVM

The Dutch National Institute for Public Health and Environment (RIVM) presented proposals to comply with the reference level of 1 mSv/year as recommended in ICRP Publication 103[26]. This work resulted from the PREPARE project and presented at a metting of the NERIS Contaminated Goods Workshop in Madrid, in 2013. For managing manufactured goods, RIVM proposed various guideline values, with approaches considering the management of a distant accident as:

- A planned exposure situation, with release levels (by type of products) complying with a reference dose of 10 µSv/year; or surface contamination controls with a maximum level set at 4 Bq/cm^2 and verifying compliance with the reference dose.
- Or an existing exposure situation, by complying with a reference dose of 1 mSv/year, considering the possibility of multiple exposures, equivalent to a reference dose of 100 µSv/year per type of product.

In 2013-2015, RIVM developed the SUDOQU model in collaboration with Bel V, the radiation protection Technical Support Organisation and subsidiary of the Federal Agency of Nuclear Control (FANC). This model allows dose assessment from using a contaminated object with various exposure scenarios.

4.3. European Commission - Article 31

The Article 31 Expert Group of the Euratom Treaty proposed a criterion in 2011 for controlling non-food manufactured goods such as ships, containers, and non-food goods imported from Japan in Europe[27]. The EG proposed to set the threshold at 4 Bq/cm^2 (**β**, γ), above which the owner must decontaminate its goods. The EG notes that the 2011 Basic Safety Standards do not define maximum permissible levels for non-food manufactured goods, and that the release criterion of 10 µSv/year is sufficient as it is much lower than the levels applicable in post-accidental situations.

4.4. HERCA

HERCA (Heads of the European Radiological protection Competent Authorities) expressed its position in 2015 on regulations for managing non-food goods[28]. The working group concluded that Europe would face significant difficulties in harmonizing its approach, mainly in establishing exemptions from existing international regulations for the transport of dangerous goods.

HERCA also highlighted that international regulations were not designed to address scenarios of accidents such as that of Fukushima, their use could seriously hinder commercial traffic even in the case of a "distant" accident. According to HERCA, a severe accident in Europe would subject commercial traffic to regulatory deadlock.

[26] Surface-contaminated non-food goods in the Netherlands after distant nuclear accidents. Van Dillen et al., NERIS ConGoo Workshop, 2013

[27] Article 31 Group of experts, meeting on 8-9 June 2011, opinion related to the accident in Fukushima, measures with regards to containers and conveyances, and goods […] imported in the EU after the accident in Fukushima. HERCA, June 2011

[28] Regulatory Deficit Regarding Contaminated Non-Food Products. HERCA, 2015

4.5. IAEA

The IAEA proposes restricting the use of vehicles, equipment, and other goods to a dose of 10 µSv per year, over the entire lifetime of the equipment and goods, regardless of the nature of the manufactured goods in its General Safety Guide n°18[29]. In this GSG, IAEA proposes an application of the concept (Annex VII) by distinguishing three cases of contaminated material transfer based on its origin and destination[29]:

- Exclusively outside the site (Off-site → Off-site)
- Inside the site (On-site → On-site)
- From the site to outside the site (On-site → Off-site)

IAEA is also revising its General Safety Guide on "Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency" (GSG-2)[30], with new method to calculate Operational Intervention Levels (OIL), and related operational criteria for trade of non-food products containing radionuclides. National (OIL_c) and international trade (OIL_{InTrd}) of non-food goods would be applicable for EPC I, II accidents, EPC IV emergencies scenarios[31]. These OILs are aimed at controlling the ambient dose rate at 10 cm from the surface of goods, together with specific surface activity concentrations for internationally traded goods, and could be used as follows:

- Use is safe for all members of the public < OIL_c ≤ Use, distribution and sale have to be restricted.
- Use is safe for all members of the public < OIL_{IntTrd} ≤ Trade has to be restricted provided that such restriction does not result in severe health impacts. If so, they can still be traded until replacements are available.

In this revision of GSG-2, IAEA recommends controlling ambient dose equivalent rate for monitoring vehicles, equipment, items, and non-food commodities during a nuclear or radiological emergency.

5. Discussion

This overview of lessons learned from the management of non-food goods in post-accidental situations demonstrates that the main control measures for potentially contaminated goods have only applied to a limited range of item types.

The focus of controls was on containers upon arrival at ports or airports, mostly using criteria adopted for the transport or detection of radioactive materials in normal situations. Thus, few measures have been taken to control non-food products, whether exported from Japan or sold in the domestic market within or outside the Fukushima prefecture. When measures were taken, they were often in response to customer concerns about the safety of the products they were purchasing.

Japan did not have a generic regulatory framework for managing non-food goods, so thresholds were established based on existing regulations for managing other types of situations. Only a few specific

[29] Application of the Concept of Clearance, GSG-18 (Revision of Safety Guide RS-G-1.7). IAEA, 2023

[30] Criteria for use in preparedness and response for a nuclear or radiological emergency (Revision of GSG-2), DS527, IAEA, Step 8 Soliciting comments by Member States

[31] EPC I involves nuclear power plants with potential for severe off-site consequences, such as core meltdowns or large radioactive releases, requiring urgent public protective actions like evacuation. EPC II covers facilities like research reactors or industrial irradiators, where accidents may cause significant on-site exposure but limited public risk, focusing on worker protection. EPC IV includes transport accidents and orphan sources, emphasizing rapid response, public safety, and source recovery in uncontrolled environments. (see link)

industries, such as the wood and automotive markets, were subject to specific radiological monitoring. Companies implemented methods for testing their products by themselves, with processes of "radiological quality certification" based on occasional measurements conducted by independent third-party organizations, to demonstrate the safety of their products to customers.

It is likely that if other specific issues had arisen, specific values for managing manufactured goods in post-accidental situations would have been defined.

The lessons learned from managing food products illustrate the high complexity of determining generic and fixed management criteria over time. When criteria were established, they were adapted to different phases of the accident. These criteria further evolved during the long-term radiological protection optimization process. They also vary in space: values are established for the immediate vicinity, others for more distant areas, or in another country.

The coexistence of multiple sets of values depends on the evolution of the health or environmental policies of the countries involved, the origin of the products, their actual or potential consumption, radionuclides to be considered, the technical or logistical control capabilities, local traditions, ethical considerations…. The temporal and spatial variations mentioned above further complicate understanding and communication, for individuals involved in radiological risk management or decision-making.

The working groups established within the framework of the European research project PREPARE concluded that it was necessary to avoid being overly rigid when establishing criteria for the radiological situation management of contaminated goods (both food and non-food) in post-accidental situations. It would be more appropriate to focus the reflection of all stakeholders involved in post-accidental management on the process of rehabilitating the living conditions of affected populations and resuming economic activity in the affected territory, rather than on the numerical values of the criteria that would need to be established and used when the time comes.

In light of these considerations, it is advised to avoid defining rigid criteria for managing manufactured goods too far in advance of a radiological accident based solely on hypothetical exposure scenarios. Such predefined assumptions risk being either overly conservative or insufficiently protective when confronted with the actual circumstances of an event. Instead, the preparation phase should focus on developing adaptable frameworks, building decision-making capacity, and establishing mechanisms for rapid assessment and stakeholder engagement. This approach would allow for a more responsive and context-sensitive strategy that can account for the specific socio-economic, health, and environmental conditions prevailing at the time of the accident, as well as the observed severity and local or national priorities.

Radiological Emergency Program of Valencia Region

M. Simeó [a], T. Cámara [a], V. Delgado [a], J. Díaz [a], M. Martínez-Roig [a], C. Roldán [b]
[a]Instituto de Física Corpuscular (IFIC), Centro Mixto, Universitat de València-CSIC
[b]Instituto de Física de los Materiales (ICMUV), Universitat de València

Purpose

The growing worldwide use of radioactive isotopes for industrial, research, power generation and medical purposes has resulted in a large dissemination of radioactive isotopes in society. Consequently, there is a concern among states and organizations regarding the accidental release of radioactivity in the environment producing a radiological emergency.

The Laboratory of Environmental Radioactivity of the University of Valencia (LARAM) has an agreement with the Government of the Autonomous Community of Valencia to elaborate a monitoring plan for radiological emergencies.

Materials & Methods

A mobile system for measuring and analysing gamma emitters in situ, that includes NaI and HPGe placed in a mobile structure was designed and built. This system allows for rapid gamma measurements in case of a radiological emergency. It is crucial to know the background in the surroundings of radioactive facilities previous to an accident.

For this goal, measurements are carried out with the aim of characterizing the environment and assessing the degree of recovery of the area after the event. Simulations of different emergency situations are conducted with the JRODOS program.

Results

With this system, a mapping of different radiological facilities of interest in the Valencia region was obtained, as well as reference data for the recovery of the areas in case of an accident. Simulations of different emergency situations were carried out, predicting the radioactive contamination for various weather conditions.

Conclusion

An action protocol for radiological emergencies was elaborated. This protocol consists of carrying out quick measurements in situ with the help of portable detectors. Background maps of the main radiological facilities of the Valencia region are being produced.

JRODOS simulations allow us to assess the risks to the population during the first hours after a radiological accident. This protocol has been tested in emergency drills organised by the local authority.

OECD-Nuclear Energy Agency Sixth International Nuclear Emergency Exercise (INEX-6)

M. Tombette[a], C. Mogg[b], J. Garnier-Laplace[b], J-H. Kruse[b], P. Wright[c], S. Runacres[d], P. Nunes[e]
[a]Nuclear Safety and Radiation Protection Authority (ASNR), France; [b]OECD– Nuclear Energy Agency (OECD-NEA), France; [c]Health Canada, Canada; [d]Department for Energy Security and Net Zero, United Kingdom; [e]Portuguese Environment Agency (APA), Portugal

Since 1993, the International Nuclear Emergency Exercise (INEX) series (NEA, 2023), organised by the OECD Nuclear Energy Agency (OECD-NEA), has proved successful in testing, investigating, and facilitating improvements in emergency management systems nationally and internationally.

Previous INEX exercises focused largely on national and international aspects of early phase management of emergencies at nuclear power plants and more recently, in INEX-3 and INEX-4 (NEA 2007, 2013), have touched upon issues associated with consequence management and the transition to recovery. INEX-6 will focus solely on the long-term recovery phase, which has not been tested before at the international level.

Long-term recovery is a challenging and costly phase after an emergency, and one that is highly complex to exercise (NEA, 2022a, 2022b). The considerable number of issues that local, national and international authorities will be faced with leads to difficulties in setting up an exercise that adequately tests all aspects of recovery. It is also difficult to replicate reality in terms of condensing the recovery timeline into a single exercise. In reality, policy leads, lawyers, decision makers, regulators, government departments and, public authorities, will have more time to deliberate and decide on the course of action to take. With this in mind, INEX-6 has been developed as a series of four modules to reduce the complexity involved and tackle each of the recovery issues as manageable, bite-size exercises.

These modules have been developed to test the management of the following recovery themes: (i) long-term health impacts, (ii) food safety, (iii) remediation and decontamination, and (iv) radioactive waste management. Cross-cutting issues, such as stakeholder engagement, communications and international assistance, have been built into all modules.

A scenario common to all modules has been developed. As this is an international exercise, the scenario needs to apply to nuclear (any type of facility) as well as non-nuclear countries. Developing a generic scenario that is applicable to all countries and contains the appropriate amount of technical detail to test long-term recovery issues presented an additional challenge for the exercise design team.

The INEX-6 exercise, which is due to take place between January and March 2024, will involve 28 participating countries, territories and International Organisations. Lessons arising from the INEX-6 exercise will be captured and reported on by the OECD-NEA, therefore providing valuable learning to feed into the International emergency preparedness, response and recovery community.

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92260 Fontenay-aux-Roses, France