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Regulatory Supervision of Legacy Sites: from Recognition to Resolution

Report of an international workshop
Oslo, 17–19 November 2015

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Abstract:
This report describes the presentations and discussions from the workshop, which also resulted in the identification of further research and cooperation needs. NRPA has substantial bi-lateral cooperation experience with the Russian Federation, central Asian countries and Ukraine with special focus on radiation and nuclear legacy problems. The objective of the last workshop was to promote the sharing of experience on practical regulation of a wide range of nuclear and radiation legacies.

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Strålevern, kjernesikkerhet, atomarv, internasjonale anbefalinger, brukt brensel, radioaktivt avfall, kontaminert land, beredskap, miljøovervåking, miljøkonsekvensutredning, strålevern av befolkning og arbeidstakere, beskyttelse av miljø, tilsyn og kontroll.

Resymé:
Denne rapporten beskriver alle presentasjoner og diskusjoner fra en workshop, som også resulterte i å identifisere videre forskning og samarbeidsbehov. Strålevernet har betydelig erfaring fra bilateralt samarbeid med Russland, Sentral-Asia og Ukraina med spesielt fokus på problemer knyttet til «arv». Målet med seminaret var å dele erfaringer om praktisk regulering av et bredt spekter av atomarv.

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Approved:

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Regulatory Supervision of Legacy Sites: from Recognition to Resolution

Report of an international workshop

Oslo, 17 - 19 November 2015

Workshop Coordinators:

Malgorzata K Sneve

Per Strand

Statens strålevern

Norwegian Radiation Protection Authority

Østerås, 2015

Preface

The following welcoming words set the scene for this report of a workshop hosted by the NRPA in Oslo, 17 - 19 November 2015, on the subject of Regulatory Supervision of Legacy Sites: from Recognition to Resolution

"Dear colleagues,

I am delighted to welcome you all to Oslo for this workshop on "Regulatory Supervision of Legacy Sites: from Recognition to Resolution".

It is a pleasure to meet again some valued colleagues, particularly those from previous successful workshops, held in Washington, on: "Coordination of Regulatory Arrangements for Nuclear and Radiation Emergency Preparedness and Response: Early and Later Phases" and then in Oslo, on: "Emergency Preparedness and Response, with Special Focus on Exercises and Training". We have also enjoyed fruitful scientific cooperation, as was most recently highlighted at the Legacy workshop held in association with the ICRER conference in Barcelona, in September 2014.

But I am also very glad to have this opportunity to meet and work with some new faces from additional organisations. This is a complex technical and regulatory area with global implications. The wider the inputs, the better the results we can expect.

Historically, our story begins with Russian-Norwegian co-operation on environmental protection established in the early 1990s; particularly the development of a Norwegian Plan of Action in 1995 to improve nuclear and radiation safety in Northwest Russia was a major step forward. This Plan focussed on managing the nuclear legacy from the cold war and other operations carried out in the time of the Soviet Union.

As the radiation and nuclear safety regulatory authority in Norway, it fell naturally to the NRPA to assist the Norwegian Ministry of Foreign Affairs in implementing the Plan of Action. A significant component of the Plan has been for the NRPA to provide support to its sister regulatory authorities in the Russian Federation. It was a great pleasure earlier this year to celebrate ten years of successful cooperation on radiation protection issues with the Federal Medical-Biological Agency of Russia. But I should also mention that our approach is very inclusive, involving the other relevant regulatory authorities in Russia and well as key operators such as Rosatom. It does not make sense for regulators to work in a closed box.

The situation was complex because of the technical and political history. Over the years a remarkable degree of confidence and mutual trust has been built up among all the relevant organizations, allowing for real progress in advancing radiation protection and nuclear safety objectives. NRPA has been delighted in recent years to extend cooperation in this area with countries of central Asia and in Ukraine. The extensive results arising from specific projects addressing real issues has been quite remarkable.

Our bi-lateral regulatory cooperation has been much wider than simple specification of rules; it encompasses the entire regulatory process supporting the development of a deep-rooted enhancement of safety culture; as our current workshop says: from Recognition to Resolution.

So now, I am especially pleased that we are able to take the discussions further at this meeting, with a wider range of organizations, including colleagues from the IAEA, ICRP and the NEA. Our bilateral activities and work in the IAEA International Forum for Regulatory Supervision of Legacy Sites (RSLS) leads us to conclude that there is a lack of international recommendations or guidance on legacy site issues. I am hopeful that this workshop will lead to closer cooperation at the international level, and support the development of practical guidance on application of nuclear safety and radiation protection at legacy sites based on some very practical experience."

I hope participants and wider readers will agree with me that the workshop fully met its objectives and that this report provides consolidated and documented input for further international collaboration in this important area. May I offer my personal thank you to all the many contributors.

Ole Harbitz, Director, NRPA

Executive Summary

The value of regulatory cooperation on regulatory supervision of legacy sites is evidenced by the International Atomic Energy Agency's International Forum on Regulatory Supervision of Legacy Sites. The Norwegian Radiation Protection Authority has been pleased to support this initiative, based on its substantial bi-lateral cooperation experience with the Russian Federation, central Asian countries and Ukraine. To support this bi-lateral work NRPA has also arranged regulatory workshops involving colleagues from the USA, European, Scandinavian and central Asian countries, on a range of scientific and regulatory issues connected with legacy sites. The positive results and recommendations from these activities, as well as further discussions with relevant organizations, led NRPA to arrange a further international workshop that is reported here.

The objective of the workshop was to promote the sharing of experience on practical regulation of a wide range of nuclear and radiation legacies, including:

- Sites and facilities affected by major accidents and incidents.
- Storage and disposal sites and facilities for radioactive waste, which were built and operated prior to there being an appropriate regulatory basis.
- Nuclear technology and development centers and laboratories that were built and operated prior to there being an appropriate regulatory basis.
- Uranium mining and milling facilities and dumpsites for Naturally Occurring Radioactive Material (NORM).
- Former peaceful nuclear explosion and weapons testing sites.

The scope of the workshop included the full range of issues linked to regulatory supervision of nuclear and radiation legacy sites, from the process of recognizing that a legacy exists through to the complete resolution of radiological protection issues associated with management of the legacy.

Participation included 42 representatives of regulatory bodies, operator and technical support organizations, and universities from 11 countries, as well as the International Atomic Energy Agency, the International Commission on Radiological Protection and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development. 25 presentations were given, divided into the following areas.

- Background Presentations
- Technological and Past Practice Operational Legacies
- Legacies Following Accidents
- Uranium Mining and Processing Legacies
- Other Legacies
- Assessments and Communication of Results
- International Perspectives

Free and frank discussion was encouraged after each session and at the end overall points of interest were identified. The workshop provided a very useful opportunity to share understanding and experience of a variety of practical challenges.

Based on all this very substantial and broad ranging input the following key points are noted.

It is evident from the presentations and discussions that many countries are working to address the latest international recommendations, standards and guidance from ICRP, IAEA and NEA. It is also evident that there is a great deal of practical experience in legacy management and regulation in many countries. Nevertheless, many countries have very limited resources or capacity to address scientific and technical aspects of legacy site remediation. Lack of guidelines on remediation and a regulatory process for return to normal unrestricted land use is a stumbling block in many cases.

Learning lessons from the past is very important: to help avoid future mistakes and creation of new legacies; to ensure that legacy management strategies are appropriate to the site of interest, meet protection and safety objectives and address a wide range of stakeholder interests; and to ensure that they are practically achievable. There is continuing scope for sharing of experience. This can be mutually effective at national and bilateral levels, as well as supporting the enhancement of international level documents relevant to legacy sites.

Both chemicals and radiation should be considered at legacy sites to facilitate proportionate risk management, act as a guide to appropriate allocation of resources for remediation and inform a wide range of stakeholders, including those with ultimate responsibility for taking decisions. However, further work is required to address technical issues around assessment and management of mixed contamination to allow this area to move forward.

Key points and challenges in moving from legacy recognition to resolution include the following.

- Every legacy is different and presents a complex variety of relevant prevailing circumstances.
- Technical methods for remediation and regulatory supervision are quite well developed and there is a lot of useful experience, but there is scope for improvement and advantages from harmonisation of methodologies and practice, while acknowledging that their implementation, including the results of optimisation procedures, may lead to different solutions at different sites, according to the prevailing circumstances.
- For successful legacy management, it is important to engage a wide range of stakeholders and seek to obtain their support in a transparent and traceable process. Effective risk communication is a very important part of the engagement process.
- There is a substantial gap between theory and practice and further international guidance on practical application would be valuable. This includes clarification of the application of the concept of emergency, existing and planned exposure situations, and the boundaries between them.
- A holistic approach to proportionate management of different risks is to be encouraged. This may require the review of protection objectives and standards that are applied to different contaminants in different contexts.
- Arising from this, it would be useful to identify common needs of further research and/or technical development based on current experience, including the results of assessments that have already been made.
- Prognostic assessment methods related to legacies that present common relevant features, such as the nature and extent of contamination are available. However, scope exists to improve assessments and bring them into alignment within a common framework of protection objectives. This would then support the consistent application of the principle of optimization.
- Strategically there is a need to link national strategies for legacy site remediation and waste management, including radioactive waste management.

Noting the above factors, the development of a common methodology for legacy management and regulation would be useful. This should be based firmly on the current international framework, with additional guidance provided on moving from the general framework to address site-specific issues. The development of a road map covering all possible legacy issues may however be difficult and an alternative may be to list the questions that should be addressed and provide qualitative criteria for when actions should be taken, what they should address and how they might be implemented. Practical experience on risk identification and risk management could be provided as examples to support the practical application of the methodology.

Remediation needs to be managed as a stage process and the methodology should reflect that process with a focus on overall optimization that integrates all the stakeholders and responsible organizations,

The opinions and other material presented in the report may not be taken to represent the views of the organizations involved. However, it is hoped that the results will support the further development and application of international recommendations, standards and guidance in the regulatory supervision of legacy sites.

Innhold/Contents

1 Introduction

1.1 Background

The value of regulatory cooperation on regulatory supervision of legacy sites is evidenced by the International Atomic Energy Agency's (IAEA) International Forum on Regulatory Supervision of Legacy Sites (RSLS). The Norwegian Radiation Protection Authority (NRPA) has been pleased to support the RSLS, based on its substantial bi-lateral cooperation experience with the Russian Federation (RF), central Asian countries and Ukraine. To support this bi-lateral work NRPA has also arranged regulatory workshops involving colleagues from the USA, Scandinavia and the Russian Federation, on "Coordination of Regulatory Arrangements for Nuclear and Radiation Emergency Preparedness and Response: Early and Later Phases" and "Emergency Preparedness and Response, with Special Focus on Exercise and Training". In parallel, the NRPA also organized international workshops with emphasis on scientific support to regulatory decisions in these areas, on "Radioecology and Assessment Research in Support of Regulatory Supervision of Protection of the Environment and Human Health at Legacy Sites" and "Application of Radioecology to Regulation of Nuclear Legacy Management". The positive results and recommendations from those meetings, as well as further discussions with relevant organizations, led NRPA to arrange a further international workshop that is reported here.

1.1 Objective and topics of interest

The objective of the workshop was to promote the sharing of experience on practical regulation of a wide range of nuclear and radiation legacies, including:

- Sites and facilities affected by major accidents and incidents.
- Storage and disposal sites and facilities for radioactive waste, which were built and operated prior to there being an appropriate regulatory basis.
- Nuclear technology and development centers and laboratories that were built and operated prior to there being an appropriate regulatory basis.
- Uranium mining and milling facilities and dumpsites for Naturally Occurring Radioactive Material (NORM).
- Former peaceful nuclear explosion and weapons testing sites.

The scope of the workshop included the full range of issues linked to regulatory supervision of nuclear and radiation legacy sites, from the process of recognizing that a legacy exists through to the complete resolution of radiological protection issues associated with management of the legacy.

Topics of interest identified from the previous activities included:

- Legacy management experience from past events: what worked, what did not?
- Basis for development and application of regulatory criteria for legacy site management.
- Effective communication processes at each stage of legacy management.
- Decision making in transition from emergency to existing exposure situation and later stages.
- Coordination among regulatory authorities and executive organizations, including those responsible for safety and protection from other hazardous substances.
- Arrangements for sharing monitoring equipment and trained staff.
- Use of prognostic assessment tools to support legacy management, including selection of options and the optimization of the application of the selected option.

- Sharing underpinning scientific information, which supports decision making on introduction and ending of countermeasures, remediation techniques and waste management.
- Identification of further research needs.

The above list of topics was offered to participants as the potential subjects for discussion, but other presentations falling within the objective and scope of the workshop were also invited. The workshop was conducted in an informal manner with a view to promoting free exchange of ideas, and development of innovative approaches to meeting regulatory challenges. To the same end, simultaneous translation between Russian and English was provided. The opinions and other material presented in the report may not be taken to represent the views of the organizations involved. However, it is hoped that the results will support the further development and application of international recommendations and standards in the regulatory supervision of legacy sites.

1.2 Participation and program of the workshop

Participation included relevant regulatory authorities, organizations responsible for management of legacy sites, site operators, technical support organizations and academic institutions. The full list of participants and their affiliations is provided as Appendix A. They included 42 representatives of 27 organizations from eleven countries as well as the IAEA, the Nuclear Energy Agency (NEA-OECD) and members of various committees of the International Commission on Radiological Protection (ICRP).

Based on the proffered inputs, the workshop was organized into the following topical areas:

- Background Presentations
- Technological and Past Practice Operational Legacies
- Legacies Following Accidents
- Uranium Mining and Processing Legacies
- Other Legacies
- Assessments and Communication of Results
- International Perspectives

The full workshop program is provided as Appendix B

1.3 Preparation and purpose of this report

This report was drafted by NRPA and reviewed by participants for correctness prior to publication. The following Sections summarize the presentations made in each of the topical areas listed above and the discussion in each area. Section 9 provides a summary of overall discussions and Section 10 sets of conclusions and recommendations on meeting regulatory challenges rated to legacies. References are provided in Section 11.

2 Background Presentations

2.1 Background of international focus and cooperation on regulatory supervision of legacies

Malgorzata Sneve (NRPA) opened the meeting by noting that it follows a series of workshops organized by the NRPA, all concerned to promote regulatory exchange and cooperation, as follow:

- Coordination of Regulatory Arrangements for Nuclear and Radiation Emergency Preparedness and Response: Early and Later Phases (Washington DC)
- Emergency Preparedness and Response, with Special Focus on Exercise and Training (Oslo)
- Application of Radioecology to Regulation of Nuclear Legacy Management (Barcelona)
- Radioecology and Assessment Research in Support of Regulatory Supervision of Protection of the Environment and Human Health at Legacy Sites (Bergen)

The highlights, including recommendations, from these workshops are presented in Appendix C.

The objectives of the current workshop were aimed at promoting the sharing of experience on practical regulation of nuclear and radiation legacies, from the process of recognizing that a legacy exists through to complete resolution of the radiological protection (and other protection) issues associated with the management of the legacy, with legacies including:

- sites and facilities affected by major accidents and incidents;
- interim storage and disposal sites and facilities for radioactive waste;
- uranium mining and milling facilities and sites associated with naturally occurring radioactive material (NORM);
- nuclear technology and development centers; and
- former nuclear peaceful and weapons testing sites.

Legacy sites are a global issue and more consideration is required as to how legacies should be regulated. Furthermore, there is currently no international definition of what a legacy is, with definitions varying nationally. The working definition of a legacy adopted the IAEA's international forum on Regulatory Supervision of Legacy Sites (RSLS) was:

> *"A facility or area that has not completed remediation and is radioactively contaminated at a level which is of concern to regulatory bodies"*

This working definition is linked to the regulatory aspects of legacies, rather than to the owner of the legacy and is intended to be broad so as to encompass the variety of legacies bulleted above.

In parallel, the ICRP and IAEA refer to exposure situations that are already present and require control decisions as existing exposure situations that can include natural background radiation as well as residual radioactive material deriving from past practices that were not subject to regulatory control or that remain following emergency situations. There is therefore a link between the NRPA practical definition of legacies and the IAEA concept of existing exposure situations as defined in the IAEA 2014 International Basic Safety Standards (IAEA, 2014). However, there are acknowledged uncertainties (IAEA, 2014) in defining the type of exposure situation that applies in particular circumstances such as the transition from emergency to existing exposure situations, leading to uncertainties in the selection of appropriate protection standards in different legacy situations (see Copplestone et al., to be published.; Sneve and Smith, 2014).

Legacy sites can vary considerably in terms of the volume and activity of wastes present and there are legacy sites at which exposures arise from both planned and existing situations. For example, the NRPA has been working practically on supporting the Federal Medical Biological Agency of Russia (FMBA) in addressing legacy issues at sites in NW Russia, see Figure 1, and in areas affected by releases planned and accidental releases from Mayak PA, in the southern Urals.

In NW Russia, the NRPA-FMBA regulatory cooperation has the objective to enhance the long-term safety culture, particularly in relation to spent fuel (SF) and radioactive waste (RW) at Andreeva Bay and Gremikha (see Figure 1), and implementation via practical projects at these sites. The projects have included threat assessments to identify regulatory priorities; development of norms and standards and regulatory guides and procedures that are specific to the identified priorities; emergency preparedness exercises, monitoring exercises; and the development of safety assessment and visualization tools for dose control and remediation planning, including innovative technologies to support optimization. The cooperation has led to a set of publications that are available from the NRPA website, www.nrpa.no.

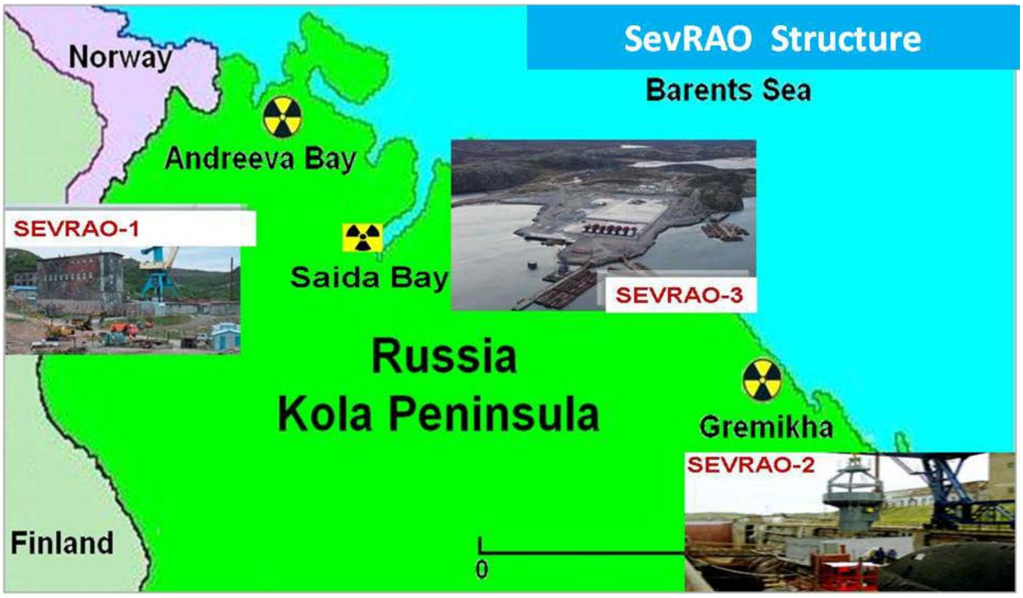


Figure 1. Location of Andreeva Bay and other Russian legacy sites.

The focus of activities at the Andreeva Bay storage facility was on practical and real activities. As a result of an initial threat assessment, a number of technical and regulatory weaknesses were identified, including:

- poor information on the radiological and the physical condition of radioactive waste and spent fuel;
- the spent fuel storage facility was not adequately maintained, with fuel having been moved to the facility following store degradation and unplanned releases;
- a need for new specific technologies and equipment to manage issues at the site;
- unsafe infrastructure and insufficient qualified workers;
- a need for specialized personal protection.

- insufficient information on the existing exposure situation and radiation conditions around the facility leading to uncertainty in dose assessments for workers and members of the public;
- insufficient organization of the interaction between relevant agencies in case of emergencies; and
- insufficient regulatory basis for the further management of radioactive waste and spent fuel, its transport off-site and treatment for storage and disposal.

In terms of regulatory improvements, norms of remediation had to be updated to take account of the abnormal conditions at the site and ongoing development of international recommendations, standards and guidance relating to emergency preparedness and response, worker dose control and performance reliability assessment, protection of the public and environment, plus criteria for long term site restoration and for waste treatment prior to disposal and further management.

Norms for different remediation strategies were developed and expressed in terms of dose constraints (Table 1).

Table 1. Radiological standards for different options of the STS remediation.

Decommissioning option	*Category*	Dose constraint or Reference Level, mSv/year			*Dose limit according to NRB-99*
		Due to residual contamination	Due to the new activity with radiation source use	*Total*	
Conservation	Workers	2	-	2	20
	Population (SA area)	0.1	-	0.1	1
Conversion (“brown lawn”)	A personnel category	3	7	10	20
	B personnel category	1	1	2	5
	Population (SA area)	0.1	0.15	0.25	1
Liquidation (“greenfield”)	Population (STS area)	1	-	1	Lack of norms in NRB-99
	Population (the rest area)	0.1	-	0.1	
Guidance R 2.6.1.25 – 07 «Criteria and Norms for Remediation of Sites and Facilities Contaminated with Man-Made Radionuclides, Pertaining the Federal State Unitary Enterprise «Northern Federal Facility for Radioactive Waste Management» (“SevRAO”) of the Federal Atomic Energy Agency» // Approved by Vladimir Romanov, Deputy Head of FMBA of Russia on 01 September 2007. Main developers: Shandala N.K. (Work leader), Titov A.V. (Responsible executer), Novikova N.Ya., Seregin V.A.					

The cooperation program also gave consideration to human factors that could affect performance reliability. One aspect of the cooperation was therefore to enhance control of human reliability through the development of equipment for pre-shift monitoring and interpretation of worker psycho-physiological conditions ((Shcheblanov et al, 2012). This technique is now applied and also used to support training and preparation of workers carrying out the most hazardous operations. These are due to take place in the coming few years, and the cooperation program continues, taking into account the results of an updated threat assessment (Sneve et al, 2015).

Parallel to the work in NW Russia, NRPA has cooperated with FMBA to consider how existing exposure situations around the Mayak PA nuclear facility. Figure 2 shows the main releases and areas, but it should be noted that the same areas have been affected by planned releases, and may continue ot be so in the future.

Three projects have focused on: characterization of the current status of fish in the Techa River, affected by accidental and planned discharges from Mayak PA; studies of options for treatment of contaminated surface water bodies; and evaluation of the internal exposure of the local population resulting from protracted exposure to long-lived radionuclides (see Suslova et al, 2015). The program provided the basis for consideration of the key scientific inputs supporting regulatory supervision of the area.

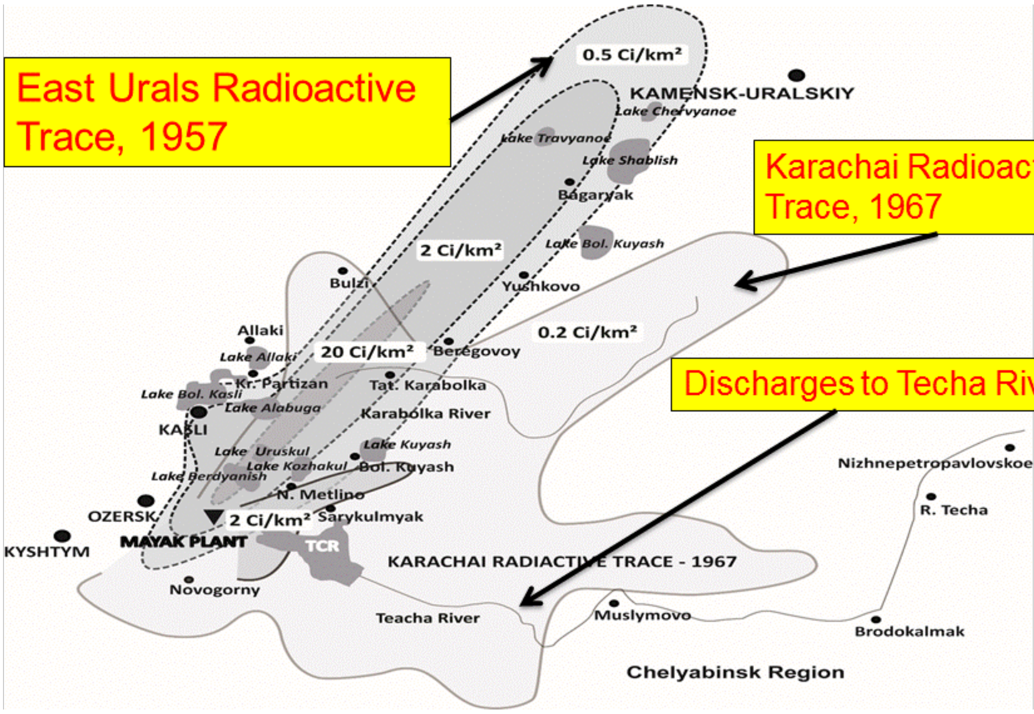


Figure 2.Existing exposure situations around the Mayak PA nuclear facility.

The outputs of the bi-lateral cooperation in Russia, including 10 years of working with FMBA, have included enhanced regulatory requirements and guidance in abnormal situations, including:

- improved procedures for emergency preparedness and response;
- independent assessment of radiation situation at Andreeva Bay;
- development of an innovative approach to performance reliability monitoring;
- practical support in the control of radiation exposures during the most hazardous remediation operations;
- radiological criteria for monitoring and site restoration;

- coordination of remediation activities with radioactive waste management programs; and,
- coordination of radiation regulation with relevant Russian Federation authorities

Based on the results of with working in cooperation with Russia, NRPA expanded its cooperation program in 2008 to address the many legacy issues in central Asia and Ukraine, many of which relate to uranium mining. Central Asia and Ukraine do not have extensive scientific or technical programs to support the management of these legacy sites and rely on international support. The NRPA cooperation program was with the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) and the applied the same overall method to that applied under the Russian cooperation program was applied. The first step was therefore to undertake a threat assessment, which is currently ongoing. Additional ongoing projects include regulation of radiation protection of sources used in medicine and radiation protection in the uranium industry and development of general safety provisions for radioactive waste disposal.

Regulatory threat assessments are an effective holistic procedure for identifying priority tasks and activities with clear objectives and scope. The assessments cover the full range of radiation protection issues, from emergency preparedness and response to long-term site management planning and optimization and radioactive waste management. In addition to being holistic, the approach taken is both integrated (e.g. in recognizing other non-radiological hazards, engaging with relevant authorities, operators and international bodies, and the sharing of experience with other countries with nuclear legacies and through engagement with relevant scientific communities) and innovative (e.g. through the application of new science and tools) to allow optimization from different perspectives and practical application to specific sites and issues.

Among the important lessons learnt from the bi-lateral cooperation programs are that scientific information should be used to address all environmental and human health issues and should not be restricted to those associated with radiation. Programs should be established to address key assessment uncertainties thus improving confidence in the assessment outcome. Furthermore, assessments should be based on a reliable prognostic assessment of future conditions at a site and should provide the basis for balanced advice to decision makers and informed and intelligent optimization. Finally, cooperation and coordination are required between regulators and operators to improve dialogue and transparency.

The main challenges identified include:

- How to reduce uncertainties in prognostic assessment of future conditions and impacts?
- How to address short and long term risks to different populations, proportionately?
- How to address *all* the environmental and human health issues, not just radiation in practice?
- How to maintain interfaces: between regulators, operators and other organisations to support clear responsibility, transparency and dialogue?
- How to improve confidence and trust among all stakeholders?
- How each of the above can contribute to international recommendations and guidance?

2.2 Regulatory challenges in legacy supervision in the Russian Federation

Nataliya Shandala (FMBC) presented.

One of the largest problems relating to legacy supervision is establishing what is the goal or purpose in remediation of a site. The regulatory framework that exists must be considered in combination with the situation to establish what is needed to be done.

The FMBA is responsible for radiation protection and safety at Andreeva Bay and other legacy sites in Russia (Figure 3). Such sites include the range identified in section 2.1. The volume of nuclear legacies in Russia, established under the 2008-2015 Nuclear and Radiation Safety Assurance program, includes 18,000 tons of spent nuclear fuel, 500,000,000 m^3 of radioactive waste located in 1,000 storage sites and facilities, 500 nuclear and radioactively hazardous facilities, and 10 km^2 of contaminated sites requiring remediation. It is envisaged that some 50 to 70 years will be required to address all these legacy issues within the continued radiation safety assurance program.

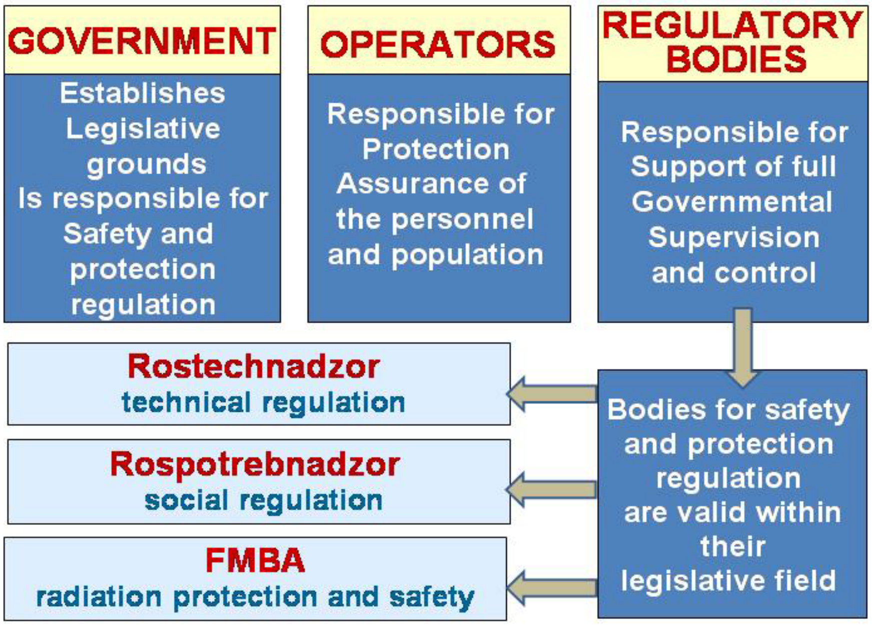


Figure 3.State regulation of radiation safety in Russia: roles and responsibilities.

The assurance programme that ran from 2008 to 2015 has had a number of achievements and a conference was recently held in Russia for all the leading organisations within the Russian Federation that have worked on the legacy issues to summarise what has been achieved to date. A significant fraction of poorly stored SF has been made safe. In addition, a number of surface storage facilities for radioactive waste have closed and sites remediated. The floating technical base 'Volodarsky' has been decommissioned with the large volume of RW on the ship being packaged and stored in special facilities constructed at Saida Bay (see Figure 1).

A new program of activities to address legacy issues in Russia is due to begin in 2016. This will include dealing with the remaining SF issues and is planned to continue until 2025.

In addressing legacy issues, a range of aspects must be regulated, involving a range of organisations with different roles and responsibilities, including technical and social regulation as well as the FMBA role in regulating radiation protection and safety. There is a need to develop new regulatory documents that address radiation safety as set out in the most recent IAEA basis safety standards (IAEA, 2014) and address the requirements of the 2011 Russian Law on RW management. Furthermore, there is a lack of regulations relating to the chronic post-accident exposure of the public and the transition from accident to existing exposure situations has not been considered in current regulations, and a parallel lack of guidance on site remediation and procedures for regulating the return to normal land use and related activities.

The focus of FMBA-NRPA cooperation has been former Russian naval bases in the NW of Russia, but bases also exist in the east (see Figure 4). According to Russian legislation, the FMBA is responsible for the regulatory supervision of all these sites and the organisations involved in addressing the issues.

Figure 4. Russian naval base legacy sites.

The main areas of study in the cooperation have been regulatory threat assessments, independent analysis of the situation and evaluation of doses to workers and members of the public, development of regulatory documents, and improvement of supervision, control and monitoring and emergency response procedures. In the 10 years since 2004 and the beginning of the cooperation agreement there have been 24 collaborative projects undertaken to address radiation safety aspects of Russian sites and develop the overall radiation safety culture. New regulatory documents have been prepared to address requirements for radiological protection of workers and the public and to develop criteria and norms for the remediation of radiologically contaminated sites and facilities. Regulatory documents have also been developed covering environmental radiation monitoring, industrial waste management, criteria for the initiation of emergency protection actions and requirements to support the safe management of nuclear materials.

For remediation activities, the concepts of green and brown sites have been adopted based on the ICRP protection system. Constraints were not deemed appropriate for remediation activities and reference levels were therefore used as the basis for updated criteria. Further achievements have been made in relation to the management of very low level waste in establishing activity levels at which wastes can be taken out from regulatory supervision (Table 2). Large volumes of very low level waste will be produced as a result of remediation activities and such wastes must be sorted and managed safely to ensure that more legacy sites are not created.

There are also mining legacy sites in Russia that are situated in areas rich in uranium and radium. Dose rates up to 15 µSv/h have been recorded and Ra-226 specific activity in soils measured in the range of 200 to 400 Bq/kg. Activities undertaken in support of remediation of these legacy sites have included research to understand the legacy and the development of documents to support the remediation process. There has also been work to supervise and control activities to ensure radiological protection of workers, members of the public and the environment.

Table 2.Categorization of very low level waste and cleared waste on the basis of activity concentrations.

Waste category	Specific β-activity, kBq/kg	Superficial contamination, β-part/m.cm²	Pγ from the package surface, μSv/h
VLLW	0.3 – 12	50 – 500	0.1 – 1
Cleared waste	≤ 0.3	≤ 50	≤ 0.1

The FMBA has also participated in activities relating to uranium legacy areas in central Asia. In support of remediation activities, and through the FMBA-NRPA cooperation, a regulatory guide document has been developed. A monitoring system is also being implemented that will monitor public health and the environment (Figure 5). The monitoring activities are important in assessing the nature of the radiological impact and whether it is responsible for the poor health of the local population. A database is under development that will contain both medical and demographic data for the populations living in the vicinity of the legacy sites. Work is also continuing to support Asian colleagues in the development of documents that will support ongoing remediation and monitoring tasks and to share experience gained through the cooperation programme with Norway on the management of legacy sites in Russia.

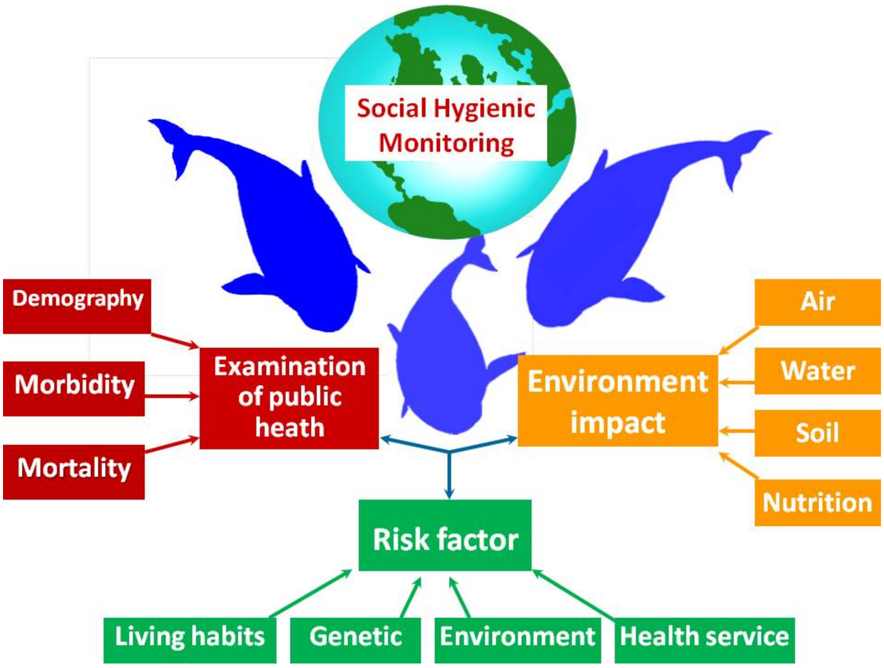


Figure 5. Conceptual scheme of the monitoring system being implemented in support of remediation of the former Russian-owned uranium legacy sites in Central Asia.

In addition to the activities detailed above, the FMBA has also actively contributed to the IAEA RSLS forum, particularly in relation to working group 1 on 'enhancing the regulatory infrastructure'. The objectives of this working group were to study the experience of regulatory bodies when implementing regulatory supervision and, from this, to develop recommendations. An IAEA TecDoc is under preparation based on the results of the RSLS forum.

The main challenges faced when addressing legacy site issues, based on the practical experience gained to date are as follows:

- In order to properly maintain contaminated sites, regulations need to be developed that are focused on the particular site and the issues faced.
- Public living standards must also be considered, bearing in mind that actions to remediate legacy sites may affect the public living in neighbouring territories.
- The credibility of the authorities responsible for developing and implementing protective strategies and the trust of the public needs to be high.
- Public concern with legacy sites may not be limited to radiation protection issues, but may also include public health, economic, social and psychological and environmental concerns.

There can also be demographic challenges such as the availability of information on legacy issues and the availability of funds to support training and legacy management activities.

When considering the challenges, key issues should be identified. The principles of justification and optimisation applied to the implementation of protection strategies, which should encompass a series of protective actions directed at relevant exposure pathways. The responsible authorities should also take the responsibility of ensuring that protection strategies provide an overall benefit to society in addition to individuals. It is also strongly recommended that local stakeholders be involved at all stages of planning, public hearing and implementation stages. Radiation monitoring systems and health surveillance strategies should also be in place, a radiation safety culture should be disseminated and local people should be appropriately trained and provided with appropriate practical knowledge.

As a result of the cooperative work undertaken to date, it is recommended that the normative and legislative framework for the management of legacy sites be further developed, with existing exposure situations being introduced to legislative frameworks and put in according with the international system of radiological protection. It is also suggested that concepts and definitions are agreed and criteria for remediation of sites are developed that will allow the return of legacy sites to normal economic activities. Recent documents from the ICRP and IAEA provide flexible approaches to help address these issues. To support regulation, a large amount of information is required to inform on the changing radiation situation during remediation, with information often being held by different organisations. A structured approach to drawing together this information is required to allow analysis of all information in support of decisions. The development of a single common set of standards for the collection of radio-ecological information would be highly beneficial in this regard, allowing the integration of data from various agencies within unified analytical information systems for the remediation of nuclear legacies.

International experience in remediation of nuclear and uranium legacies shows that site contamination is complex, including both radioactive and chemical contamination. The complex nature of contamination should be evaluated at sites and taken into account when developing derived standards for the remediation of sites. Current knowledge is not however sufficient to allow a full evaluation of the impacts of mixed contaminants on people and the environment as a result of synergistic and antagonistic effects. The monitoring of radiation, chemical and biological aspects of legacy sites could provide the basis for important regulatory tools to be developed upon which standards could be based and further environmental monitoring targets identified at other sites requiring remediation activities.

3 Session 1: Technological and Past Practice Operational Legacies

3.1 Lessons learned from the Marshall Islands: a nuclear legacy

Patricia Worthington (US DOE) presented.

The US has a number of international cooperative programs on radiological and environmental monitoring. For example, there is a governmental agreement with Russia for joint cooperation on research of radiation effects through the Joint Coordinating Committee for Radiation Effects Research (JCCRER) and a Russian effects database has provided the basis for the US to revise protection standards. Monitoring programs have also been undertaken on the health of Japanese atomic bomb survivors. Department of Energy worker studies have also been undertaken and a program addressing the clean-up and resettlement of populations affected by past weapons test activities in the Marshall Islands continues, which provides a unique case study on the management of a legacy site.

The Marshall Islands are located between Australia and Hawaii (Figure 6). The location itself provides a real challenge in terms of legacy management due to the logistics involved in getting people and equipment to the area for field missions. The clean-up and resettlement program is driven by science.

The Marshall Islands were the site of 67 atmospheric nuclear tests conducted by the US between 1946 and 1958. The tests were conducted at Bikini Island and Enewetak Island, with the most significant in terms of creating a legacy being a 15 MT detonation at Bikini Island in 1954. As a result of these tests, the surrounding islands have been impacted, particularly the northern islands located to the east of Enewetak and Bikini Islands. Civilian populations living on Rongelap and Utrok Atolls had to be evacuated to Kwajalein Atoll to minimize further exposure and to receive medical care. Evacuees from Rongelap received about 1.9 Gy whole body radiation and thyroid gland doses up to 52 Gy, although no deaths directly related to thyroid cancer have occurred to date. Skin lesions were evident in the immediate aftermath as well as abdominal discomfort, loss of appetite and reduction in white blood cell counts with around half of those affected being under 18 years of age. The atmospheric tests, and particularly that resulting in evacuation, severely damaged relations between the US and the people of the Marshall Islands. Recorded deaths among the population have resulted from acute myelogenous leukemia in a young child and from breast, prostate and lung cancers. Monitoring of the environment and the population has continued to support decisions on site restoration and on the relocation of people as well as to monitor the health of people affected and address anxiety issues.

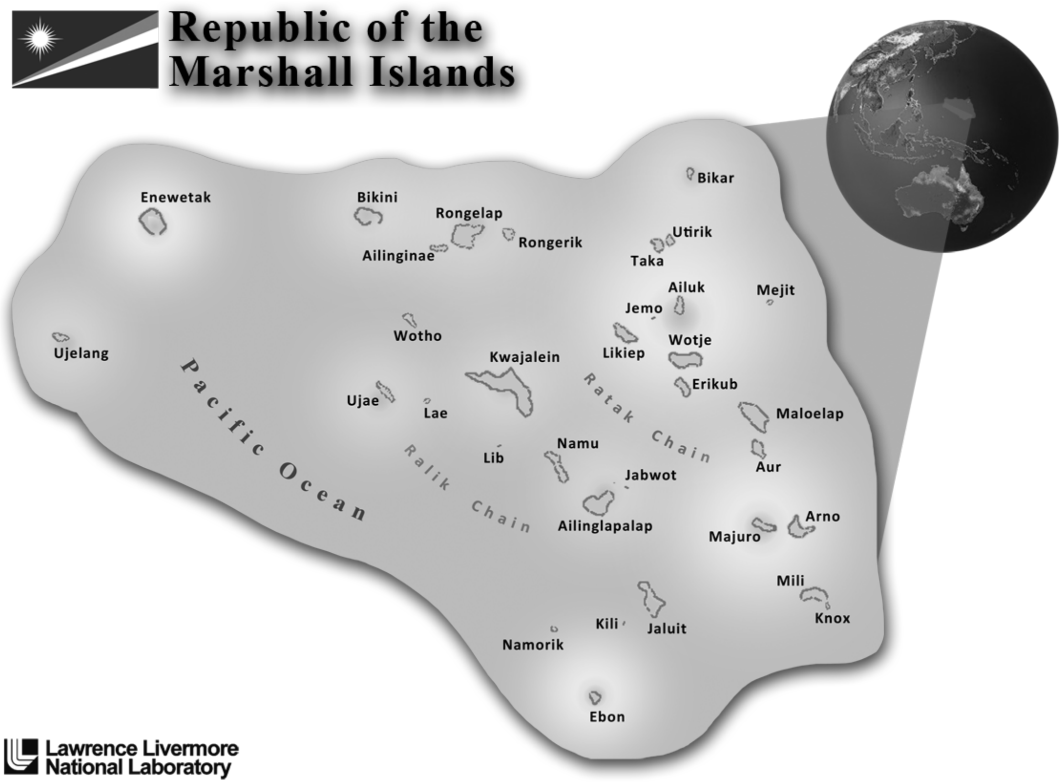


Figure 6. Location of the Marshall Islands.

Events since the nuclear tests have led to greater distrust among the affected population. For example, in 1968 Bikini Atoll was declared safe and several families re-inhabited the area in 1972. However, in 1978, monitoring of the population indicated that a number of people had exceeded the maximal permissible body burden of Cs-137, leading to the US authorities calling once again for the evacuation of the resident population. Rongelap Atoll was resettled in 1957, three years after the worst of the atmospheric tests. A radiological survey was conducted by the US DoE in 1978 to provide information on levels of radiation in soils and foods. The resultant report, issued in 1982, caused alarm within the community and there was a perception among people that evacuation was again required. To date, the area of Rongelap Atoll is still not considered to be completely resettled.

As a result of these experiences with resettlement, the Marshalls Islands national government contracted an independent advisory group of scientists to conduct a comprehensive radiological survey although the results were never accepted. In 1992 the US government funded further independent assessments to characterize the contamination over the entire atoll and examine the feasibility of resettlement at Rongelap Island. The results of this study led to a general consensus that, whilst a significant proportion of the adult population resettling on the island would exceed a 1 mSv/y dose criterion (based on utilizing only locally derived foods), resettlement was possible. The assessment was driven by science with those undertaking the assessment working directly with local governments to ensure that the evaluation related to local habits. Whilst the evaluation assumed a locally derived diet, it was assumed that residents would consume a mixed diet of local and imported foods and, as such, there was an added level of safety supporting the decision to resettle. A phase 1 resettlement program of the island began in 1998 with soil remediation and construction activities.

The public response to the assessment was considerably different to the scientific interpretation. For example, the public interpreted the 1 mSv/y dose criterion as an absolute limit with any uncertainties conveyed being interpreted as proof of lingering long-term danger. The previous resettlement attempt was also perceived to have been a human experiment.

Communication and education are therefore vital in managing legacy sites. On the basis of the experience gained from the Marshalls Islands legacy, it is recommended that scientists are made available to present and discuss issues and findings with the local population.

In 1999, a permanent whole body counting program was established with body counters being installed at three different locations throughout the islands. One counter is located in the capital to allow the monitoring of people travelling to and from the islands. The use of the whole body monitors is of added benefit in communicating with the public allowing assessors to communicate what is actually in the body of affected people. An environmental monitoring program has also been established with food samples being collected for analysis from various locations. The analysis is performed in a laboratory that has achieved very low limits of detection. A public outreach program has also been established with training, educational and self-help programs being available to help gain the trust of the local people, who view radiation as poison.

The current status of the Marshall Islands program is that a new standard, lower than for workers and lower than the US EPA standard, has been adopted. As well as whole body monitoring, plutonium bioassays have been performed. The adopted standard has not been exceeded by any inhabitants, yet there remains distrust of US activities and concern that all medical issues result from the presence of radiation. Work is ongoing, therefore, to compare health on the islands to health in other locations. Medical support is also made available to all local people developing cancer, irrespective of whether the cancer is attributable to radiation exposure.

Environmental support programs are also ongoing. For example, soil remediation has been completed in the area inhabited on Rongelap Island, reducing external gamma dose rates by around a factor of 8, to less than 0.1 mSv/y. The treatment of soils with potassium fertilizer has further reduced soil contamination, but not all areas have been treated and the local government is due to make a decision on whether these efforts should be completed for remaining agricultural fields. Updated predictive dose assessments, based on improved understanding of the cycling of Cs-137 in the environment, full implementation of recommended remedial measures, and a diet consisting of both imported and local foods, indicates the population average annual dose on Rongelap is around 0.03 mSv (Figure 6). However, whilst remediation activities have greatly reduced radiation levels and monitoring has shown the area to now be safe, it may not be possible to have complete resettlement of the most impacted areas due to continued public concern.

No remedial actions have occurred at Utirik Island and people continue to inhabit the island. A full characterization program is planned to evaluate where activity is present and to study the uptake of radioactivity by different crops and whether alternative crops could be introduced. Diabetes and hypertension are health issues evident among the population and a changed diet, to include more leafy vegetables, could help address these non-radiological health issues.

The US DoE Marshall Islands medical program is aimed at providing a comprehensive annual medical screening service and cancer treatment to affected people and the environmental program is designed to address a wide variety of issues and questions relating to the health and safety of residents, their environment and food supply. The environment program is considered to be world class and, together with the medical program is aimed at supporting resettlement. All islanders have the option however to reside in the US and to attend local facilities for medical examinations should they wish.

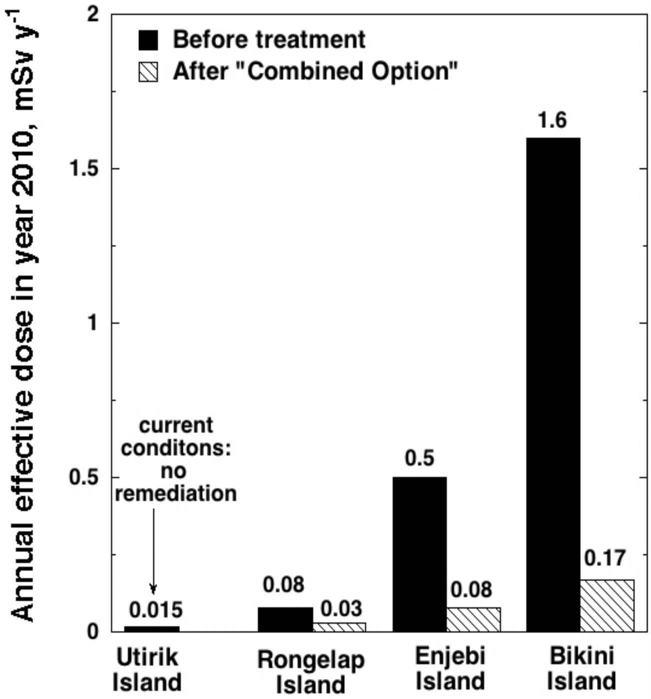


Figure 6. Annual effective dose in the year 2010 with and without remediation activities in the Marshall Islands.

The key obstacle to clean up and resettlement has been risk communication. This in part relates to the language used in relation to radiation and to the lack of clarity in the application of protection standards. Past management activities have also led to deep rooted mistrust of the US authorities, which is further fueled by conflicting advice from local scientists and environmental groups. Social and cultural differences can also impact on risk communication and this is an area being worked on. Where there is distrust of the recommendations made by the US authorities, additional groups have been brought in to address issues. A website has also been made available with all information and data published with international peer review by the scientific community. Work is also continuing with the IAEA to support the islanders. It is planned that a workshop, joint with the IAEA, will be held in the next few years to revisit what has been done to address the legacy issues at the Marshall Islands.

Issues of particular concern to local people have related to the continued availability of funding and compensation, with a driver for this to be considered based on social need rather than scientific findings. There is also a view amongst locals that decisions made by the US are purely political. Furthermore, there are some atolls within the islands that may be affected as a result of the nuclear tests, but these have not been monitored and people feel that monitoring is required to ensure that the full situation is known and understood.

Whilst much has been learnt as a result of the Marshall Islands program, more needs to be done. In terms of lessons learned, communication through open and honest partnerships with local stakeholders and the general public is essential; it is very difficult to mend lack of trust issues once they have been formed. Formal mechanisms for stakeholder engagement can be beneficial in this regard such as organized meetings, workshops and community outreach programs. Making available experts to the general public can also be very beneficial in allowing the community to raise concerns and gain direct answers to questions, as can provision of free and open access to all data and information. A further learning point has been the use of local physicians in addition to those brought in from the US and, due to ongoing health concerns, consideration is being given to monitoring people inhabiting Honolulu that have never been to the Marshall Islands as a control group to alleviate concerns that all health issues arise from the presence of radiation. The key issue for impacted communities has been their health and ensuring that their health is being protected. To achieve the required trust, there is a need to begin with a clear endpoint in mind and to build credibility through implementing effecting outreach and educational programs alongside clean up, resettlement and long-term monitoring programs.

3.2 Remediation of contaminated lands: Maralinga experience and lessons learned

Stephen Long (ARPANSA) presented.

From 1952 to 1957, the UK undertook 12 atomic tests in Australia, the majority of which were in the Maralinga territory in the period 1956-1957 (Figure 7). Three tests were conducted on the Monte Bello Islands, two at the Emu Field and 7 were conducted at Maralinga. The tests gave rise to mainly short-lived fission products, and only some radionuclides remain, predominantly Co-60, Eu-152, Cs-137 and Sr-90. Dose rates in 2012 were recorded at less than 1 µSv/h and it was deemed that there was no requirement for remediation activities to be undertaken as a result of these atomic tests. The Monte Bello Islands have been released back to the public. There is no permanent water on the islands however and, combined with their remote location, public occupation rates are low.

In addition to the atomic tests conducted, the UK also undertook a number of minor trials at within the Maralinga territory. These included:

- A series of neutron initiator development trials at Emu in 1953 that involved Po-210 and beryllium (*Kitten trials*);
- Fissile material compression tests with natural or depleted uranium and some Po-210 plus beryllium in the period 1955-61 and again in 1963 (*Tims trials*);
- Fissile material compression tests involving uranium and intense gamma sources (*Rats trials*);
- Burning trials on rods of plutonium, uranium and beryllium in 1959 and 1961, with explosive dispersions involving uranium occurring in 1961 (*Vixen A trials*); and
- Safety/development trials to determine the characteristics of nuclear warheads in 1960, 1961 and 1963, involving detonations to measure nuclear characteristics (*Vixen B trials*).

The effect of these trials was to disperse radioactive and toxic materials across a large area. The residual contamination resulting from these trials is illustrated in Table 3. By far the greatest impact resulted from the Vixen B trials. The uranium present as a result of the trials poses a greater chemotoxic than radiotoxic risk.

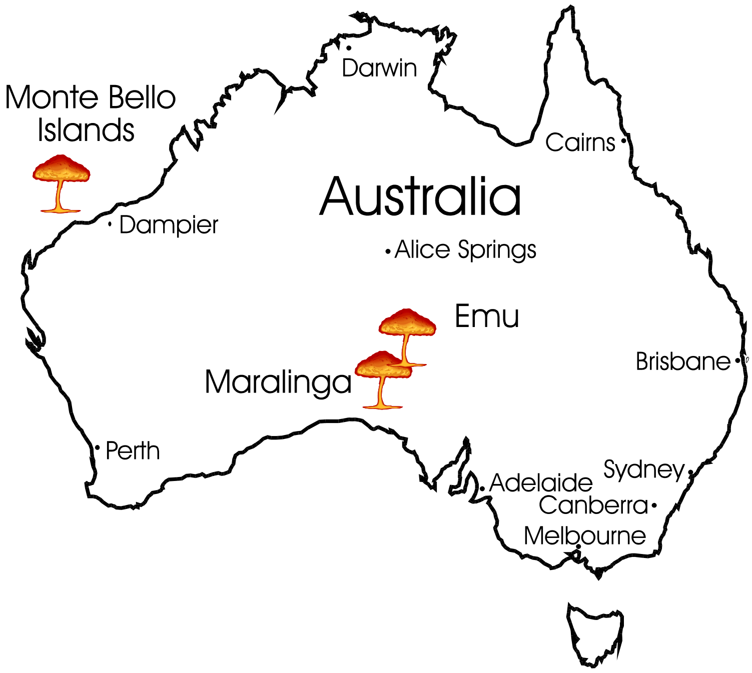


Figure 7.Location of UK atomic test sites in Australia.

Table 3. Residual contamination in the Maralinga area resulting from UK minor trials.

Trial	Pu-239 (kg)	Uranium (kg)	Ac-227 (MBq)	Beryllium (kg)
Kittens		120		0.75
Tims	1.2	15360		120
Rats		375		
Vixen A	0.98	57	5	9
Vixen B	**22**	**46**		**18**

In 1967, the British conducted Operation Brumby to clean up the Maralinga area affected by the UK tests. In undertaking the operation it was assumed that the land would be used in the future for grazing animals with the key exposure pathway being inhalation by stockmen. It was further assumed that there would be rapid natural revegetation of the areas affected by the clean-up operations. Risks posed by plutonium contamination on fragments were not however addressed and no allowance was made for risks posed by shallow burial and debris pits that were potentially at risk from subsidence.

The approach taken in Operation Brumby was to remove general debris and dilute contamination through either ploughing soil to disperse contaminants or by covering contaminated areas with clean soil. In the most highly contaminated areas soil was removed for burial. Debris pits were capped with concrete blocks that were randomly placed.

Since 1967 there have been changing attitudes to land. Prior to the remediation activities performed by the British, the region was considered to be uninhabitable and worthless desert and Australian Aborigines had no rights. In the 1980s however the importance of Australia's natural and historic heritage was recognized with the inherent beauty of natural areas. The need to restore dignity to the Aborigines and the land rights of traditional owners were also recognized. There was therefore a move in the mid 1980's to restore the Maralinga lands to the Aborigines. In support of this, a brief survey of the area was undertaken. The survey showed that land should not be passed to the traditional owners due to high contamination levels. Further aerial surveys were therefore undertaken in 1987. Plumes some 10's of kilometers long were evident (Figure 8), based on aerial gamma detection of Am-241 (from the decay of Pu-241). Based on the aerial surveys, and a Pu-239 to Am-241 ratio of 8:1, activity concentrations in excess of 1 MBq/m^2 Pu-239 were evident. Particles and fragments contaminated with activities in excess of 1MBq Pu-239 were also identified.

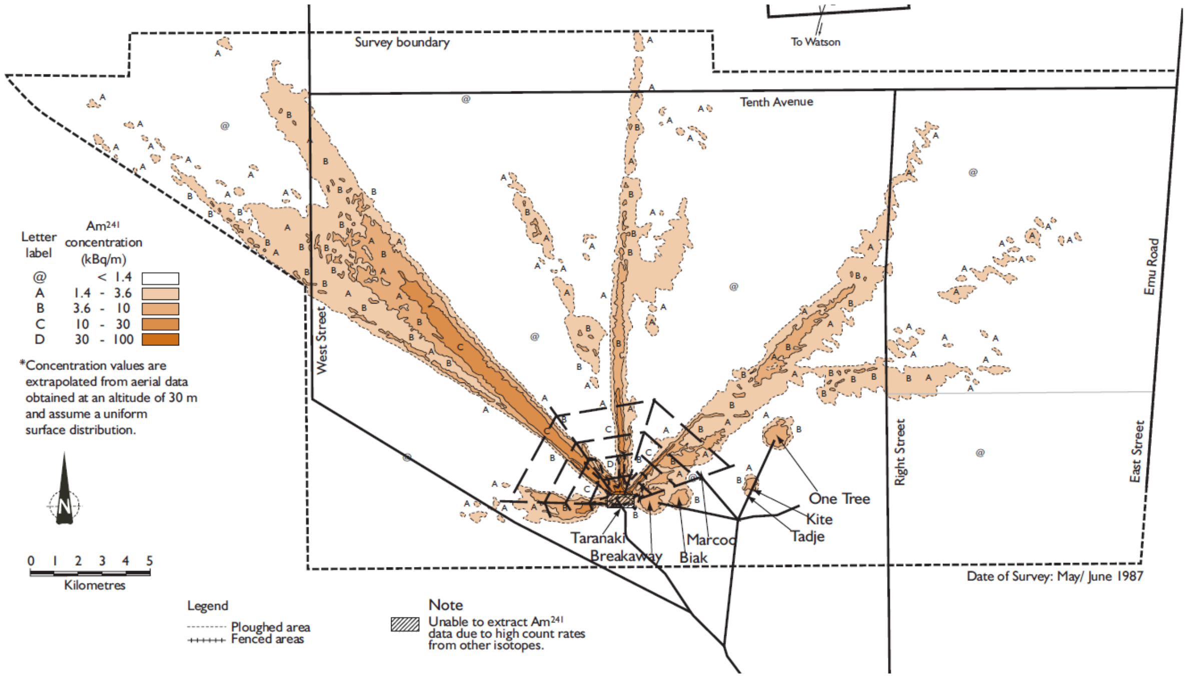


Figure 8.Extent of contamination of the Maralinga territory.

There was a resolve to take action following the discovery of the remaining legacy at the site that was in part driven by social/lifestyle issues (desire of Aboriginal stakeholders to resume ownership and use the lands), political and radiation protection concerns (levels of contamination were such that a person could be inadvertently exposed to enough plutonium to result in death). ARPANSA (previously the Australian Radiation Laboratory) has the responsibility to ensure that the public are protected from harmful effects of radiation.

In the late 1980's a series of technical assessments was undertaken to determine the nature of the hazard, to characterize the contamination, determine the effects on the environment and uptake into plants and animals and to determine the full spatial extent of the contamination both through aerial and ground-based surveys. Stakeholder consultation was also established, involving the local population and landowners, local and national governments. The consultation included the development of realistic exposure scenarios through consideration of lifestyle habits of the local people and to gain an understanding of the expectations of the local population into the future in terms of land use. Stakeholders were also provided with the opportunity to feedback on the remediation project. The consultation program has been running for over 30 years' to date and has helped to develop a deep level of trust between the local people and the authorities responsible for management of the legacy.

Clean up operations were taken in the 1990's with the objective of reducing the radiological hazard to allow Aboriginal traditional land use and transfer of the land back to the Aboriginal people and to reduce (and possibly eliminate) the need for control and surveillance of the site and remove potential Commonwealth liabilities arising from the contamination. A 5 mSv/y criterion was applied for rehabilitation. The inhalation of plutonium was the major radiation hazard in the area and, based on the assumption of 100% occupancy to a representative person (an Aboriginal child living a semi-traditional lifestyle), a Pu-239 soil activity concentration of 25 kBq/m^2 was calculated as meeting the safety criterion. Around 120 km^2 was contaminated to the extent that this criterion was exceeded, based on the 100% occupancy assumption.

A consultation on the clean-up criteria was held. The need to balance cost against risk reduction was recognized. Furthermore, the local people did not want widespread destruction of the vegetation and soils, which reduced remediation possibilities. There were also sacred sites identified that could not be disturbed.

It was concluded, following consultation, that only the worst aspects of contamination should be addressed by soil removal with the remaining areas of the 120 km^2 zone being marked with signs to indicate a non-residential area. Removed soil was to be buried at a depth greater than 5m and fragments and particles should also be removed. The burial pits created during Operation Brumby were to be exhumed and reburied, again at a depth of at least 5m. Monitoring was also undertaken to ensure that criteria were met. Since landowners were not given full use of the land following remediation, compensation of AU$45M was provided. The full cost of the rehabilitation project was AU$110M.

The clean-up project was consistent with current radiation protection principles. A reference level of 5 mSv/y (within the 1-20 mSv/y reference level band) was applied and a reference person was used to evaluate dose. The principle of optimization was also applied to decision making on remediation options.

There were 7 key lessons learned as a result of the project.

1. *Every site is different*. Variation may be noted in relation to the local environment or geosocial aspects, differences are likely according to the value placed on land and available disposal options and associated costs. The radionuclides comprising the contamination will also vary, in turn affecting exposure pathways and potentially clean-up criteria and methods. It is therefore important to treat each site on its own merits.

2. *Things change with time*. Land use, public attitudes, technology, scientific knowledge and protection objectives may change over time. There is a need therefore to ensure that any actions taken to address contamination issues do not make future clean-up (as technology, knowledge etc. change over time) more difficult and costly; the initial Brumby operation resulted in contamination being spread more widely and further remediation was made more difficult (and costly) than it would have been as a result.

3. *Consultation is critical*. Trust must be built between stakeholders and politicians and scientists with stakeholders being consulted on desired end-states etc, and scientists developing clean-up criteria and strategies. Engineers and technologists should also be involved in the consultation process to advice on available specialist technologies. Ensuring all relevant parties are involved in the consultation process can lead to people feeling that they own the outcome and that the outcome relates to what the people want.

4. *The process has thirteen steps*, with a focus on reducing the possibilities for very high doses occurring:

   I. Discovery of problem;
   II. Resolve to intervene;
   III. Technical assessment of problem;
   IV. Consult on problem;
   V. Determine rehabilitation criteria;

VI. Determine rehabilitation strategy;
VII. Obtain approval from regulators and stakeholders;
VIII. Obtain Funding;
IX. Determine rehabilitation boundaries;
X. Conduct rehabilitation;
XI. Verify criteria have been met;
XII. Re-assess doses; and
XIII. Conduct ongoing checks.

5. *Effective and efficient regulation* is required. Regulators can rapidly stop a process or at least slow a process down, but is unlikely to be able to speed up the remediation process. The terminology used is important; radioactive waste may never be accepted by the public, but if referred to in terms of contamination then the public may be more accepting as something that can and should be addressed. Regulators also need to be open to the differences between existing and planned exposure situations and to appropriately intervening in existing exposure situations to reduce doses.

6. *Cooperation is key*. During the technical assessment phase, regulators and those responsible for managing the clean-up should cooperate to ensure that impossible tasks are not imposed and that what should be done is achieved. There should also be cooperation between regulators and the scientific/technical community to aid in meeting common clean-up goals as quickly and efficiently as possible. All parties should be working together to the same end.

7. *Keep it simple*. Clear and defensible dose criteria/reference levels are required that can be translated into practical clean-up criteria (derived standards) that are averaged over relevant areas. Where there are large areas of contamination, these should be sub-divided into manageable lots allowing small areas to be focused upon and remediation approaches tested before applying more widely. This approach allows strategies to be reviewed and revised if required. Furthermore, if new technologies are to be trialed, fall-back strategies should be available in case problems are encountered.

3.3 Regulatory supervision during remediation of Russian nuclear legacy sites: scientific and practical achievements

Sergey Kiselev (FMBC) presented.

In the 1960's the Russian Ministry of Defence established technical bases in the far east and northwest of Russia to receive and store SF and RW from the fleet of nuclear submarines. This was followed in the 1980's and 1990's with the decommissioning of many nuclear vessels out of service. Environmental contamination remained following these activities. The Ministry of Atomic Energy took over from the Ministry of Defence in 2000 and two companies were established. SEVRAO was set up in the north-west, working on radioactive waste management at Andreeva Bay, Gremikha and at the storage facility established at Saida Bay for the long-term storage of reactor blocks from nuclear submarines (see Figure 1). DALRAO was the company established in the far-east where a storage facility was established at Sysoeva Bay and work undertaken on receiving and further transport of RW from Razboinik Bay. A further storage base for RW was established at Krasheninnikova Bay (Figure 9). It is intended that Sysoeva Bay will a regional centre for storage of radioactive waste in eastern Russia.

Figure 9. Location of radioactive waste storage areas and activities under the responsibility of DALRAO in the far east of Russia.

The remediation strategy for the Russian legacy sites has comprised various stages (Figure 10). The first stage was to modernise the general infrastructure and then to establish the technologies that would support SF and RW management and rehabilitation. Once this had been completed, activities were commenced such as the recovery, removal and transport of SF, and the processing and conditioning of RW. Very low level waste was disposed of in situ. Remediation of the old buildings and the environment have also been started.

At the beginning of the remediation program a threat assessment was undertaken, within the cooperation agreement with Norway. The main threat factors related to the poor condition of the infrastructure for spent fuel and radioactive waste storage; insufficient radiation protection methods for workers during remedial operations; lack of information on radioactive contamination of facilities and the environment leading to uncertainty in public dose estimates; and insufficient interaction between regulators and operators and emergency responders. The threat assessment was carried out for the NW Russia, with findings then being used to inform planning of actions in the far-east of Russia.

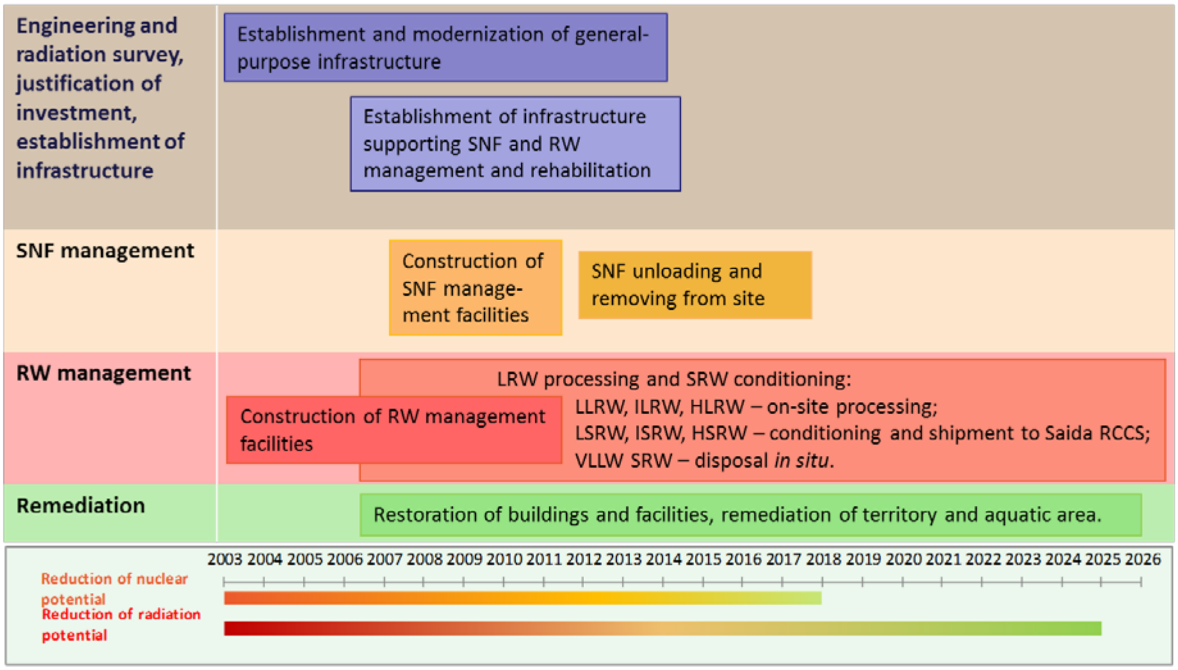


Figure 10. Remediation strategy for Russian Nuclear Legacy Sites.

The findings from the threat assessment were collated into the three main areas of regulatory supervision at nuclear legacy sites: public radiation protection; radiation protection of workers; and emergency preparedness and response.

To improve regulations for the radiation protection of workers, several activities were implemented. An information analytical system was established to evaluate personnel doses that covers the routes personnel use both within the sites along with radiation data for indoor and outdoor areas. The system therefore allows individual dose to be forecast for routine operations. The system also allows areas contributing most to individual exposure to be identified and transportation routes optimised to minimise exposure. Areas with the highest uncertainty with regard to radiation contamination can also be identified for which additional monitoring or surveying may be required (Chizhov et al, 2014).

Andreeva planning software has also been developed. This software allows the risk of doses to personnel to be evaluated in relation to the handling of SF, some of which is known to be damaged. The software allows different scenarios to be simulated and integral and collective doses calculated along with dose rate. The software is used to support decision making to minimise worker risks.

Personnel reliability monitoring has also been a focus to address a variety of risks faced by workers. Personnel are monitored prior to work in order to select people to undertake certain operations. The safety culture among workers is also evaluated. Personnel at all levels, including management, are asked to complete questionnaires and results are evaluated. The evaluation identifies growth points defined by workers for which management need to be made aware.

Improvement of the emergency preparedness system has taken place over the 10 years of cooperation with NRPA. Two exercises have taken place, one a medical service drill at Andreeva Bay and the other an emergency prevention response in Gremikha village. There have also been seminars, workshops and various training sessions. Documents have been produced for use in future training exercises with interactions between the different organizations during emergencies being very important.

The optimisation of safety of the public and environment requires reliable data on contamination and understanding of how the situation could develop. Databases have therefore been developed for radiation data and exposure monitoring. Monitoring maps have been developed to allow visualisation of the situation during operations. Experience from the sites has indicated that, in order to conduct environmental remediation, monitoring should be improved so that decisions can be made on the basis of a holistic understanding of radiation and chemical contamination. Monitoring programmes have been established at the sites to evaluate chemicals and radionuclides in groundwater and sub-soil samples. Whilst radioactivity has only been found in some groundwater samples, heavy metal contamination is present in all and in many instances the level of contamination exceeds allowable limits. In addition to radiation and chemical monitoring biological monitoring is also required in order to understand possible environmental impacts arising from the contamination. Work is just beginning on this aspect with holistic indicator organisms such as plants and microbes being identified.

Doses to the public living close to the legacy sites have been evaluated. No significant impact on populated areas is evident with annual effective doses remaining below 1 mSv/y while natural background giving rise to effective doses of 4.5 mSv/y (at Danube village). Mushrooms and berries are key contributors to dose.

Danube village is located 5km from Saida Bay. A federal motorway runs through the village that is used for the transport of SF, leading to concern in the local population. Many surveys have been conducted and medical demographics analysed over a 5 year period. A growth in birth rate is evident, but also an increase in mortality that is not connected to the aging of the population. Both birth rate and mortality rate are nonetheless typical for the whole country. General morbidity has also been investigated. Adult morbidity and incidence of malignant neoplasms have been evaluated to determine whether there is a link with the presence of the legacy sites. No trend was evident (Figure 11). Results of an analysis of child health were similar with no trends being evident in relation to total morbidity in children or congenital morbidity in babies.

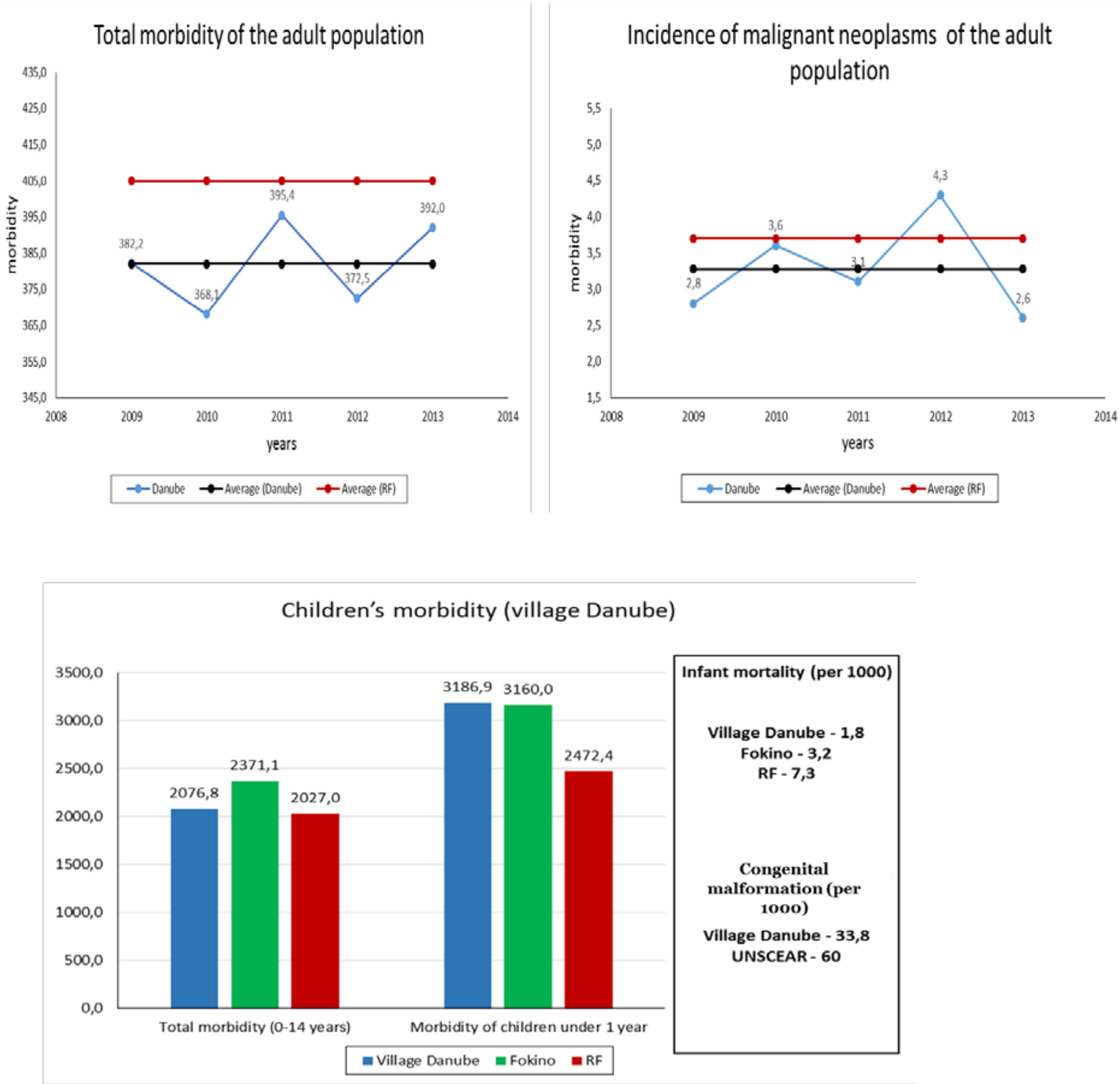


Figure 11. Total morbidity (upper left) and incidence of malignant neoplasms (upper right) in the adult population of Danube village and in children and babies (lower) as compared with the wider population and the average across the Russian Federation.

The work program to develop the safety culture has shown that the development of methods and comprehensive radiation and chemical monitoring programs and models to evaluate the risks are necessary. In terms of environmental impact assessment, biological indicators that show the holistic effects from radiation and chemical contamination are required. There is also an urgent requirement to develop practical guidelines on procedures for establishing reference levels for public radiation protection during legacy site remediation and to consider reference levels for chemicals in addition to radiation[1]. Whilst a range of 1 to 20 mSv is proposed for radiation, no practical recommendations are given on how to select a value within this range to support remediation activities. Finally, public awareness and the development of effective communication strategies can greatly improve cooperation between local authorities and the public.

[1] Note that criteria set out in Table 1 relate to constraints.

3.4 Points from discussion

Differences in public perceptions of risk are evident from the examples given. At the Marshall Islands, the public want to know whether it would be safe to resettle and so surveys and other measures were undertaken to evaluate whether homes are safe and whether foods are fit for consumption. Trust was identified as a very important issue in deciding whether the population believes the science and numbers presented. A 'grow your own scientist' approach was adopted to improve public confidence.

At Maralinga, public consultation began at an early stage with radiation risks being discussed in the context of other risks that people have accepted, such as risks from heavy smoking. The local islanders are prone to kidney disease as a result of a high sugar diet and a starting point to discussions was therefore what constitutes a healthy lifestyle. This early communication helped the local population to understand risk factors.

The medical program for Marshall Island inhabitants has been focussed on those receiving substantial doses, but more recently a control group has been included to allow comparison between cancer rates. Indications are that the cancer rate in the exposed people is marginally larger than in the control group. The control group is currently small however and cancer rates may not therefore be representative of the wider population. The US DoE is not making value judgements on behalf of the islanders with regard to whether people should resettle. Activities are focussed on remediation and monitoring, allowing locals to decide on whether to resettle. Where resettlement is chosen, monitoring takes place both before and afterwards. Resettlement is not the end of the story.

The scenarios used in the evaluating exposures have changed with time in the light of changes in behaviours and information from local people. This illustrates the significance of changes in circumstances, which might increase as well as decrease dose estimates. In determining appropriate remediation, it is not just radiation exposure that should be taken into account. For example, at Maralinga, the affected population also wished to avoid damage to their land. Stakeholders of all types can recognize a trade-off in selection of a particular strategy or option.

Concerning responsibilities, in Australia, each state is responsible under the national regulatory framework for radiation protection, although ARPANSA has a mandate to ensure uniformity across states. There continues to be discussion between federal and state governments to negotiate the handover of sites with the appropriate assurance that states can handle the legacy issues and that adequate support can be provided as required. From discussion, it was noted that this approach can be helpful within international cooperation whereby, when help is given, consideration also needs to be given as to the appropriate way to step out from the issue whilst maintaining support, should it be required.

4 Session 2: Legacies Following Accidents

4.1 Clean-up endeavor after misfortune at Fukushima NNP – activities at work front

Yoshiharu Hashizume (Obayashi Corporation) presented.

The Japanese construction industry grew rapidly since the 1960's to develop the infrastructure for economic growth (Figure 12). However, the over-heated economy thereafter collapsed in the 1990's and a large earthquake occurred on land. Construction investment decreased but then recovered again in the late 2000's due to government reforms and other factors. The economy was just starting to improve when the ocean-based earthquake off the coast of Japan in 2011 caused a very large tsunami, with much other damage along the north-eastern coast, caused the accident at the Fukushima Dai-ichi nuclear power plant. This had a significant impact on procurement linked to clean up and recovery operations. As a result, there was a notable shortage of everything - engineers, workers, equipment, and material. Clean-up work was therefore impacted by many workers and management staff being inexperienced at construction contractors.

There were two types of clean-up project. The central government established clean-up projects for the heavily contaminated areas near the damaged NPP. The local government was responsible for the remaining clean-up activities. The number of daily workers involved in central government clean-up projects reached 18,000 in the last two years. In comparison, a monorail project in Dubai has a peak of around 500 workers over a 36 month period to construct 5 km of monorail and associated terminals. The clean-up operations in Japan were highly labour intensive and time consuming.

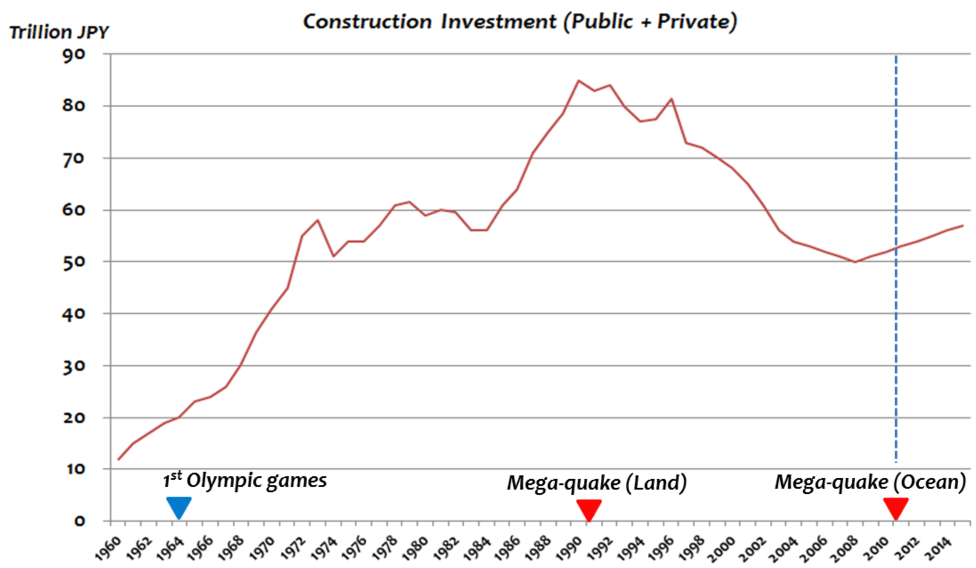


Figure 12. Construction investment in Japan.

Some of the main constraints associated with clean-up activities were the safety control of workers to protect from exposure, as were the maintenance of workmanship standards to ensure compliance with contract documents and preventing non-conformant activities.

Table 4. Summary of clean-up activities required to address contamination issues following the Fukushima incident.

Category	Type of ground	Action
Houses	Roof	- Wipe - Flush with high-pressured water
	Unpaved or turf	Remove surface with sod cutter
	Paved	- Remove humus - 1) Flush with high-pressured water 2) Shot blasting if highly contaminated
Woods	Sediments	Remove sediments and leaves
Roads	Paved	- Remove leaves - 1) Flush with high-pressured water 2) Shot blasting if highly contaminated
	Rough terrain/dirt	- Remove leaves - Replace surface soil with non-hazardous soil
	Guardrails	- Wipe/brush - Flush with high-pressured water
Fields	Rice field Vegetable field	- Turnover - Soil removal + cover with uncontaminated soil if highly contaminated

The clean-up activities required and actions to address are illustrated in Table 4. For built up areas, house roofs, paved and unpaved ground all needed to be considered in terms of decontamination activities, whereas for woods the focus was on soil contamination within a 20m boundary from populations. Work to clean-up forestry areas is limited since the budget would sky-rocket, if the works went further. High pressure washing was used to address roof and paved area contamination, along with the removal of humus, as appropriate. Shot blasting of paved areas was only used when areas were highly contaminated due to the generation of secondary wastes.

To address contamination in agricultural fields, farmers were consulted on a case by case basis. Various options were considered such as the mixing of soil layers or removal of contaminated soil and cover with uncontaminated soils. Some farmers did not want new soil added to their land.

A reduction in contamination was evident following the clean-up activities (Figure 13), with the greatest reduction in contamination relating to remediation activities for houses. Dose rates in air were also substantially reduced.

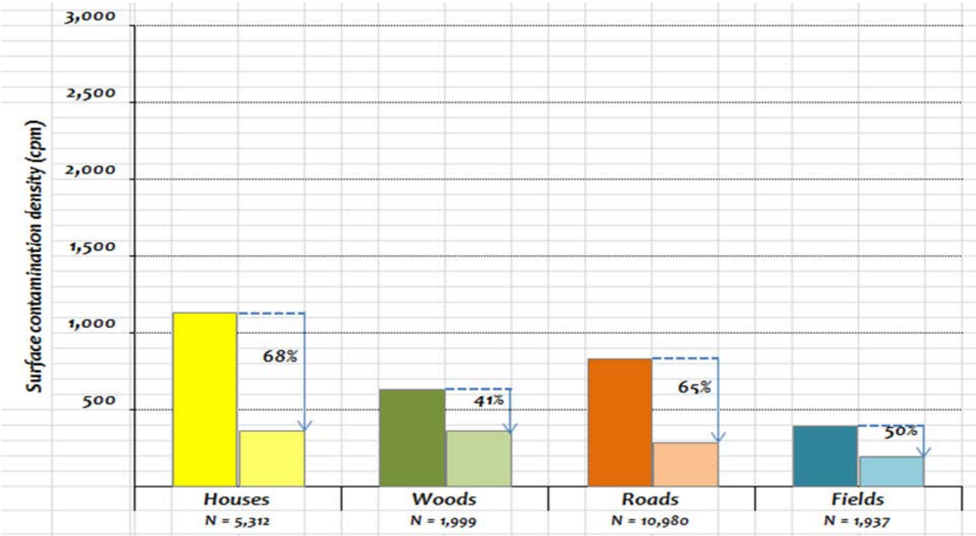


Figure 13. Surface contamination (counts per minute) before and after remediation activities at Kawauchi-mura.

Six contracts have been awarded for pilot programs on the interim storage of contaminated waste. The contracts are to verify the traceability of waste bags transferred from temporary storage areas to interim storage areas and of the movement of dump trucks used for transportation. The current contract held by Obayahi Corporation is for the transport of 6,ooo bags (equating to 6,000 m^3 of waste) over distances of around 50 km in the period October 2015-March 2016.

The Government's Ministry of Environment is offering an approving test stage when new technologies or methods are implemented. For the clean-up stage, a radiation survey mechanism was proposed with approaches for the integrated accumulation of data (Figure 14).

The proving stage for interim storage is due to begin to consider what will occur at the storage areas. The design of the storage area has not yet been finalised and is likely to take a little more time to complete. One approach for monitoring that is being trialled is the use of multiple NaI sensors to survey trucks transporting wastes to minimise survey time (Figure 15a). A SCAN SORT technique (Figure 15b) is also being developed to assist in the segregation of contaminated materials according to the level of radiation contamination. The approach will use an arm to separate wastes that are scanned on a conveyor belt.

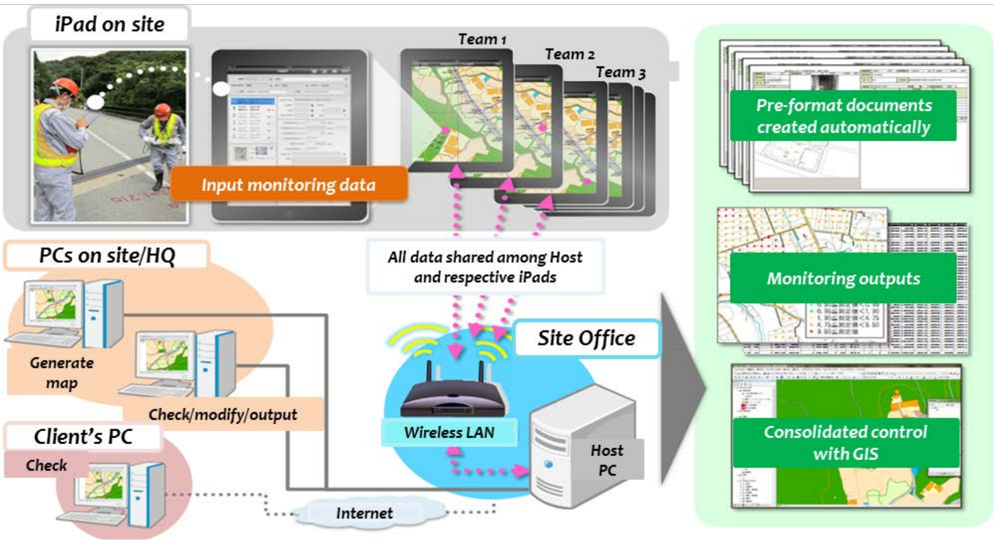
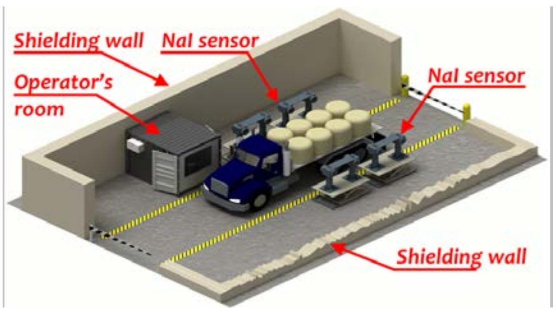
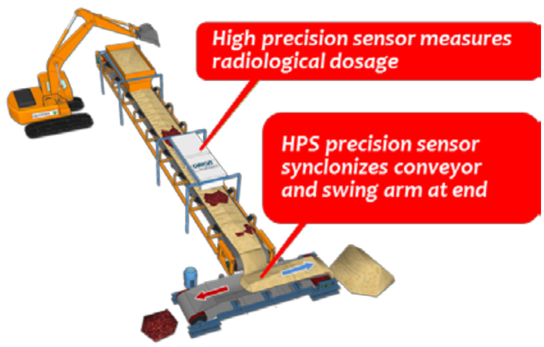


Figure 14. Integrated data accumulation for radiation surveys.



a)



b)

Figure 15. Technical developments to support interim storage of wastes, a) TRUCK SCAN for truck surveying, and b) SCAN SORT for waste segregation according to contamination level.

In addressing clean-up, an objective is to prioritise stakeholders, which is a particular field of expertise of the Obayashi Corporation as a contractor. It is therefore an objective to gain local stakeholder consent for remediation activities.

In the long-term, there is a need to begin decommissioning of the undamaged nuclear power plants and to move toward developing an approach to final disposal of radioactive wastes. However, the key focus at present is to address the need for interim storage sites.

4.2 Regulatory lessons following the accident at the Chernobyl NPP: 30 years after.

Anatoly Simakov (FMBC) presented.

The Chernobyl accident is the largest radiation accident occurring in the world to date. There were a number of regulatory issues in addressing the emergency. Radiation monitoring was required to establish the situation and to evaluate the exposure of workers. There were however issues with the availability of appropriate monitoring tools for high dose-rates and the availability of appropriate personal dosimeters because these conditions had not been envisaged by site operators. In the first few hours after the accident, people did not understand the radiation situation, nor the doses they were exposed to. Ten days into the accident, attempts were made to evaluate doses received by personnel to decide whether individuals could continue work. The results were also used to help doctors choose care plans for those admitted to hospital.

The next focus of the response to the incident was the evacuation of members of the public. Around 50,000 people were resident in the nearest town. Once the decision had been made, evacuation was completed within 4 hours. However, the time that people would be away from their homes was not communicated, which added to the psychological trauma experienced by the local population. Health care posts were established as the third response to the accident. Temporary decontamination facilities were required and workers were provided with special clothing that was to be changed between the site and home, a costly but necessary measure.

Temporary regulations for all parameters of radiation protection were introduced. For example, workers within the especially hazardous zones were provided with necessary personal protective equipment, including respiratory systems and police were charged with controlling the movement of people and for ensuring the appropriate use for protective equipment.

To contain the radiation source, the damaged reactor (unit 4) was back-filled with ballast material and shielding constructed. Figure 16 illustrates unit 4 before the accident, in the immediate aftermath and following actions to contain the radiation source.

Decontamination of the area proved to be a major problem. Roads and vehicles, the site itself and personal protective equipment all required decontamination. Transportation of workers etc. led to the spread of contamination as vehicles transported contamination on roads. High pressure water was used several times per day on roads to reduce the spread of contamination and signs erected to warn against moving off roads due to the contamination present. Vehicles used to transport workers were decontaminated as they moved into and out of the 30 km restricted zone and a special unit for the decontamination of protective equipment was constructed.

As a result of the accident it was concluded that all nuclear power plants should have the appropriate devices for radiation and dose monitoring with personnel being provided with dosimeters that would allow large doses to be monitored. The overall master plan for the Chernobyl site was also revised. The site had only one entrance from the South that was routed past the fourth unit. People were stopping in order to look at the devastated reactor, leading to increased doses that should not have occurred. Multiple exit points were therefore established with monitoring points to control people and exposures.

The importance of emergency preparedness and response was evident following the accident. Within the first hour following the accident, firemen arrived and attempted to put out the fire in the reactor by pouring water from the roof. Six firemen died shortly after due to radiation exposure. Provision of instructions and training for emergency preparedness could prevent such incidents from occurring. Training exercises should therefore be undertaken for accident situations with training needs being organised and well documented.

The initial responders to the Chernobyl accident who ran the route to the damaged reactor and worked to shovel sediment into the reactor with minimal protective equipment received very high doses, of the order of 1,000 Sv. These responders received diplomas expressing gratitude from the Russian Government.

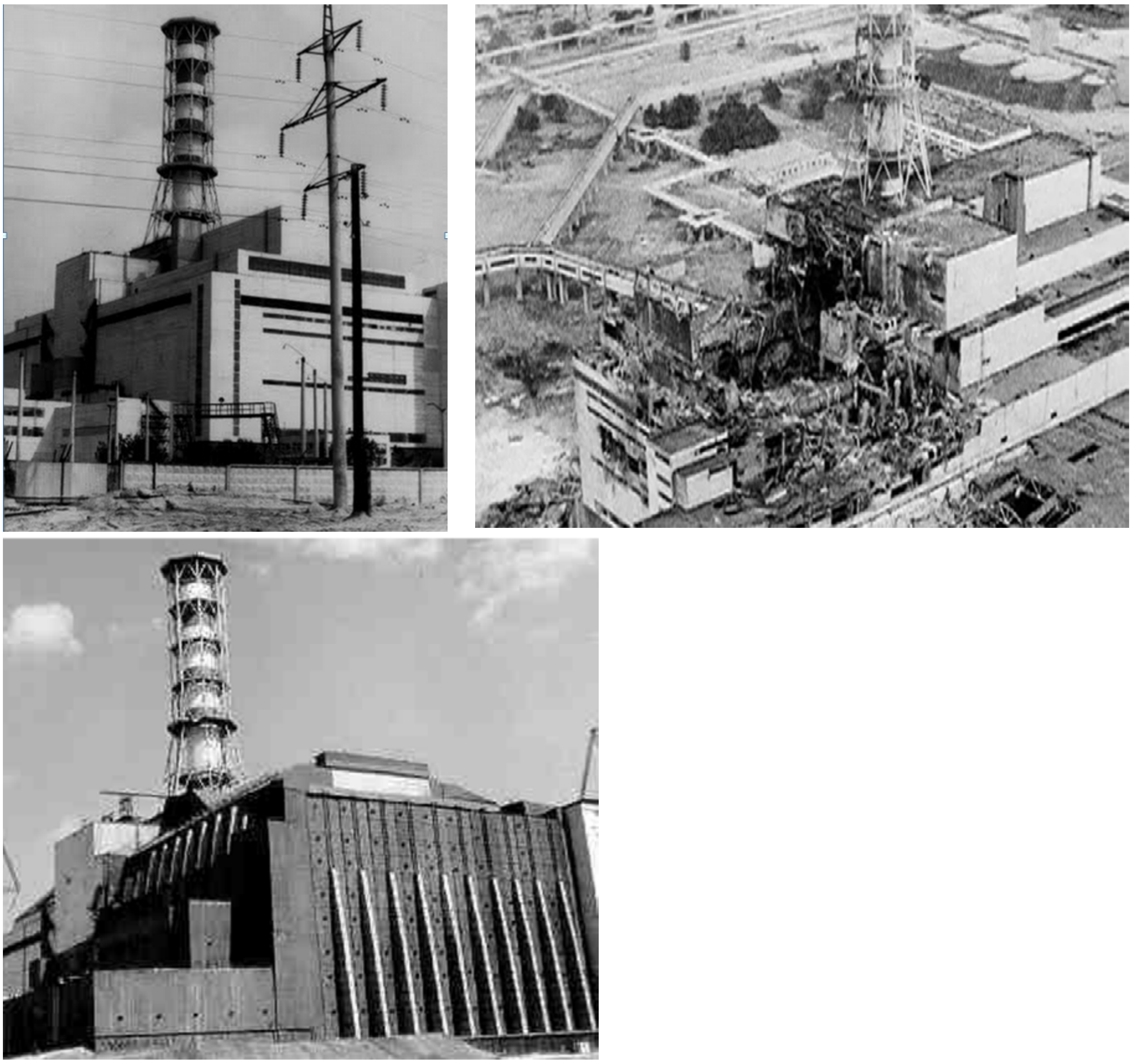


Figure 16. Chernobyl Unit 4 prior to the accident (top left), immediately following the accident (top right) and following the construction of a cover to contain the source (bottom).

Plans should also be in place for increased radiation exposure, including ensuring adequate provisions for medical facilities for persons receiving higher exposures. The plans should stipulate who should and shouldn’t undertake emergency activities, such as women of child-bearing age.

Following the Chernobyl accident, the production of mobile decontamination facilities began. The facilities have the capacity to decontaminate up to 10 people at a time and are recommended for use in contaminated areas.

4.3 Dose estimation for reuse of material contaminated by Fukushima Daiichi NPP accident

Seiji Takeda (JAEA) presented.

As a result of the Fukushima accident, caesium was dispersed over a 250 km from the nuclear power plant (Figure 17). A large challenge has therefore been how to handle the large volume of contaminated material generated as a result of clean-up operations. One strategy for addressing this issue would be the reuse of material.

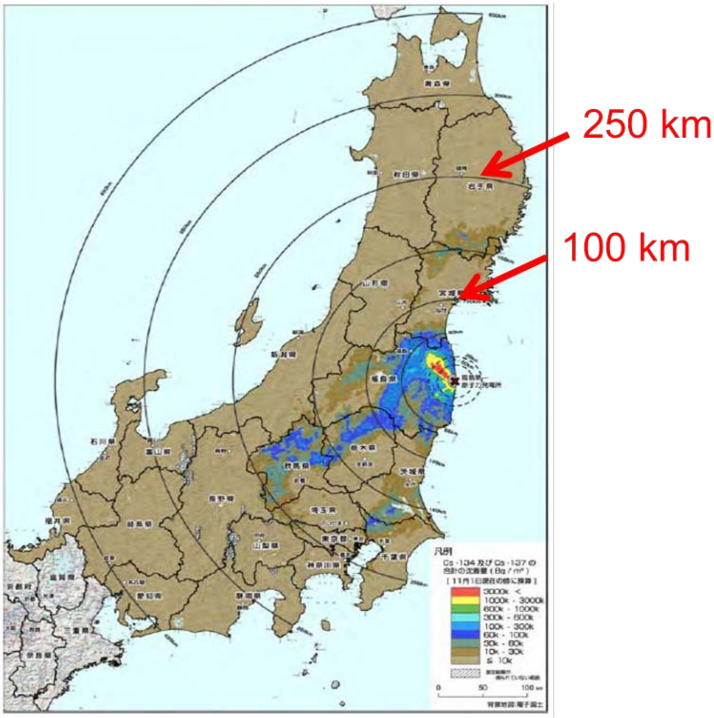


Figure 17. Cs-134 and Cs-137 deposition following the Fukushima accident. (http://savechild.net/wp-content/uploads/2011/06/zentaidojyo.gif)

In June 2011, the Nuclear Safety Commission issued a policy to ensure safety of workers and members of the public from the treatment and disposal of contaminated wastes (http://warp.da.ndl.go.jp/info:ndljp/pid/9483636/www.nsr.go.jp/archive/nsc/info/20110603_2.pdf [in Japanese]). The policy stipulated that worker doses should not exceed 1 mSv/y and doses to residents in the vicinity of treatment facilities should also remain below 1 mSv/y. Recycled materials have to be monitored to ensure activity that any doses would be below 10 µSv/y. These dose criteria were used, along with the results of dose estimation, to calculate the radioactive caesium concentration corresponding to the dose criteria.

Wastes arising from decontamination activities are treated in the same way, irrespective of the location from which they arise. The treatment is determined according to the level of contamination (Figure 18). Wastes with contamination levels exceeding 100,000 Bq/kg are sent for interim storage. The Ministry of Environment planned to reuse some contaminated materials to reduce the volume of wastes sent to landfill (http://www.env.go.jp/jishin/attach/memo20120111_shori.pdf [in Japanese] and http://josen.env.go.jp/en/documents/pdf/documents_04.pdf?130111), but there were no criteria in place by which reuse can be evaluated. A dose assessment was therefore carried out to establish the required criteria for the reuse of contaminated materials.

Two sets of criteria were required for the reuse of contaminated materials, one for unlimited use, the second for limited and specified reuse. The New Act established an unlimited reuse criterion of 100 Bq/kg (Cs-134 and Cs-137), based on existing clearance levels for concrete and metals. However, the clearance level had not been evaluated for the reuse of wooden and other wastes and a dose estimate was required to confirm the validity of the clearance level for such materials.

A key factor was the balance between the large volume of contaminated material being generated and the need for materials for use in reconstructing infrastructure damaged by the earthquake and tsunami. A dose assessment to establish new criteria for the reuse of wastes, primarily concrete, in infrastructure was focussed on the demand for construction materials and the restoration plan for the area in and around Fukushima.

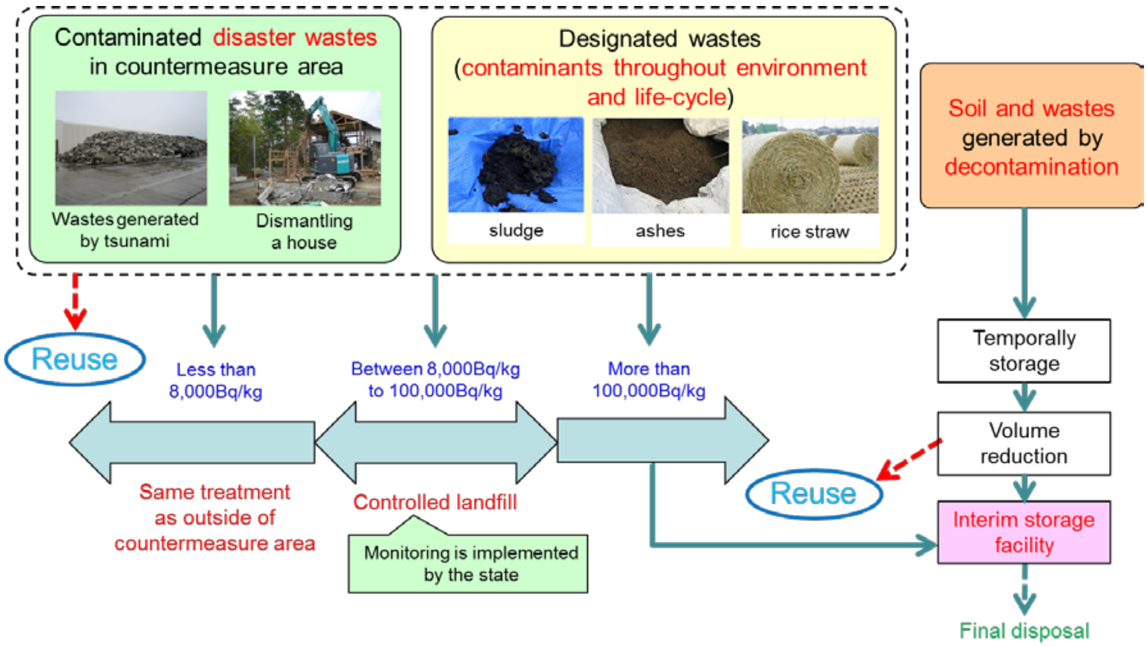


Figure 18. Flow chart for the treatment of contaminated wastes according to the level of contamination.

For contaminated wood, the focus was on the use of wood chips within five reuse scenarios: particle board, paper, compost, biomass power generation and mulch (Figure 19). Several scenarios were considered for workers and members of the public exposed as a result of the manufacture and reuse of wood-based products, taking into account source volume, level of radiation contamination, exposure time and type of exposure (external, ingestion, inhalation).

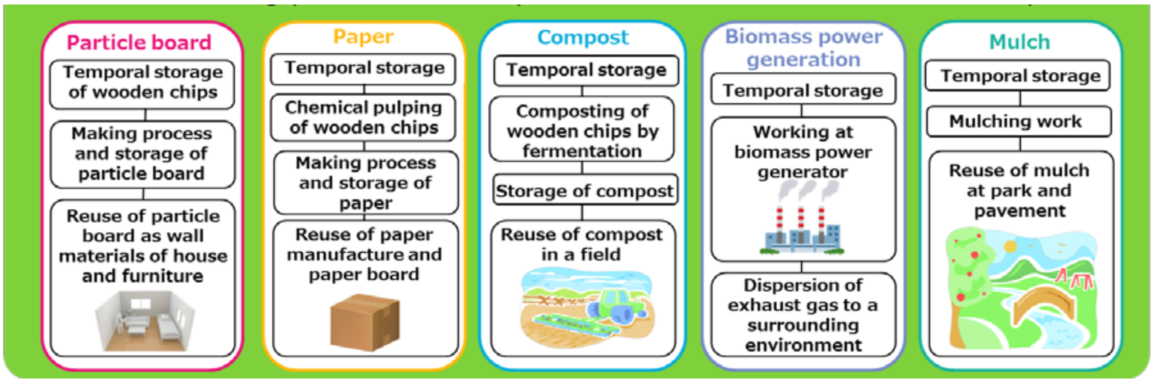


Figure 19. Working process and final products considered for the reuse of contaminate wood chips

An assessment code, PASCLR2, was developed to derive clearance levels on the basis of a dose estimation assuming a unit radioactive caesium concentration in wood chips. Dose conversion factors for external exposure pathways were based on conservative source geometry assumptions relative to working conditions for transportation, temporary storage and processing of wood chip products. Other parameters were derived from previous clearance estimates undertaken in Japan. The code was used to derive the minimum radioactive caesium concentration (Cs-134 + Cs-137) that was practicable for the reuse of wood chip under each scenario, relative to the effective dose criteria. All concentrations corresponding to the dose criteria were greater than 100 Bq/kg, with the lowest concentration value relating to the reuse of wood chips in particle boards (120 Bq/kg)(Figure 20).

Scenarios	Main Exposure pathways in scenario of reusing wooden chips		Total radioactive cesium concentration in wooden chips corresponding to the effective dose criteria (Bq/kg)	Minimum radioactive cesium concentration in each scenario (Bq/kg)
Particle board	Work in a storage yard of wooden chips	External		120
	Residence near particle board factory (child)	External		
	Use of bed (child)	External		
Paper	Work around a black liquor tank	External		1900
	Maintenance of a recovery boiler	External		
	Residence near the paper factory (child)	External		
Compost	Transportation of wooden chips	External		2700
	Agriculture in a field containing compost	External		
	Ingestion of crops grown in the field (adult)	Internal		
Biomass power generation	Work around a storage silo of wooden chips (child)	External		2200
	Maintenance of an incinerator	External		
	Inhalation of dust released from the incinerator (child)	Internal		
Mulch	Work of mulching wooden chips in a park	External		260
	Use of mulched park (child)	External		
	Use of mulched pavement (child)	External		

1E+01 1E+03 1E+05 1E+07

Figure 20. Minimum radioactive Cs concentration (134Cs + 137Cs) which is practicable for the reuse based on the results of dose estimation

In the dose estimation for limited reuse purposes, doses to workers and members of the public at all stages between production of recycling material and final reuse were calculated, based on realistic information on the treatment and reuse of material in and around Fukushima. Pathways considered including seepage of rainwater to groundwater following reuse of materials for the construction of pavements or coastal defences and subsequent use of well water. The transfer of caesium from soil to plants was also evaluated for protection forests and migration in groundwater and uptake in marine products. Again, caesium isotope concentrations relating to criteria ensuring safety were derived for the different scenarios (production of recycling material and reuse in pavements or roads or to develop coastal protection forests). The dose assessment took into account the type of material used, the thickness of shielding materials and where reused materials were located e.g. roads or pavements. The highest activity concentration that could be reused in inland infrastructure projects equated to 2,700 Bq/kg when material was used as a 30 cm sub-base course material for road construction with a 30 cm cover layer consisting of base course material and asphalt. Concrete wastes with contamination of up to 3,000 Bq/kg could be reused for coastal protection forest development where shielding material of 1 m was used.

Two types of criteria were therefore required in the initial stage of response to the Fukushima accident to allow general recycling of materials with free release to the market and to achieve volume reduction of contaminated materials and progress infrastructure reconstruction. The development of these criteria during the initial stages of the accident response was an important aspect for progressive recovery from the accident. Further work is ongoing to determine guidelines and criteria for the reuse of soil removed as part of the immediate remediation activities and for the reuse of materials such as concrete and metals with low levels of contamination that will be generated during decommissioning activities at the nuclear power plant.

4.4 Emergency limitation of radionuclide concentrations in foodstuffs: from temporary permissible levels to normal practice

Alexey Titov (FMBC) presented.

Following the Chernobyl accident, the radionuclide content of foods was required to be regulated, e.g. through the introduction of temporary permissible levels of contamination for foods.

In the first month following the accident, the key focus was on limiting thyroid exposure due to the intake of I-131. A permissible activity of I-131 of 3,700 Bq/l in milk was therefore introduced and was followed by the same permissible level being introduced for drinking water, fish and green vegetables. Permissible concentrations were calculated based on a monthly permissible dose to the thyroid of 300 mSv for an adult. The permissible concentration for children was 10 times lower.

As I-131 decayed, the focus moved to caesium isotope concentrations in food and drinking water. The temporary permissible levels in the move from an emergency to existing exposure situation are presented in Table 5. After the first few years, annual dose reduced significantly (50 mSv to 5 mSv over a 7 year period). By the mid-1990's, the exposure situation was steady and the principal mitigation measures were complete. The use of temporary permissible levels had, however, resulted in restricted trade between Russian regions, which in turn affected the development of agriculture and livestock production in the affected areas. In response to this issue, unified Russian permissible levels of radionuclide specific activities in foods were introduced throughout the country. These permissible levels existed for 5 years, before being revised in 2001.

Table 5. Temporary permissible levels (Bq/kg or Bq/l) of cesium isotopes in foods over the transition period from an emergency to an existing exposure situation

Year	1986	1987	1988	1991	1993
Dose, mSv/year	50	10	8	8	5
Baby food		370	370	185	185
Milk	370	370	370	370	370
Potato	3700	740	740	600	600
Meat	3700	1850	1850	740	600

The permissible levels were revised to account for changes in food intakes in different regions of Russia and new knowledge on factors such as the transfer of radionuclides from soil into foodstuffs and loss of activity through food processing. International regulations on radiation protection had also changed since the accident and these revisions needed to be captured within revised criteria.

Compliance with the food regulations was based on the specific activity of the radionuclides relative to their permissible concentrations. Where the sum of these ratios (for the different radionuclides) is less than 1, compliance is assured. The revised permissible levels have been set out in a regulatory document '*Hygienic requirements for safety and food value of foodstuffs*', which covers 141 foods within 13 categories. Some differences are evident between the levels stipulated in this guide and those given by the EC and WHO, which largely arise from the use of different criteria (5 mSv/y in Europe and 1 mSv/y in Russia).

Bringing the permissible levels in Russia in line with those of the EC would require the revision and acceptance of the regulatory basis on radiation safety, and would reduce the level of radiation protection of the public achieved in Russia. Harmonisation would however allow the return of most contaminated areas in Russia and Belarus to normal life with almost all local foods complying with permissible levels. This would have a large and positive impact in allowing the economy and agriculture of the affected regions to develop.

4.5 Points from discussion

Reduction of contamination levels in the most heavily contaminated areas, relating to evacuation zones, was effective with up to 60% reduction in activity being observed. The remediation works could be repeated to further decontaminate the area, but the effect would be less effective than the first attempt. A judgement was therefore made by the Ministry of Environment, based on cost-benefit, that repeating of the process could not be justified. The experience gained in decontaminating different surfaces is important knowledge that others can learn from.

Whilst clean-up activities in the areas affected by the Fukushima Dai-ichi accident have served to significantly reduce contamination levels and allowed some areas to be released from their evacuation orders, it is possible that a large proportion of the affected population will not return to their homes. This is in part due to houses remaining unoccupied since the accident leading to structural issues and the resultant lack of property maintenance. On the other hand, farmers well may choose to return to farm their lands due to the long history families have with their lands. Decisions will also largely depend upon what evacuated families are now doing and whether they are established in new areas. This may complicate follow-up health studies, compared with the Marshall Islands case. In that case, people largely moved in groups to one or two areas, which facilitated continued monitoring. In Japan, the movement of people was down to individual choice, resulting in greater dispersion. Following individuals will therefore be more complex.

Whether or not it would be important to establish generic criteria for foods and release of materials etc., that could be used in future incidents was questioned. The experiences in Russia and Japan, e.g. on the transition of permissible levels from emergency to existing exposure situations in Russia, could be used as a basis for establishing recommendations for major incidents. The development of generic criteria would not be an easy task, particularly in light of the range of reference levels proposed for existing exposure situations (1 to 20 mSv), which can be variably used. It was noted that it is hard to relax radiation protection criteria, even if that provides major benefits to those exposed. Also, it can appear difficult to support lower doses to workers involved in post-emergency remediation work (a planned exposure situation), than to the people whose land is being remediated (whose exposure is an existing situation).

There are also issues around different foods and consumption habits varying between populations. There is also confusion as to when an emergency situation ends and an existing situation begins and how this transition would affect permissible levels and clearance values. Rationalisation of the different values applied would be beneficial, providing background on their derivation and the context in which they are meant to be applied. In an emergency situation, it may not be possible to remove all contaminated food from diets and psychological impacts may occur where diets are forcibly changed from the foods normally consumed in order to avoid exposure.

It was noted that pre-planning can help in this regard is seen as beneficial, as was noted in Appendix C2. Giving consideration as to how to apply criteria at different phases of a response would also be beneficial to avoid confusion and loss of trust. Consideration should also be given to the development of communication tools and the testing of the tools for public communication prior to any incident, again, as was noted in Appendix C2.

It is important not to set rigid criteria for legacies since each legacy issue will have its own individual characteristic. Optimization should focus on the actual situation, taking into account local characteristics and stakeholder views, and communication with stakeholders should be undertaken in a way that promotes trust. However, there can also be advantages in the harmonisation of standards internationally.

5 Session 3: Uranium Mining and Processing Legacies

5.1 US NRC's uranium recovery decommissioning program and non-military radium program

Michael Norato (US NRC) presented.

The regulation of nuclear sites in the US comes under the remit of the NRC, DoE and EPA. The NRC ensures adequate protection of public health and safety, common defence and security, and protection of the environment in the use of radioactive materials at nuclear power, research, test and training reactors as well as medical, academic and industrial facilities. The NRC is also responsible for ensuring safety with regard to the transport, storage and disposal of nuclear materials and waste. A further responsibility is the development of regulations for the safe use and remediation of radioactive materials at NRC licensed sites.

In the US, laws are enacted through code of federal regulations. NRC guidance and regulations then fall below the code of federal regulations, and ensure compliance with the overall regulations and laws. The main acts and regulations relating to legacy sites in the US are the:

- Atomic Energy Act of 1954 (as amended), the Energy Reorganization Act of 1974 (as amended);
- Uranium Mill Tailings Radiation Control Act of 1978;
- Nuclear Waste Policy Act of 1982, as amended;
- Low-Level Radioactive Waste Policy Amendments Act of 1985;
- National Environmental Policy Act of 1970; and
- Title 10 of the Code of Federal Regulations (10 CFR).

All acts are subject to the National Environmental Policy Act that requires the preservation of historic sites and important species.

Within the Uranium Control Act, two types of site are recognised; those that were inactive prior to the act (Title 1 sites) and those that were licensed by the NRC in or after 1978 (Title 2 sites). The owner of Title 1 sites may no longer exist whereas Title 2 sites have existing licensees. All 22 Title 1 sites have been transferred to the DoE, resulting in the situation whereby one regulator is responsible for controlling another. Four of the Title 1 sites are located on the Navajo Nation, which is native American territory and there are therefore a number of sensitivities that must be considered. Of the 17 Title 2 sites, 11 are currently undergoing decommissioning and 6 have been transferred to the DoE.

Decommissioning standards for sites have been set by code of federal regulations. For soil, an activity concentration of 5 pCi/g averaged over the first 15 cm applies with an activity concentration of 15 pCi/g averaged over 15 cm applying to the next 15 cm of soil. For radon, the standard applied is 20 $pCi/m^2/s$ and for groundwater, the lower of background or maximum contaminant levels apply, although alternate concentration limits can be proposed where these targets are not achievable, but they are subject to approval by the NRC.

For Title 1 sites, the EPA is responsible for establishing standards for clean-up and disposal for contaminated material and the DoE is responsible for identifying and remediating all sites to meet the EPA standards and for remediating properties in the vicinity of Title 1 sites. The NRC then evaluates the remediation plans and ensures that remediation has been adequately completed. The DoE is the long-term site custodian under NRC general license.

For Title 2 sites, the EPA is again responsible for establishing standards for clean-up and disposal of contaminated material. The NRC (or Agreement State[2]) is then responsible for reviewing license applications, issuing licenses, conducting inspections and overseeing decommissioning. The NRC also reviews and approves DoE's long-term surveillance plans, approves Agreement State license termination and terminates specific licenses. The DoE again becomes the long-term site custodian under NRC general license.

To date, all 22 Title 1 sites have had surface remediation works completed. Groundwater remediation continues at some of the sites. It has not been feasible to achieve background levels at 3 sites and, as such, alternative concentration levels have been approved by NRC. Of the 6 Title 2 transferred to DoE, all have had surface remediation works completed and groundwater remediation works have also been undertaken with alternative concentration levels having been applied at 3 sites that are subject to continued monitoring. No groundwater monitoring is undertaken at 3 other sites. Of the 18 remaining Title 2 sites that are undergoing decommissioning works, 11 are NRC licensed and 7 are Agreement State licensed.

The locations of Title 1 and Title 2 sites are illustrated in Figure 21. The majority of sites are located in or near the Rocky Mountains and particularly in the states of Colorado, Utah and New Mexico.

There is a 5-year Navajo Nation plan ongoing. The Navajo Nation territory was the location of some of the first uranium deposits that discovered in the US and 4 disposal/processing sites are located in this region (Figure 22). Tailings have been removed from the Monument Valley site and works are currently ongoing to remediate the groundwater through the use of phytoremediation techniques. The tailings from the Monument Valley site were moved to the Mexican Hat disposal site where they have been placed in a disposal pit and covered to minimise radon emission. The Shiprock disposal site in New Mexico is comprised of a coarse rock pile of tailings that has been fenced off. This site remains under active control.

A further recent project has focussed on a mill site and mine at Church Rock, New Mexico that is close to the boundary with Navajo Nation. The Navajo Nation has agreed for mine waste to be removed and placed on top of mill tailings at the site. Work is ongoing to investigate the potential impacts of this with regard to groundwater movement and the potential for increased pollution of the area. If this work does go ahead, an amendment of the current NRC license will be required.

The main challenges to the ongoing uranium decommissioning program relate to the large extent of the program and determining long-term care fees. Licensees are meant to provide financial assurance to the DoE to fund the long-term maintenance of sites, but experience has shown that the funds are not sufficient to cover the remediation programs required. As such, the DoE has taken over a number of sites and there are insufficient funds available to appropriately maintain the sites. A further challenge relates to exceedances of alternate concentration limits. These limits are derived from groundwater modelling. However, experience shows that, following transfer of sites to long-term care, exceedances have occurred that have required additional remediation measures that have significantly increased the costs associated with maintaining these sites, compared with original estimates. Budget constraints faced by the NRC also limit site inspections.

[2] 38 Agreement States have been approved by the NRC as being responsible for decommissioning sites.

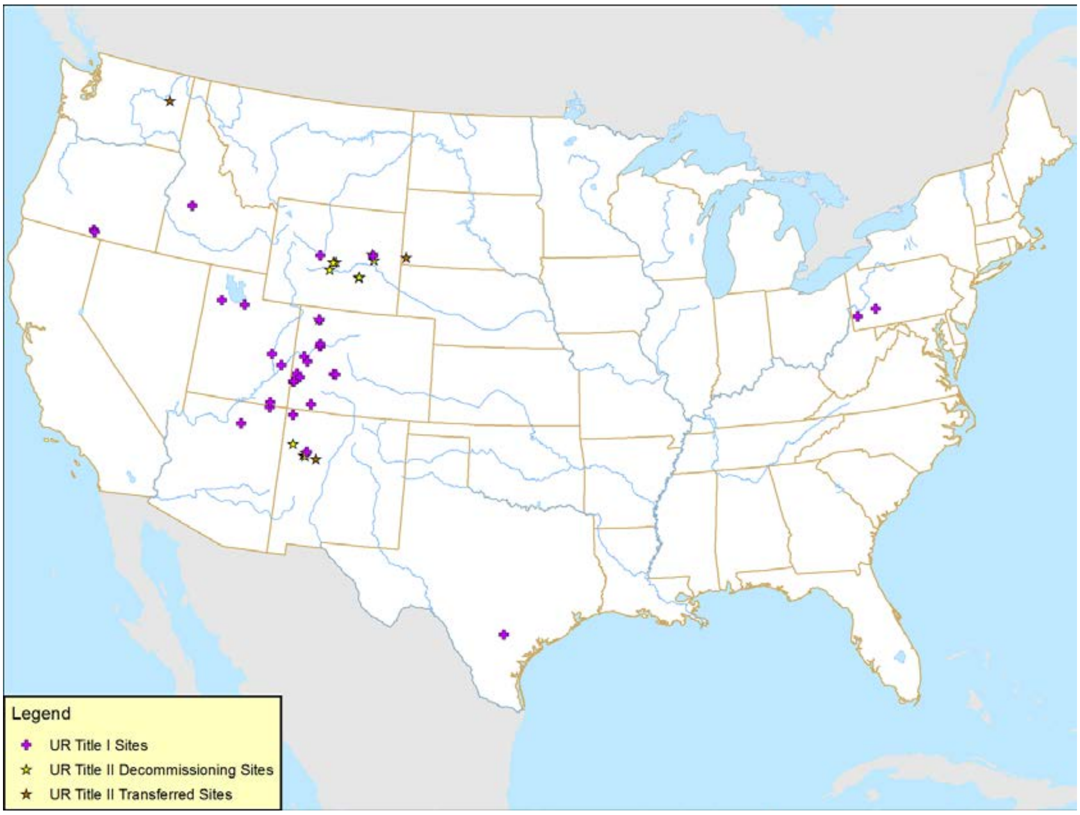


Figure 21. Location of US Title 1 and Title 2 sites.

Figure 22. Location of the Navajo Nation territory and associated processing and disposal sites.

In terms of radium, the 2005 Energy Policy Act stipulates that the NRC has the regulatory authority over all past, present and future discrete sources of Ra-226 and any contamination associated with these sources. There are two parts to the radium program. Military bases contaminated with radium (especially naval bases) require the EPA and NRC to work together with the NRC having jurisdiction for sites that do not fall within the National Priorities List. The EPA has jurisdiction for sites on this list. The other part of the program relates to non-military sites.

Radium was historically used in a range of consumer products such as shoe polish, make up and clocks and many of the facilities that manufactured these products now require remediation, such as the former Waterbury Clock Company facilities. Radium was used in the manufacture of clocks from 1919 to the 1930's resulting in the residual contamination of the company's building, both with radium and asbestos. The NRC is coordinating the clean-up of the site with the EPA under the EPA's brownfield program. Great Kills park is another Ra-226 contaminated site. The park was built on a former landfill and radium needles from hospitals and other contaminated products have been discovered. Currently around 265 acres of the park are closed to the public. The NRC is coordinating with the park owner (the US National Park Service) to characterize the site and undertake clean-up activities. With the awareness of these sites, the NRC has initiated a program to identify other sites that may have historical radium contamination. More than 30 sites have so far been identified and the program is ongoing.

5.2 Experience of Ukraine in implementing rehabilitation and decommissioning programs for uranium facilities

Alexander Sotnikov (SNRIU) presented.

Currently within the Ukraine, uranium ore is produced by three state-owned mines that are situated in the Kirovograd region. Uranium ore is processed in a hydrometallurgical plant and waste stored in a tailings pond in Shcherbakovskaya. The pond is nearing capacity and a design to allow more capacity is therefore needed and the current dam will be expanded (Figure 23).

A former uranium site at Devladovo has undergone remediation. During the 1970's and 1980's, raw uranium was produced at the site by underground leaching. All remediation activities have now been achieved at the site. Generally speaking, remediation activities are performed within the framework of projects that are implemented by site owners. Risk evaluation is performed for all projects and no issues have been encountered with their implementation to date. There is however another legacy issue in the Ukraine – the Pridneprovsky chemical plant.

Figure 23. Tailing pond showing current dam at Shcherbakovskaya

The Pridneprovsky chemical plant is located in Dneprodzerzhinsk, in the Dnepropetrovsk region. The plant was used between 1949 and 1991 to process uranium raw materials from Ukrainian sites and eastern Europe. As a result, there are 7 tailings ponds and 2 storage areas with close to 42 million tons of waste from uranium ore processing, with a total activity of $3.14\ 10^{15}$ Bq. Since 1992 there has been significant restructuring of activities at the plant with the result that there are now around 50 different companies registered as working there. There are difficulties in regulating the activities of all these different companies. The majority of contaminated buildings are located in the southern area of the site (Figure 24). The facilities are situated within the city with the tailings ponds being located in the outskirts. The water level has been reduced over the years within the ponds (Figure 25).

In order to remediate facilities, Ukraine has adopted two government programs to remediate the site to an environmentally safe status and to protect the public. The main objectives are to undertake investigations and radiation monitoring to identify the status of buildings and facilities and practical work to minimize the impact of uranium objects on the environment.

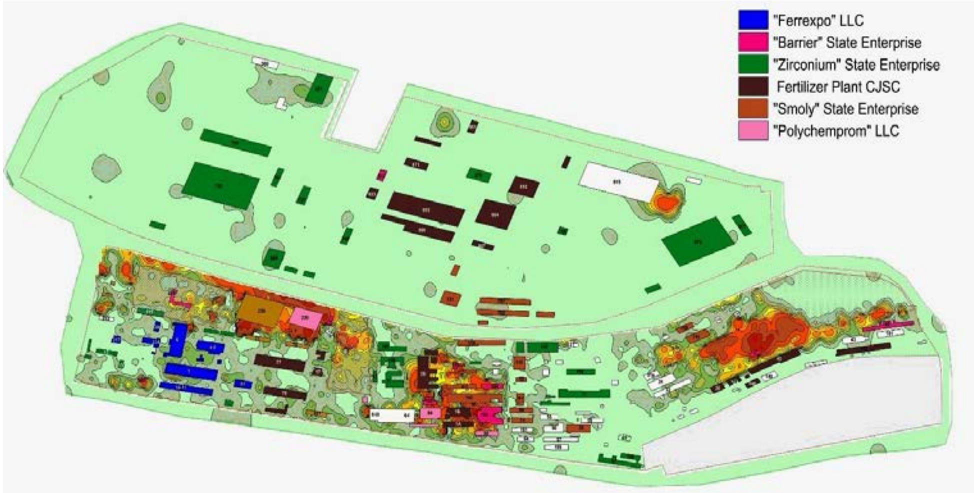


Figure 24. The Pridneprovsky chemical plant.

Figure 25. Pridneprovsky chemical plant tailings ponds and technological sumps building. Upper left – tailing pond Sukhachevskoye, upper right – tailing pond Yugo-Vostochnoe, lower – Building 103 Technological sumps.

The main program stakeholders are the Ministry of Energy and Coal Industry, which is responsible for the development and management of the programs; the State Nuclear Regulatory Inspectorate, responsible for regulatory support including licensing, development of regulatory documents and supervision of the program implementation; and the State enterprise 'Barrier', which is the main executor of program measures. Barrier was established in 2000 to implement remediation activities at legacy sites. However, the enterprise made some mistakes due to lack of strict control measures, resulting in a number of issues. Barriers license has therefore been suspended by the regulator and consideration is being given to replacing the enterprise.

During the implementation of the State programs, a lot of research has been conducted to understand waste composition and condition, possible migration routes, and the possibility for the application of different technologies. Several projects were also developed to minimize the impacts on personnel, members of the public and the environment. A priority project was to reconstruct and convert the Sukhachevskoye tailings pond and to construct a decontamination site.

The Barrier enterprise has carried out monitoring activities at the site along with other organisations, including the centre for monitoring research and environmental technologies, Ukrainian Hydro-Meteorological Institute, the Institute of Hygiene and Medical Ecology and Dneprodzerzhinsk hydro-meteorological station. Various objects are monitored, including the tailings ponds and buildings, adjacent settlements and some rivers. Sites and objects are monitored for gamma dose rate, Rn-222 in air and emanation from the soil surface, total alpha activity and the activity of uranium and thorium series radionuclides, and heavy metals in air, water, soil and foodstuffs. Monitoring reports are submitted annually.

Whilst the programs have been ongoing since 2003, only 3 practical remediation activities have been undertaken to date. These include the construction of a protective cover on the Zapadnoe tailings pond, dismantling of the most contaminated pipeline and emplacing within container storage, and creation of a protective covering over the Yugo-Vostochnoe tailings pond to reduce Rn-222 emanation and the migration of other contaminants.

Problems have been identified with the implementation of the State programs. The first issue has been the absence of approved strategies for rehabilitation activities and agreed end state for further use of the site in the future. The lack of vision as to future use of the site has hindered regulatory supervision of remediation activities. Designating the site as a special status area, such as that given to the area around Chernobyl, could be a useful approach. Greater control of activities by the government authorities is also required over the executor of the program. The availability of funding for State programs is also an issue. Work is ongoing to find solutions to these issues.

5.3 Regulation of uranium legacy in the Russian Federation

Vladimir Seregin (FMBC) presented.

The FMBC is a technical support organisation to the Russian regulatory body, FMBA. Tasks of the FMBC are to undertake research at legacy sites and facilities, develop documents on radiation safety and protection at various stages of uranium legacy remediation (following ICRP and IAEA recommendations), undertake expert reviews of documents provided by operators, and supervision and control of radiation protection of workers, the public and the environment.

There remain operational sites in Russia that have been operating for over 50 years. Others have been decommissioned, but radon can remain an issue in tailings areas. The Priargun Production Mountain Chemical Association uranium mine, situated in Krasnokamensk, was established in 1968 and continues to produce uranium oxide. Ore processing is carried out in hydrometallurgical plants and at the heap leaching site. Operations at the site have resulted in a contaminated area of 1.5 km^2 with half of this area being outside the actual mining site. The maximum dose rate in the local city was around 15 µSv/h as a result of soil contamination that has occurred during flood events with the concentration of Ra-226 in soil being in the range of 200 to 400 Bq/kg. Ore has also been scattered along roads during transportation.

Monitoring activities were undertaken in the area between 2008 and 2013. The program involved improved understanding of radiative and chemical contamination dynamics and evaluating contamination levels at work places and in homes. The radio-ecological condition of surface waters, groundwater and drinking water were also investigated and the health of mine workers assessed.

Monitoring of groundwater indicated that over 40% of samples had abnormal levels of Pb-210. Plants sampled also had higher activity concentrations of U-238 series radionuclides than those sampled at Soktuy, located 40 km distance from the mine (Table 6).

Table 6. U-238 series radionuclides in plants (Bq/kg) sampled in the vicinity of the uranium mine and at Soktuy, 40 km from the mine.

Radionuclide	Octyabrsky	Soktuy
^{238}U	130-1200	
^{226}Ra	50-500	7-14
^{232}Th	12-45	
^{210}Pb	53-15200	11-31
^{210}Po	17-10000	4

Total alpha activity in drinking water was also high, exceeding the intervention level (Figure 26). High activity concentrations of Ra-226 and Pb-210 have also been recorded in local foods, and particularly in milk and potatoes. Studies of occupational morbidity were also undertaken for a range of indicators (Table 7).

Several guidance documents were also produced during the work program, including:

- Guidance on “Criteria of the Environmental Remediation of the Uranium Mining and Milling Sites”;
- Recommendations for “Monitoring of effective equilibrium activity concentration of radon in dwellings and public buildings of Krasnokamensk of Trans-Baikal Territory”;
- Recommendations for “Monitoring of radiation conditions of the Umykei Lakes”; and,
- Methodical guidelines on “Optimization of radiation and hygienic monitoring in the vicinity of the repurposed facilities for mining and processing of radioactive ores”.

In addition to the Priargun mining site, a hydrometallurgical plant at Lermontov has also been investigated. Water contamination has occurred at the site as a result of soil erosion and a lack of reprocessing of mining water. The situation in mines, tailings and facilities has been investigated and radioactivity in Lermontov city and surface water monitored. This work was completed between 2014 and 2015 and guidelines on radiation monitoring around the plant have been produced and submitted to FMBA for evaluation.

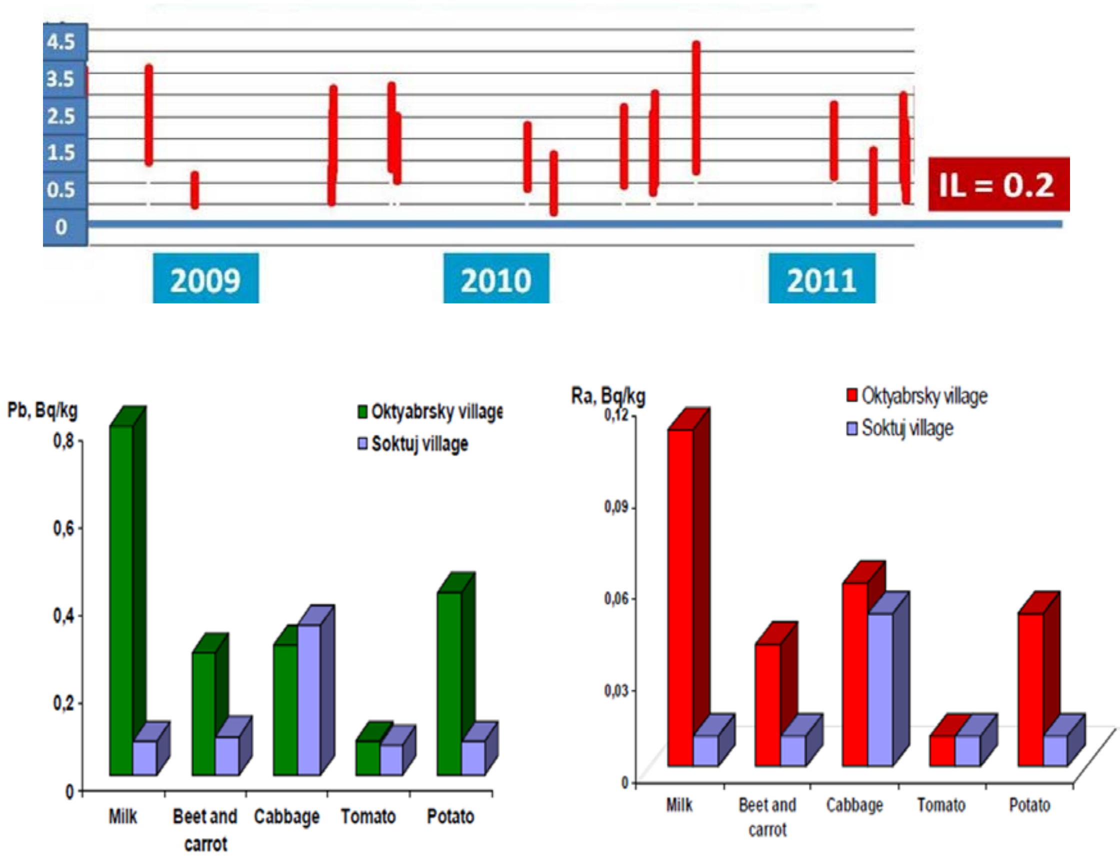


Figure 26. Total alpha activity in drinking water (Bq/l) relative to the intervention level of 0.2 Bq/l (upper figure) and activity concentrations of Ra-226 (lower left) and Pb-210 (lower right) in local foods (Bq/kg).

Table 7. Morbidity indicators in mine workers and number of incidence recorded since 1969.

Morbidity indicator	Incidence (1969 to present)
Professional hearing loss	212
Dust bronchitis	91
Vibration disease	138
Onco-pathology of lungs and upper respiratory tract	88
Occupational diseases of peripheral nervous and musculoskeletal systems	140
Total	699

FMBC and FMBA also participate in the interstate target program on the remediation of territories of EurAsEC Member States affected by uranium mining industries. There are two directions of activities within the program. One aspect focuses on testing elements of the overall system of environmental and socio-hygienic monitoring at sites. The other is focussed on the development of a database of medical and demographic data of populations living in areas of reclaimed sites.

From the period 2013 to 2015, five expeditions were undertaken to legacy sites to undertake surveys to evaluate resident doses and evaluate radioactivity in foods and drinking water. Population health monitoring was also undertaken through the accumulation of copies of national state medical statistics reports. Individual effective doses to members of the public in settlements in Kyrgyzstan were dominated by Rn-222 in most instances. A similar situation was observed in the Republic of Tajikistan.

Documents developed during the EurAsEC program included:

- "Improvement of the system of targeted inspections of the public in the areas affected by natural uranium mining and milling facilities for 2016-2020"; and
- “The radiation survey in the settlements located near the sites under remediation”.

A series of recommendations has also been made for the next stages of the program, such as improving addressing anxiety, depression and stress disorders among the population and developing measures to reduce socio-psychological tension, further developing the monitoring program and undertaking wider and more detailed studies on radon activity concentrations and their variability. Recommendations have also been made with regard to training.

During the work program, regulatory challenges were identified. For example, the term ‘uranium legacy sites and facilities’ is not recognised in Russia and, whilst legislation provides for the safe implementation of programs to address these sites, documents to support activities are not yet sufficient. The Russian Law on radioactive waste management, implemented in 2011, also requires updating to take account of new guidance and recommendations from the ICRP and IAEA, including the introduction of the term ‘existing exposure situation’.

In the joint program with the NRPA on legacy sites in Central Asia, radio-ecological monitoring data has been studied and analysed and documents developed by Central Asian states have been reviewed. The need to improve the legislative basis for remediation of legacy sites has been identified and a document developed on radiation safety regulation during remediation of uranium legacy sites and facilities.

5.4 Criteria, process, and technical approach for remediation of uranium processing legacy sites in the USA

Dan Gillen (for US NRC) presented.

The US has an established program to clean-up legacy uranium mill tailings sites. As noted in section 5.3, the US has two categories of uranium mill tailings sites. Title 1 sites are those that are abandoned and for which there is no licensee remaining, whereas Title 2 sites have known licensees. The mill tailings issue was first recognised in 1978 and all 22 Title 1 sites have subsequently been remediated although some minor groundwater works continue at some sites.

There are three levels to the regulatory framework. Laws and supporting regulations must be followed and guidance documents are provided to support regulatory compliance. The main laws for uranium legacy sites are the National Environmental Policy Act of 1969 and the Uranium Mill Tailings Radiation Control Act of 1978. There are also laws describing the scope of remediation and assigning responsible parties for the development of regulatory criteria, regulating remediation activities and provision of long-term care. How the different parties should interact in carrying out remediation programs are also described.

The National Environmental Policy Act established policies and processes for the protection of the environment and required agencies to consider the environmental impacts arising from their actions, identify unavoidable environmental impacts and make the information public. All environmental consequences of actions must be considered.

The Uranium Mill Tailings Radiation Control Act established programs for the stabilization and control of mill tailings at uranium and thorium mill sites. Part 1 of the act addresses the remediation of legacy/unlicensed sites (i.e. Title 1 sites) and Part 2 created a framework for regulating wastes at NRC-licensed sites. The Act also set out requirements for three agencies to be involved in the program. The EPA was assigned responsibility for establishing remediation criteria, the DoE was made responsible for carrying out remediation activities and the NRC was assigned responsibility for overseeing the works and for approval that activities have been carried out to meet remediation criteria. The DoE was also identified as the long-term custodian for the legacy sites whereas the NRC had responsibility for licensing the long-term care for these sites.

For remediation criteria, boundaries are set for what actions are needed and what is enough to protect public health and safety and protect the environment. The criteria relate to 5 main categories, including:

I. *General control of tailings*. Responsible parties are required to ensure that facilities are closed in a way that leads to control, minimization or elimination of post-closure release of hazardous materials, leachate, contaminated run-off, or hazardous waste decomposition products to groundwater, surface water or atmosphere. Maintenance requirements should also be minimized.

II. *Stability period*. Control of residual radioactive materials and their listed constituents are required to be designed to be effective for up to one thousand years. It was however recognised that there could not be 100% assurance of effective control over 1,000 years so a minimum 200 year control period applies for any design.

III. *Clean-up of land and structures*. Remedial actions are required to be conducted so that, as a result of residual radioactive materials from any processing site, the concentration of Ra-226 in land averaged over any area of 100 m^2 is not exceed the background level by more than 5 pCi/g, averaged over the first 15 cm of soil below the surface, and 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface. Furthermore, in any occupied or habitable building remedial action is required to achieve an annual average radon decay product concentration (including background) less than 4pCi per litre.

IV. *Groundwater clean-up and protection*. Residual radioactive materials are required to be disposed of in a manner that ensures hazardous constituents entering groundwater from a tailings site will not exceed established concentration limits (or approved supplemental standards) in the uppermost aquifer underlying the site beyond the point of compliance. This is normally the boundary of the site, but can related to the boundary of a tailings pile.

V. *Radon attenuation*. Control measures for residual radioactive materials are required to provide reasonable assurance that releases of Rn-222 to the atmosphere will not exceed an average release rate of 20 $pCi/m^2/s$.

Roles were defined under the Uranium Control Act within an action framework for legacy sites that ensured the separation of roles between the regulator (or competent authority) and the operator, with the former being responsible for establishing standards and for overseeing activities, undertaking inspection and enforcing requirements. The operator (or responsible party) is responsible for designs, operation, decommissioning and reporting. The process of interaction between the different parties is illustrated in Figure 27. Once long-term care is approved for a site, the DoE is responsible under general license issued by the NRC. Inspections are required on an annual basis and NRC accompanies DoE representatives.

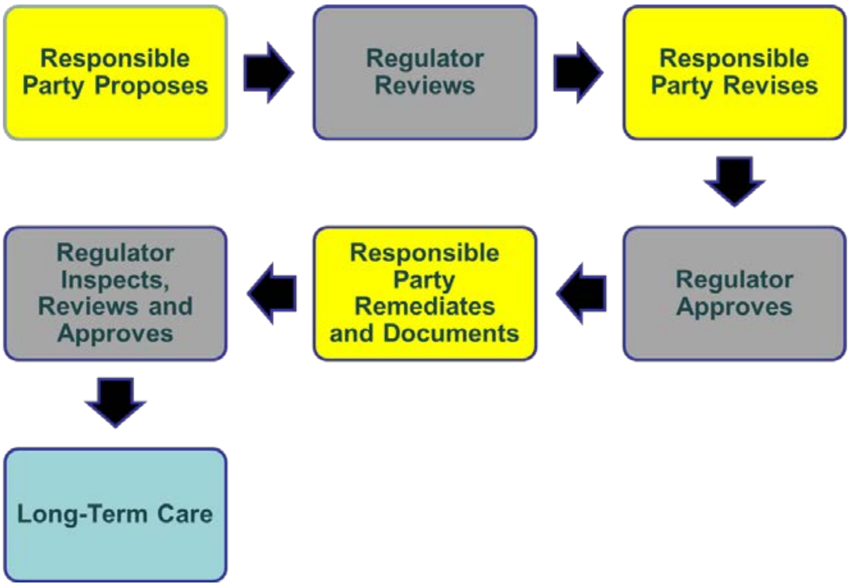


Figure 27. Process of interaction for the management of legacy sites within an action framework.

Action plans for remediation or decommissioning submitted by the operator are required to cover aspects such as environmental impact statements, detailed information on construction specifications such as the materials to be used in covers, inspection plans and remediation designs to meet required standards. The plans are then submitted to the NRC for review by a technical review team, headed by a project manager and consisting of other appropriate technical experts from the fields of health physics, hydrogeology, geotechnical engineering, surface water hydrologists and erosion experts.

The responsible party for a legacy site is required to undertake environmental monitoring throughout remediation and decommissioning projects and to compare the findings against the original situation. Monitoring can include radon in air, air particulates, and samples from biota, water and soils. Direct radiation may also be monitored.

The NRC has a program for inspection at all licensed premises with inspectors being required to pass strict qualification exams. Inspections may be announced or unannounced and additional experts may be brought in as appropriate. Inspections can include the review of site records and interviewing of staff. Where issues are identified, violation notices or civil penalties may be issued.

Public involvement is an important aspect of remediation programs. The NRC aims to involve the public in a number of ways, for example, providing information on a public website, provision of information through freedom of information requests, public hearings and the opportunity for the public to attend meetings with responsible parties. The public are also encouraged to provide input to the environmental evaluation process through feedback to consultation documents.

Within the technical approach to management of legacy sites, characterisation of the site and materials present is required. Factors such as slope stability, settlement and erosion protection and the design of covers and lining should all be considered. Geotechnical characterisation may also require borehole construction, in addition to literature survey to identify required data on the site such as geomorphic features and the potential for flooding and seismic events. Slope stability is required to be maintained during all conditions of construction and operation and the potential for settlement must be analysed to ensure that covers and liners will maintain their integrity when subjected to induced strain. Liquefaction should also be considered; soils that are loose, near-surface, saturated and sandy are of particular concern, particularly in areas that may be subject to seismic events. The most disruptive natural phenomenon affecting long-term stability of tailings is, however, erosion. A good hydrological description of the site is therefore required to support erosion protection designs. A probable maximum flood event, based on probable maximum precipitation is commonly used to test designs for resilience to erosion. Rock lined ditches are often incorporated into designs with the positioning being upstream of tailings cells to prevent flood water access. Vegetation or rock and vegetation protection covers are also often used.

Good control of operations is required for all earthwork projects. Construction specifications are written to describe emplacement and compaction methods, and aspects such as dust and moisture control. Radiation safety requirements for workers are also stipulated in the specifications. Cover design is required to meet NRC criteria. The criteria relate to erosion resistance, promotion of run-off and limitation of infiltration, minimization of radon emission, minimization of long-term maintenance requirements, risk to human health and the environment, and animal and human intrusion events. To achieve these requirements, covers need to be constructed of natural materials and be designed for extreme events. The inclusion of a low permeability clay layer is recommended to address radon emanation and water infiltration requirements and use of rock or self-sustaining vegetation can be used to resist erosion. The general cover design used at many legacy sites is illustrated in Figure 28a. More recently, however, an additional frost protection layer has been incorporated into designs to protect the clay barrier and provide a zone to control against root ingress (Figure 28b). There are no standard procedures or 'recipes' for the design of covers and not all covers have ended up behaving as designed. As such, there may be a need to abandon the barrier control philosophy in favour of an ecosystem-type approach that incorporates local plants and soils, leading to self-sustaining covers.

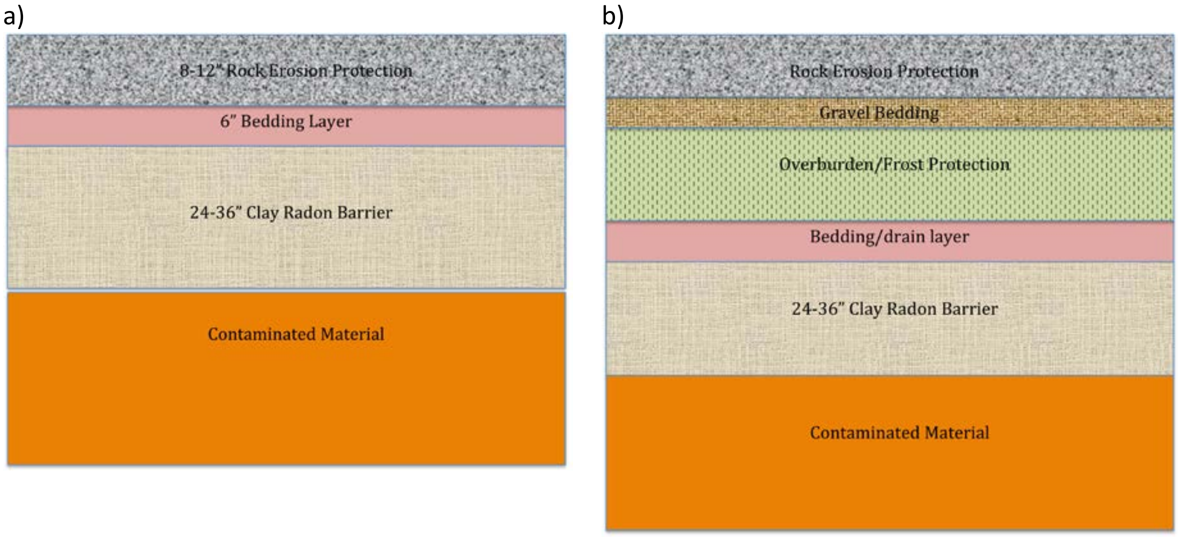


Figure 28 Traditional cover design (a) and revised design (b) to incorporate frost and root ingress protection.

The main regulatory challenges that have been faced in addressing legacy sites have been:

- Maintaining regulatory independence between operator and regulator when all involved organisations are regulatory authorities;
- Establishing appropriate remediation criteria, which can be dose-based or clean-up level based;
- Setting appropriate inspection levels;
- Handling long-term institutional controls where NRC is responsible for long-term oversight, but the DoE is responsible for the site itself; and
- Monitoring the effectiveness of remediation measures and effectiveness of designs.

As a result of the US program on legacy uranium tailings sites, the following 10 key points for uranium production regulatory programs were made:

I. Government should develop a clear national policy and strategy for regulating new, existing, and/or legacy uranium production sites, facilities, projects, and programs, and should provide adequate funding to carry out that strategy.

II. Government should enact clear laws that form the legal basis for the policy/strategy: that are focused on public health and safety and protection of the environment; that define the entities involved and their responsibilities; that describe the process of interaction of those entities; and that maintain separation of regulator and operator.

III. The Regulator as defined by law should have appropriate and adequate staffing for technical review; program management; environmental assessment; guidance development; and legal analysis.

IV. The Regulator should define the details of the regulatory process (organizational interaction and internal processes) from application to post-closure.

V. The Regulator should develop and provide appropriate regulations and guidance for applicants/operators and for its own staff to ensure efficient and consistent reviews, and safe operations.

VI. The Regulator should provide requirements on timeliness for decommissioning uranium production facilities.

VII. The regulatory program should include the following important aspects of regulation:

   a. health and safety of the public and workers
   b. assessment of environmental impacts
   c. stability and control of waste
   d. radiological criteria and monitoring programs for soil, water and air
   e. financial assurance requirements for operators
   f. development of closure plans at the inception of projects (lifecycle planning)
   g. long-term surveillance for remediated sites.

VIII. The Regulator should develop a strong program of inspection and enforcement

IX. Both the Regulator and Operators should maintain a strong program of stakeholder involvement throughout the entire lifecycle of facilities.

X. All involved organizations should learn from experience; remediation is an evolving process.

5.5 Points from discussion

The criteria developed in the US are not legal requirements as such, but are rather an accepted approach. Deviation from criteria is possible, provided that an equivalent level of safety is achieved. Stakeholder input is an important aspect to establishing criteria, but final endpoints are based on regulatory requirements and local conditions at a site. If an operator can demonstrate that the ALARA principle has been applied and that regulatory criteria have been met then work can be considered complete.

For barriers, designs are required to last a minimum of 200 years and, as such, a lot of design effort is required to ensure that, even if some degradation occurs, requirements for emanation of radon etc., are still met. Annual inspection programs are undertaken. If minor issues are identified then repair programs will be undertaken, such as the removal of vegetation posing risk to barriers or repair of fences. The combination of robust design with regular inspection is intended to ensure that barriers will remain effective for the required timeframe. Barriers for other radioactive wastes typically require timeframes in excess of the 200 years required for uranium tailings. However, there are no timeframes at which sites will no longer be under institutional control. Differences may be observed with other sites such as those associated with nuclear fuel production whereby there may be ultimate release of a site for public use or for restricted use. Unrestricted release of sites is the preferred end state.

6 Session 4: Other Legacies

6.1 Radiation protection for legacy sites: a perspective from the UK

Tiberio Cabianca (PHE) presented.

Public Health England (PHE) is an advisory organisation to the UK Government on radiation protection. Addressing radioactively contaminated land issues is part of the remit of PHE and work has been undertaken over the last few years to address land contamination by discrete radioactive objects at two locations, Dalgety Bay in the east of Scotland, and Sellafield in northwest England.

Within the UK, there is a distinction between the regulation of licensed sites and other sites. For licensed sites, a release risk criterion of 10^{-6}/y applies. For other sites for which no land use change is proposed, a reference level of 3 mSv/y is applied; other sites where redevelopment is planned are subject to local authority regulation for planned exposure situations.

Dose assessment for large areas of contaminated land, even those with patchy contamination, is relatively simple and there are generic values and models available to support such assessments. However, where small discrete contaminated objects are present, assessments can be very complicated. Problems relate to lack of knowledge of the number and characteristics of the objects, such as the size, chemistry and solubility. Whilst the probability of encountering objects may be low, the consequences in terms of dose may be high. Furthermore, any dose criterion for contaminated land is inappropriate due to the need to account for the probability of exposure.

Since the probability of exposure from an object is less than 1 for stochastic effects, a risk level is considered in place of a reference dose level. The risk equates to the annual probability of coming into contact with an object combined with the risk of contracting a fatal cancer during a lifetime if contact did occur. A risk level of 10^{-6}/y is normally used in the UK. However, consideration is also required as to whether doses could be high enough to result in deterministic effects. Where absorbed doses are well below thresholds, deterministic effects will not occur, irrespective of the probability of encounter.

Dalgety Bay is the site of a former Ministry of Defence airfield that was operational between 1917 and 1959. Activities at the airfield included aircraft repair, refitting and salvage. Luminized instruments, containing Ra-226, and other waste materials from aircraft were incinerated and the residue subsequently disposed of locally. The level of Ra-226 activity in luminized instruments was variable, ranging from 2 MBq Ra-226 in an average compass to between 20 and 50 kBq Ra-226 in other instruments. In 1962, the area of the airstrip became the location of the town of Dalgety Bay (Figure 29). The town currently has a population of around 10,000.

Radioactivity was first discovered on the headland at Dalgety Bay in 1990 during a survey. Around 200 radioactive particles were detected with activities ranging from 2 to 390 kBq. Additional surveys took place in the period from 1990 until 2005 of the beach, foreshore, gardens and radon in houses, but systematic monitoring did not take place. Then, in 2006, the regulator SEPA (Scottish Environment Protection Agency) set up a stakeholder group and undertook an assessment against the contaminated land regulations. This assessment indicated that more detailed work was required to better understand the situation and the hazards and risks posed to public health and the environment.

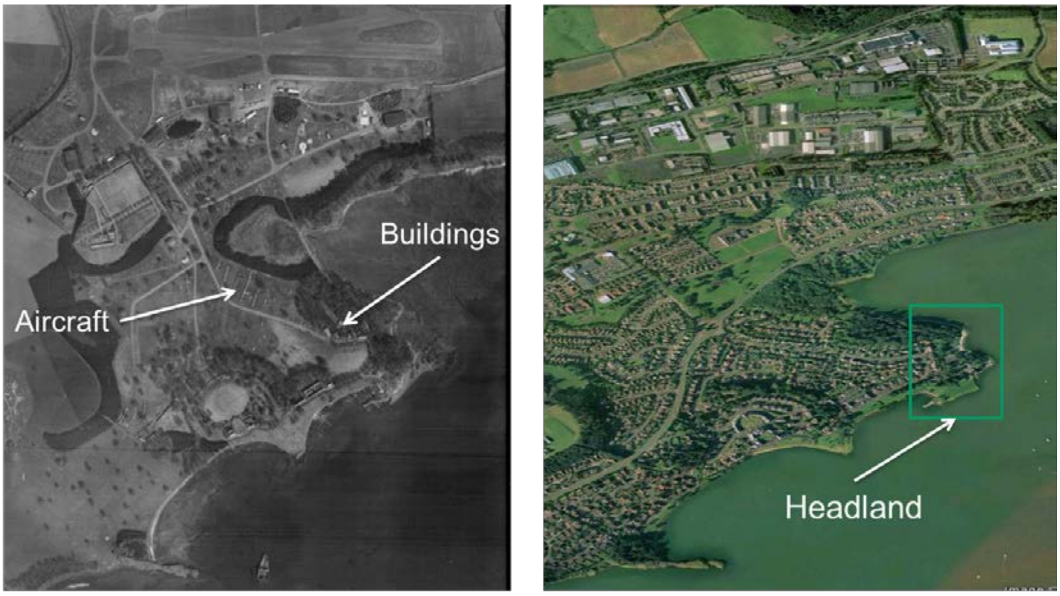


Figure 29. The former Ministry of Defence site at Dalgety Bay (left) and current township (right).

In the autumn of 2011, an object was discovered by SEPA at depth that contained 76 Mbq Ra-226, which resulted in greater concern around the public health implications of the discrete particles. The Health Protection Agency (now part of PHE) was requested to undertake a scoping assessment to evaluate the likelihood that people using the local beaches would come into contact with objects and the doses and associated health risks that may arise as a result of contact. To support the assessment, a map of particle finds was generated along with information on activity of each particle. Of the around 500 particles found, most were associated with low Ra-226 activity (less than 10 kBq). Only 11 particles were associated with activity in excess of 100 kBq (Table 8). Fragmentation was evident with some of the objects found (Figure 30).

Table 8. Ra-226 concentrations of particles found at Dalgety Bay.

Activity band (KBq)	Max activity (KBq)	No. of objects
≤ 10	10	379
10 to 100	91	70
100 to 1000	360	7
≥ 1000	76,000	4

A classic approach to dose assessment was taken whereby a range of exposure pathways was considered, including among others, external exposure from objects being trapped on the skin or under nails, in ears or in eyes, and from objects being carried in pockets. Beach activities considered included walking, general recreation, boat maintenance, bait digging and fishing. Three age groups (adult, child and infant) were considered.

The maximum committed effective dose calculated was 300 mSv following ingestion of a particle by a 1 year old child. The equivalent dose for an adult was 55 mSv. Objects were too large for inhalation doses to arise. With regard to skin contact, an object with 100 kBq Ra-226 activity would give rise to a dose rate of around 0.1 Gy/h. Only 4 objects have been found that could give localised ulceration if they were carried for up to 2 hours.

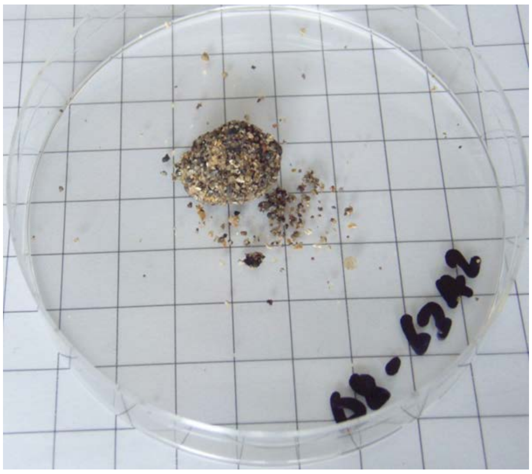


Figure 30. Dalgety Bay object illustrating fragmentation.

For a typical adult beach user, the likelihood of encounter of an object of any activity and any exposure pathway was calculated to be 1 in 2000, but this likelihood is dominated by low activity objects that comprise over 90% of those found. Risks from encounter were dominated by skin contact, but in practice, many particles would be too large to remain trapped in stationary contact with the skin. Whilst small objects could remain unnoticed on skin for several hours, the likelihood of this occurring for an object with high enough activity to cause skin ulceration was very low. The overall lifetime risk of a radiation induced fatal cancer following ingestion was less than one in a 100 million per year.

As a result of the assessment, the public health advice issued to SEPA was that, whilst some objects could have high activity, there was no need to undertake a full remediation program to remove objects from the beach. It was further advised that it would be unnecessary to prevent people from using the area, but that some warnings should be given such as for parents to prevent children from digging in the sand. Further monitoring and characterisation work was also recommended, including undertaking a habit survey to support a full health risk assessment. Monitoring of the beach has continued any detected objects removed. Around 40 objects have been recovered since 2011 and activities have all been lower than in previous findings. Whilst not recommended by the study, warning signs against using the beach have been erected. No full health risk assessment has been carried out to date.

Radioactive objects have also been detected on the beaches north and south of the Sellafield reprocessing plant. An intensive monitoring program has been carried out by Sellafield Ltd on local beaches since 2006 to identify and remove objects. The source of the objects is unclear, but it is most likely that they were released with the liquid effluents via the sea pipeline between the late 60s and the early 80s[3]. The frequency of finds tends to be associated with storm events. To date, around 2,000 radioactive objects have been recovered and classified according to size (particles (< 2mm) or stones) and radioactive content (alpha-rich objects (Pu and Am-241), beta-rich objects (Cs-137 and Sr-90) and Co-60 rich objects. The number of Co-60 objects found is very low compared to alpha- and beta-rich objects.

At the request of the Environment Agency, PHE undertook an assessment in 2008 of the health risks associated with particles on beaches. The approach taken to the assessment was similar to that for Dalgety Bay, but more data on object activities was available. A statistical approach was applied, reflecting the large variation in habits of locals using beaches and the variability in parameters used to describe exposure to objects. Estimates were also made of the number of

[3] http://www.sellafieldsites.com/wp-content/uploads/2012/08/Sellafield-alpha-rich-finds-report-Sept-2010.pdf

particles on beaches, based on data for those found and assumptions for detection frequency. The estimates of objects on Sellafield and St Bees beaches are indicated in Table 9.

Table 9. Estimated number of radioactive objects on Sellafield and St Bees beaches.

Beach	Object class	Population of objects per hectare		
		(3 – 30 kBq)	(30 – 300 kBq)	(>300 kBq)
Sellafield	Alpha-rich	1	0.3	0.003
	Beta-rich	2	0.2	0.02
St_Bees	Alpha-rich	1	0.04	0
	Beta- rich	0.08	0	0

There was good information available on the habits of people from local surveys and mechanisms by which people could come into contact with objects were similar to those at Dalgety Bay.

The annual probability of encountering a particle was calculated as between 10^{-7} and 10^{-5} for typical beach users, with the highest probability of encounter being associated with adult anglers and adult dog walkers. The probability was dominated by particles with activities in the range of 3 to 30 kBq. Overall, the probability of encountering objects was lower than for Dalgety Bay. The highest risks were again associated with skin contact or with a particle being trapped in clothing.

The greatest potential for significant health risks was associated with the ingestion of an alpha-rich particle. The most important factor determining effective dose from ingestion is uptake from the gastro-intestinal tract. A series of experiments was therefore undertaken by PHE to investigate uptake, through both *in vitro* and *in vivo* studies. The findings of these experiments were used to inform assumptions for dose coefficients. For alpha-rich particles, a dose coefficient of 2 10^{-8} Sv/Bq Pu and Am was derived.

For stochastic effects, the overall risks for 1 year's potential exposure were calculated for different bands of activity (see Table 10). The highest overall risk was less than 1 in 10,000 million. Risks of deterministic effects were also calculated. For the highest activity beta-rich particle found (110 kBq Cs-137), a skin dose rate of 100 mGy/h could occur. Given the threshold for skin ulceration by a point source, 20 hours of contact would be required for ulceration to occur. It was considered that it would be highly unlikely for such prolonged stationary contact to occur.

It was concluded that overall health risks to beach users are very low and are significantly lower than other risks that people accept when using beaches. The risks are also at least 10,000 times lower than the 1 in a million upper limit for an acceptable level of risk commonly applied in the UK.

As a result of the study, PHE recommended that three criteria should be adopted for triggering an urgent review of health risks to beach users:

- Finding an object with a total activity of alpha-emitting radionuclides greater than 10^7 Bq;
- Estimation of an overall lifetime risk of radiation-induced fatal cancer for a beach user of greater than 1 in a million noting that this is unlikely to be the limiting criterion;
- A skin dose rate greater than 300 mGy per hour following characterization of objects with a Cs-137 activity greater than 10^5 Bq.

Table 10. Overall risks of developing fatal cancers following ingestion of objects by infants.

Activity band, kBq ^{241}Am – alpha-rich ^{137}Cs – beta-rich	Lifetime risk of cancer if particle ingested, %	Highest annual probability of ingesting a particle	Overall risk of fatal cancer
Alpha-rich			
1000 (>300)	4	-	-
100 (30 – 300)	1	$6\ 10^{-10}$	$6\ 10^{-12}$
10 (3 – 30)	0.2	$3\ 10^{-8}$	$6\ 10^{-11}$
Total			$7\ 10^{-11}$
Beta-rich			
1000 (>300)	-	-	-
100 (30 – 300)	0.2	$7\ 10^{-11}$	$1\ 10^{-13}$
10 (3 – 30)	0.06	$3\ 10^{-10}$	$2\ 10^{-13}$
Total			$3\ 10^{-13}$
Lifetime risk is calculated for the most active particle in the activity band			

Monitoring of the beaches is continuing and the requirement for continued monitoring is now a requirement within the Sellafield site authorisation. There is a general downward trend in the frequency of object finds. Further work is also being undertaken to characterize the contamination on particles and stones in order to refine dose assessments. No stakeholder group was formed in response to the objects being found, as was the case with Dalgety Bay.

6.2 The use of decision support tools in remediation projects with mixed contamination

Koen Mannaerts (FANC) presented.

In Belgium, like many other countries, sites requiring remediation are largely chemically contaminated, but some are also associated with radioactive contamination and some are close to public dwellings. There is extensive regional regulation and methods to support remediation activities at chemically contaminated sites, but this is not the case for radioactively contaminated areas. Questions therefore arise on how to address sites that have mixed contamination.

Belgium is a small, but densely populated country comprised of three regions, each of which has a regional government that is responsible for addressing environmental matters. There is also a federal agency (FANC) for all nuclear matters.

A graded and iterative approach is used to address contaminated sites in Belgium. No rigid technical procedure is applied, rather a generic framework is applied to support decision making on remediation and waste management strategies on a case by case basis.

There needs to be a link made between the theory of what should be done, such as selecting remediation criteria and performing site characterization, and how to achieve these aims in practice. This can be particularly complex in cases of mixed contamination where both federal and regional regulators are involved and different methods applied for the different contaminants (Figure 31). There are databases on chemical contaminated areas and also for radioactively contaminated areas that can be analysed to identify those sites with mixed contamination. Investigation phases are common to all sites, but are associated with different levels of risk assessment complexity depending on the type of contamination. For radioactively contaminated sites, investigation is followed by risk assessment and options appraisal, but this approach is not taken for chemicals. The establishment of remediation or risk management plans is also common, but there are differences in the implementation of those plans. For example, if on-site disposal of radioactivity is to occur then this must be licensed by FANC and subject to long-term management whereas a certificate of conformity is required for non-radioactive waste disposal and there is no requirement for long-term management. Decisions are required at all stages of the process and are controlled within a protocol for cooperation among federal and regional authorities.

Figure 31. Differences in the Federal and Regional approaches to legacy contamination issues.

The assessment method for evaluating remediation requirements and approaches is comprised of a range of multi-disciplinary tasks. For radioactively contaminated land there are three focus areas, see Figure 32, that feed into and support remediation decisions. Either remediation or risk management approaches may be taken. Within phase 1, all information available should be evaluated and assessed, and then used to support the development of different options within phase 2. Phase 2 also involves the appraisal of the different options and making justified decisions on the approach to take forward. Phase 3 then involves the implementation of the selected option and aftercare through surveillance and maintenance.

There are two general approaches that can be taken with respect to decision making. An ad hoc approach can be taken whereby general and detailed information from different stakeholders is evaluated in a subjective way. Alternatively a holistic approach can be taken where all information is shared and optimized. The holistic approach is less subjective, but can be significantly more time consuming. Stakeholder management tools and decision support tools can be valuable in supporting the decision making process. However, the first step to making any decision has to be identifying who has the responsibility for making the ultimate decision, whether this be a single entity or multiple entities.

Different thinking systems can be applied. In one system, general experience can be used along with a superficial analysis or interpretation of relevant information. This represents a fast approach. A slower approach applies conscious analytical thought and detailed evaluation of a broad range of information. This latter approach is largely considered to be more accurate and should be the encouraged approach, assuming that there is no need for urgent action.

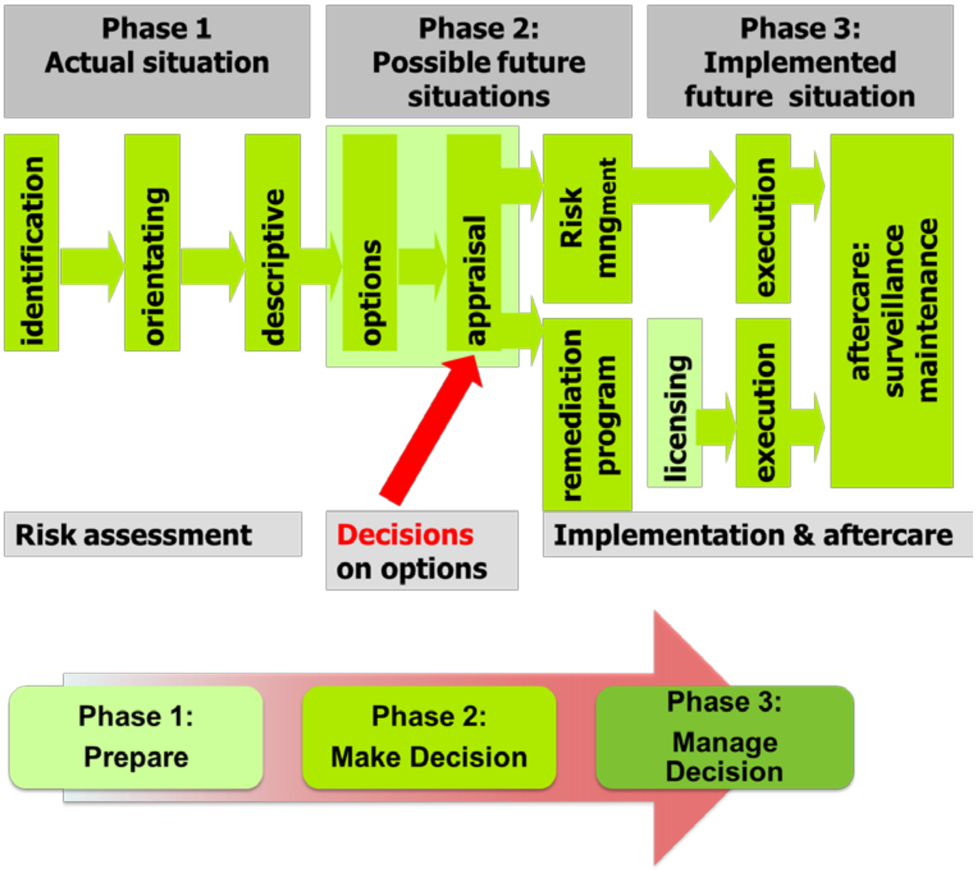


Figure 32. Method for deciding upon remediation actions for radioactively contaminated land.

There also needs to be a balance struck between scientific knowledge for which, in the case of low risk rates (such as those associated with low levels of radiation exposure) there is seldom a single view and often considerable uncertainty. In addition, stakeholder values are more subjective and variable according to the perspectives of the different interested parties.

Science and values come into play at different stages and throughout a decision making process. For example, science is closely linked to evaluations of possible effects of contamination whereas what is ultimately to be achieved is more a value judgement. Strategies and actions used to achieve the overall objective and ultimate consequences and uncertainties are again largely linked to science whereas whether a consequence or uncertainty is important is linked to values. Both experts (science) and interested parties (values) have important roles in the decision making process, but analysts are also required. The analysts should be well skilled to facilitate discussions between experts and interested parties and to apply analysis tools. A project manager, mostly belonging to the party responsible for the remediation, should be assigned to decide how to run the project, who should be involved and to identify the data and models required and also to manage expectations once a decision has been made. The majority of the work is undertaken during phase 1, in ensuring the appropriate people are involved and to gather the required information. The stakeholders involved in the process may not however remain the same throughout the project timeline; this could be the case for instance if chemical toxicity is judged as 'no risk' while radiological impact remains dominant. The regional authority can still be an observer in the whole process but leaving most of the regulatory constraints with the nuclear regulator.

The key drivers behind remediation programs relate to risk (e.g. the proximity to populations, risk of surface or groundwater contamination or potential for impact on ecologically sensitive areas), impact on receptors (people or wildlife), and regulatory and legal drivers.

The first step in addressing an issue should be problem formulation, i.e. defining the objectives and the wider assessment context, which should relate to the decisions to be made (Figure 33). The type and values of relevant criteria should also be considered at the outset, as part of the assessment context. A staged approach to modelling should be then be undertaken to make sense of the data available, to explore and analyse the situation and options, and to interpret the output and support implementation. Both uncertainty and preference modelling should also be undertaken within the overall evaluation process. Decision models, ranging from simple to very complicated models, are available that can then be applied to support decision analysis such as (the more complex) multi-criteria decision analysis tools, which can be used to evaluate the impact of different views on decisions. The choice on the decision aiding tool will largely depend on project and stakeholder complexity. By taking such an approach to decision making, the final decision should be clear and an understanding gained of how options preference may change in response to different views, which can greatly help in stakeholder communication.

The conduct of the assessment will depend on a number of aspects such as management (who is in charge of the risk assessment), the drivers behind the assessment (e.g. to assess end use, support funding decisions, regulatory constraints, etc.), the timescale of assessment (e.g. to address immediate risk or to support change of use in the long-term), and the confidence expected, which relates to whether a preliminary or comprehensive assessment is being undertaken. Decisions to be taken will be based on multiple objectives such as public and worker safety, feasibility, costs, environment, timing etc. Together, these factors form the main attributes to be evaluated within decision aiding tools.

Different options should be identified that take into account the applicable regulatory regimes and strategies that can be applied to different contaminants. Whether or not options are feasible, credible or preferred should then be considered to identify sets of options that should be evaluated further. Screening out of new options should be fully justifiable. The appraisal of remaining options should then be based on criteria or attributes that reflect the different values of all stakeholders.

The attributes should be unique, quantifiable and equivalent for all options. Different approaches can be taken to options appraisal, such as scoring of options and their attributes during workshops or use of value trees.

Where stakeholders score attributes, the decision reached will reflect the stakeholder views and may vary among different stakeholder groups. The approach taken to options appraisal should be determined taking into consideration the scale of the hazard and hence the need for detailed analysis and stakeholder complexity, with the simplest approach being an evaluation matrix or simple cost-benefit analysis and with a non-quantitative multi-criteria decision analysis as the more complicated approach.

The use of visual presentation of decisions can be very beneficial in illustrating how decisions shift between options with different stakeholder views. Such approaches can also be used to help explain how decisions have been reached and to build consensus, whilst recognising that there are different value perspectives and scientific limitations. Whilst technical models play an important role in reaching decisions on remediation projects, decision tools cannot make decisions, but can help in structuring and communicating a decision.

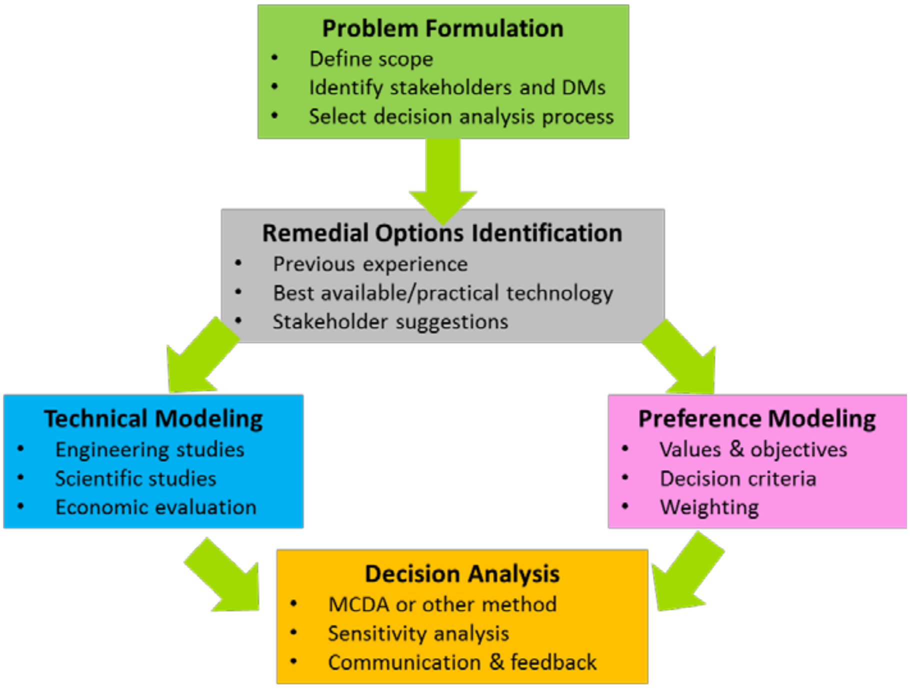


Figure 33. Approach to decision support (preliminary; from IAEA-MODARIA WG1 – TRS on decision aiding in remediation; draft - to be published).

6.3 US EPA Superfund remedial program's approach for risk harmonization when addressing chemical and radioactive contamination

Stuart Walker (US EPA) presented.

The US EPA is responsible for addressing the clean-up of sites under several laws and programs, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), which is also termed Superfund. CERCLA is enacted through the National Contingency Plan (NCP) regulations and a national priorities list guides the EPA's remediation program on which sites require attention in terms of long-term remediation. Under CERCLA, radionuclides are required to be addressed alongside other hazardous substances.

Of a total of 1,320 Superfund sites, only 66 are radioactively contaminated and, as such, the focus of the Superfund program has largely been on chemicals. For those sites with mixed contamination, consideration was required as to how radiation should be addressed. It was decided that radiation should be addressed in a consistent manner with chemicals, but taking account of technical differences posed by radiation. By addressing both types of contamination consistently, the objective was to improve public confidence by taking some of the mystery and fear away from radiation.

Radiation fits within the remedial program's framework since the primary effect of radiation is cancer and a number of chemicals are known carcinogens. The pathways for exposure are also similar; people ingest, inhale and eat the same amount of contaminated dust and food irrespective of the type of contamination. The migration of inorganic elements through the environment also occurs irrespective of the type of contamination.

Overall there are nine CERCLA remediation selection criteria, two of which are threshold criteria that must be met. These criteria are to protect human health and the environment, and to comply with other federal and state laws setting out applicable or relevant and appropriate requirements

(ARARs). Within the compliance with federal and state laws, it is required that current of future sources of drinking water must be protected.

The ARARs often determine clean up levels but, where these are not available or protective enough, the EPA sets site-specific clean up levels that, for carcinogens, represent an increased cancer risk of between 10^{-6} and 10^{-4} and, for non-carcinogens, will not result in adverse effects to human health. Clean up levels are also established to ensure ecological protection. The clean-up levels are not based on requirements in place elsewhere, such as NRC decommissioning requirements. Whilst the science from risk management guidelines is applied, the framework is focussed on cancer risk rather than a radiation framework relating to dose. Slope factors are employed in place of dose conversion tables to estimate cancer risk from radioactive contaminants.

Remediation decisions are made at a regional level. To support consistency in the application of the approach across sites, guidance documents and calculators are provided by the EPA and training is provided. Guidance, models and training are all made available on the internet. Meetings are also held every 2 years with the different EPA regions.

The key guidance documents are:

- *Establishment of clean up levels for CERCLA sites with radioactive contamination* (8/22/97) requiring radioactive contaminants to be governed by the NCP like all other contaminants, using ARARs or risk ranges and ensuring groundwater is restored to beneficial reuse. Reasonably anticipated land use is also to be taken into account. For example, if sites are in industrial areas then clean up would be required to an industrial use level, allowing a higher residual contamination level than if the site was to be cleaned for unrestricted use.

- *Radiation risk assessment at CERCLA sites: Q&A* (12/99), superseded in 2014 (5.2014), which provides an overview of current EPA guidance for radiation risk assessment and provides guidance on dose assessment for ARAR compliance.

Decisions on remediation are normally made on the basis of land use rather than the contamination present. Policies for remediation have recently been updated to account for new science, including a reduction in the effective dose standard ARAR that is considered protective from 0.15 mSv/y to 0.12 mSv/y, with clean up levels not based on an ARAR continuing to be based on a cancer risk range of 10^{-4} to 10^{-6}.

To gain a greater level of consistency in risk assessments for radioactive and chemical contaminants, improved guidance has been developed on recommended tools and the need for risk assessments to be consistent for both types of contaminant at a site and also consistent with assessments undertaken for other regional sites. Furthermore, the type of model applied for chemicals and radiation are consistent such that steady state models are not applied to chemicals and dynamic models to radioactivity. Greater consistency in survey approaches for the different contaminants is also required with guidance being provided on recommended tools and the need for consistency within a site and between regional sites. Consistency in averaging approaches to contaminants is also required.

Soil screening guides have been published for chemicals, along with guidance on screening out areas, pathways and/or chemicals early in the assessment process. A version has also been produced for radiation that again allows for the screening out of radionuclides early in the process. Guidance includes survey procedures for site characterization and provides an evaluation of soil to groundwater models.

A chemical calculator (RSL) has been developed to establish screening or clean up levels when an ARAR is not available or is not sufficiently protective. A base risk level of 10^{-6} is normally used although this can be an order of magnitude higher. The calculator also provides the means by which risk assessments can be undertaken, based on 9 scenarios or land uses, including residential, recreational, construction, indoor worker, outdoor worker, fish ingestion, tap water, soil to groundwater and air. The calculator includes the chemical toxicity of uranium.

The radiation calculator (PRG) is very similar, again allowing criteria to be established where ARARs are not available or sufficiently protective. The calculator accounts for technical differences of radiation as compared with chemicals such as exposure from gamma radiation. The scenarios considered are also largely the same, but an additional farmer scenario is considered. The radiation models have the same look and feel as the chemical calculators to help people move easily from one to another. Parameters are also laid out in the same way and consistent exposure assumptions are applied to help in coordinating risk assessments.

Following the 9/11 terrorist attack on the World Trade Centre, a benchmark guidance document was developed for clean-up levels to be applied in the reuse of contaminated buildings. Exposure pathways considered included ingestion, inhalation and dermal contact. One scenario was considered (residential) and two exposure routes (settled dust and ambient air). The clean-up criteria were for the reuse of contaminated buildings and not for demolition. A similar calculator (BPRG) has been developed for radioactively contaminated buildings, which considers two scenarios (residential and indoor worker) and, in addition to settled dust and ambient air exposure routes, incorporates direct external exposure for a range of room sizes and receptor locations. A dose based calculator is also available, based on single dose limit ARARs.

A calculator (SPRG) is also available for outdoor hard surfaces (pavement, sides of buildings etc.,) to evaluate the level of contamination that can be acceptable and whether remediation is required. The exposure routes include settled dust, fixed direct external 3-D street level exposure (surface and volumetric) and fixed direct external 2-D slab level exposure (surface and volumetric). For external radiation from contamination, dose rate factors are used instead of slope factors.

Recently, a natural attenuation policy document for metals and radionuclides has been published, which helps to clarify policy issues that are unique to inorganics and that were not addressed in the 1999 policy document on '*use of monitored natural attenuation at Superfund, RCRA Corrective Action, and underground storage tank sites*'. There are three technical reports behind the policy document with volumes dedicated to radionuclides and non-radionuclides:

- Volume 1 - Technical Basis for Assessment" 2007.
- "Volume 2 - Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium" 2007.
- "Volume 3 - Assessment for Radionuclides Including Americium, Cesium, Iodine,
- Plutonium, Radium, Radon, Strontium, Technetium, Thorium, Tritium, Uranium" 2010.

The EPA has a range of tools to facilitate stakeholder involvement with Superfund sites, including two tools specifically designed for use at sites with radiative contamination. These tools are based on earlier tools for chemical contamination at sites. A community involvement national conference is regularly held and information booklets have been made available that provide information on chemicals and radionuclides commonly found at Superfund sites and EPA policies for clean-up. Health effects of radionuclides are also covered. The chemicals booklet has now been superseded by a website providing all relevant information and, in June 2014, a radiation risk assessment toolkit was issued. The toolkit comprises a collection of 22 fact sheets for the general public on Superfund and radiation, risk assessment processes at radiation sites and the different calculators. Videos on chemical and radiation risk assessment have also been produced about the risk assessment process and how members of the public can be involved at a site specific level e.g. through providing information on unusual food habits or known burial sites for waste materials. The videos are aimed at a basic level to assist in communication.

All documents and training materials are available from the US EPA website.

6.4 Regulation of the Norwegian mining Legacy

Jelena Popic (NRPA) presented.

In January 2011, revised legislation for radiation protection came into force with the Pollution Control Act, which is enacted through regulations on the application of the Act to radioactive pollution and waste, and regulations relating to the recycling of waste. A holistic approach is taken in Norway to the protection of human health and the environment, recognizing that radioactive waste and pollution present similar protection issues to other pollution and hazardous waste. A holistic ecosystem based approach to the regulation of waste management and pollution was therefore introduced under the Pollution Control Act. Both forms of waste are strongly regulated and safely managed.

The Act applies to all activities, including nuclear and NORM related industries, to provide the same level of regulation and protection for humans and the environment, irrespective of the source. All potential stressors within an ecosystem are therefore considered. This allows regulatory decisions to be made on the basis of complementary and consistent ecosystem knowledge, drawing from a range of experience on environmental chemistry, ecology, radiobiology etc.

A tiered approach to waste management is applied. For wastes categorised as radioactive, the management solution relates to the degree of radioactive contamination (Figure 34). Waste with an activity concentration below 1 Bq/g is not regulated as radioactive and waste with an activity concentration in excess of 10 Bq/g must be disposed of to a radioactive waste repository operating under license from NRPA. For wastes falling between these activity levels, decisions are taken according to the mix of hazards. Some waste that is only radioactively contaminated can be disposed of under license from the NRPA whereas waste also containing hazardous material can be managed under either hazardous or radioactive waste licenses. Where such waste is directed to a hazardous waste disposal site, NRPA is nonetheless kept informed.

Environmental concerns relating to mining in Norway are addressed under the Mining Act, Pollution Control Act and the Planning and Building Act. A license from the Directory of Mining must be granted for investigations and mining activity as stipulated under the Mining Act. A specific chapter is included within the Pollution Control Act on mining waste; mining and refining activities likely to result in discharges to air or water must be permitted by the NRPA.

The NRPA is working on mapping all mining sites (existing and legacy) where radiation protection and radioactive pollution to the environment could be potential issues for consideration. Currently, no radioactive waste generation nor radioactive pollution have been identified at currently operated mines. There are a number of legacy mines however and variable magnitudes of radioactive waste and/or radioactive pollution are evident. These include:

- Søve, a former niobium mining site in Telemark County;
- Oterstranda, a former molybdenum mining site in Nordland County where around 90,000 tons of uranium contaminated waste has been deposited on a local beach;
- Elsjø, a former zinc mining sites in Akershus County (alum shale bedrock, rich in uranium); and
- Lindvikskollen, a former iron, feldspar and TiO_2 mining site in Telemark County which has a lower level of NORM contamination evident as compared with the previous examples.

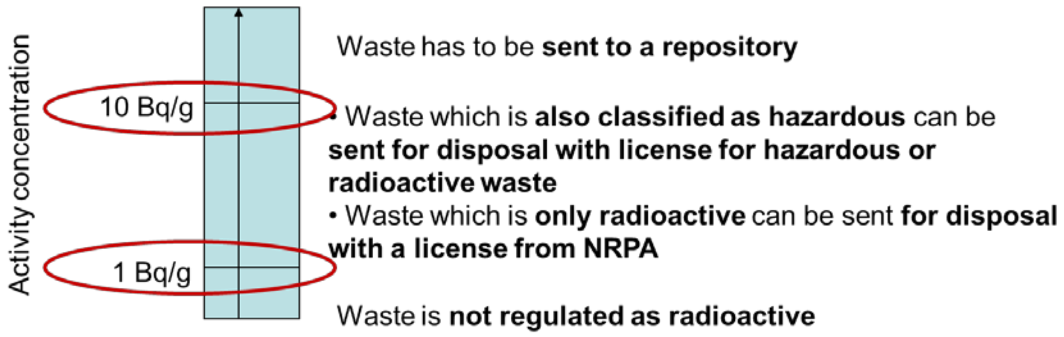


Figure 34. Tiered approach to management of radioactively contaminated waste.

The Søve mine was presented as a case study. The mine is located in the Fen complex in Norway, approximately 120 km south of Oslo (Figure 35). The Fen complex is well known in geological terms. The bedrock is of magmatic origin and is rich in iron, thorium, uranium and niobium. The Fen complex was a focus in Norway due to its potential energy resource, of between 170,000 and 700,000 tons or more of thorium ore, although estimates are uncertain. The resource has the potential to provide an energy source of greater value than the oil and gas industry in Norway. Historically, two mining sites were operational, one for iron and the other for niobium. The iron mine was operational between the 17th and 20th centuries. Niobium mining and production took place between 1956 and 1963.

After decommissioning for economic reasons, remediation was undertaken by covering parts of the site with sand. Measurements over the last decade have shown high gamma dose rates and hot spots of uranium and thorium contamination. Risk communication with those living near the site has been problematic, partly due to insufficient information on the existing exposure situation and there has been increasing public attention at the site with speculation over the magnitude of doses. The responsibility for clean-up of the site lies with the Ministry of Trade, Industry and Fisheries, with guidance from the NRPA. There is also municipality and university level involvement. With the mix of organisations involved, it has been difficult to communicate clear messages to stakeholders, including local people.

The waste volume at the site is currently estimated at 2,500 m^3, consisting of sludge, soil, rocks, apatite and magnetite. In the period following remediation, measurements were made that confirmed the presence of NORM pollution resulting in an enhanced risk for the environment and human health. More recently, site characterization efforts have been made and impact and risk assessments undertaken along with an evaluation of the different options for waste management. Clean up of the site is due to be completed in 2016.

Prior to the characterization work, background information on the source and potential for mobilisation and transfer within the ecosystem were considered. Site characterization was then undertaken to support a tiered and integrated impact assessment for people and biota (Figure 36).

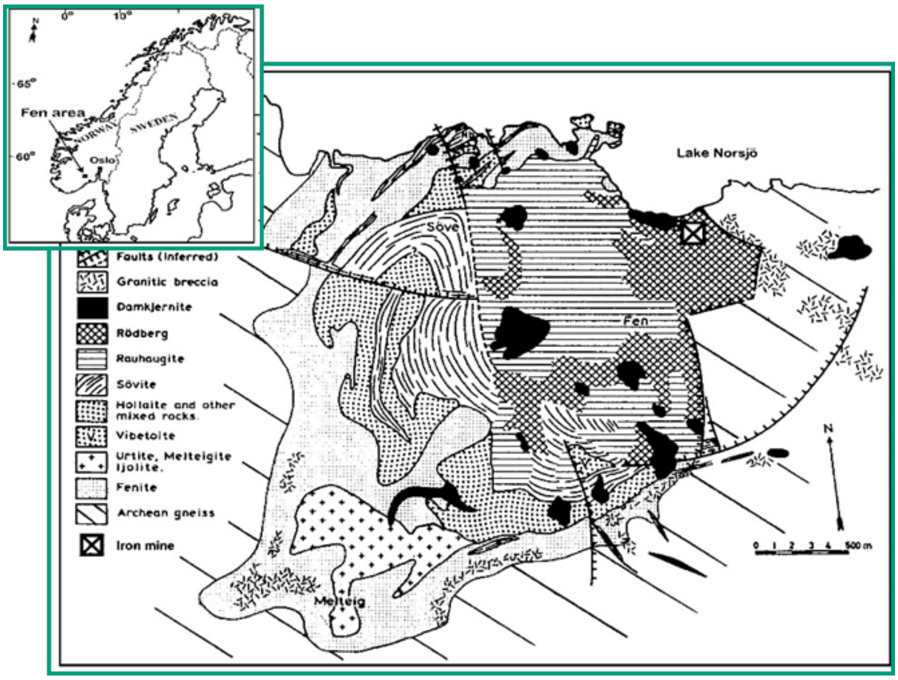


Figure 35. Location of the Fen Complex and the former Søve niobium mining site.

Air gamma dose rate mapping was undertaken in 2009 with site measurements being used to confirm helicopter measurements. The maximum gamma dose rate in air was 20 µGy/h. Maximum values of Rn-220 were also high (1,200 Bq/m^3). NORM activity concentrations in soil and waste material at different sub-sites were also analysed with data being presented relative to exemption levels, as required under legislation. The activity concentrations were used calculate biota dose rates using the ERICA assessment tool. The ERICA screening value of 10 µGy/h was exceeded for the lichens and bryophytes reference organism. A conservative exposure assessment for people gave rise to a dose estimate of up to 30 mSv, but assumptions were very conservative and a large uncertainty is associated with this value.

The main findings of the program were that high activity concentrations were evident in air, rocks and soil, but low in water.

The mobility of natural radionuclides was elevated as a consequence of historical mining activities. There was however limited transfer of U-232 and U-238 series radionuclides to biota although dose rates were slightly elevated above natural background, although not of a sufficient level to induce population level effects. Effects from multiple stressors on other organizational levels could not however be excluded. For humans, terrestrial gamma radiation was the main contributor to outdoor exposure with doses up to 30 mSv being estimated for some scenarios. There was however difficulty and uncertainty associated with the inclusion of Rn-220 in the dose assessment. Overall, on the basis of the study, it was recommended that intervention action was merited at the Søve NORM legacy site.

The majority of waste NORM concentrations were in excess of 1 Bq/g. Therefore, in line with Norwegian legislative requirements, wastes were required to be disposed of to a site licensed by NRPA. The alternative management solutions considered included:

- Doing nothing. This had been the actual situation at the site for some years and was not deemed to be a viable option.

- Local disposal at a waste facility to be built at a location close to the Fen Complex. This was not considered to be an achievable option, partly due to risk perception of local people.
- Local remediation solution with sand or soil used to cover the area. This had been tried previously and shown to be insufficient.
- External storage at existing waste disposal sites for which two sites were available, Wergeland Halsvik repository in Gulen and the NOAH disposal site at Langøya, Hemsedal.

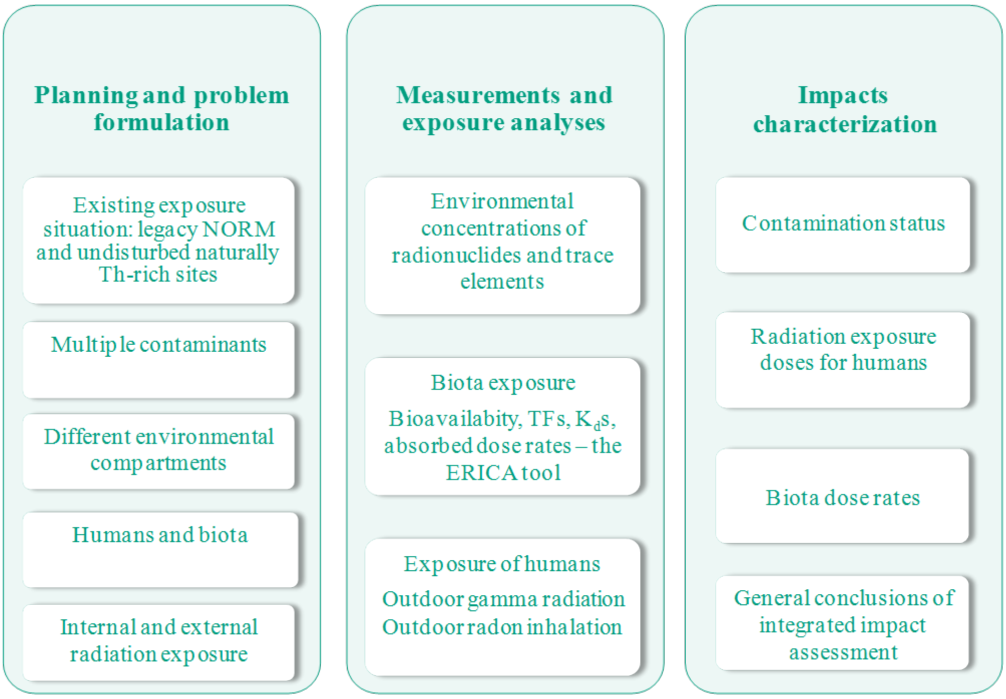


Figure 36. Tiered approach to integrated impact assessment.

The external solution was decided on by the responsible state authority. Challenges faced in achieving this solution included the high concentrations of NORM in the waste and the possibility for radionuclide migration in the disposal site environment as a result of leaching and soil weathering, as well as public perception of waste management solutions.

In 2011, the Ministry of Trade, Industry and Fisheries took responsibility for waste management at the site and were ordered by NRPA to undertake appropriate site characterisation and develop a plan for site remediation by 2012. Between 2012 and 2015 site characterization was completed and a proposal made for disposal of waste to the NOAH disposal site. In order for disposal to be accepted by the NOAH site, soil leaching tests are required and these are ongoing. The final solution and completion of site restoration is due to be completed in 2016.

The NRPA is main the regulatory body for the NORM wastes and have provided support to the Ministry of Trade, Industry and Fisheries with regard to clean up options and radioactive waste management questions. Coordination was required between the regulator, operator and other organisations of concern to achieve the best results through understanding of the issues and the sharing of responsibilities in a transparent way and with open dialogue.

Legacy issues are however complex and can be time consuming to address. Consideration should therefore be given to clean-up alternatives and the restoration of sites following decommissioning to avoid creation of legacy in future. Transparency is required in risk communication and consideration must be given to perceived risks and public attitudes.

6.5 Comparative analysis of the countermeasures to mitigate exposure of the public to radioiodine following Chernobyl and Fukushima accidents

Sergey Shinkarev (FMBC) presented.

Prior to Chernobyl, guidance was available in Russia on how to maintain radiation protection for workers and the public, and on establishing radiological criteria for introducing countermeasures in the early response phase. There were two levels of response (Table 11). Where doses were not expected to reach exposure level A, the introduction of countermeasures was not planned. If exposure levels were expected to exceed level B then countermeasures should be introduced immediately. For exposure levels between A and B, countermeasures should be decided according to local circumstances. The exposure levels set were measurable quantities.

Table 11. Exposure levels for the introduction countermeasures prior to the Chernobyl accident.

Parameter	Exposure level	
	A	B
Whole-body dose from external exposure, Gy	0.25	0.75
Absorbed dose to thyroid from intake of radioiodines, Gy	0.25-0.30	2.5
Time-integrated concentration of ^{131}I in ground-level air, kBq s L^{-1}		
children	1,480	14,800
adults	2,590	25,900
Total integrated intake of ^{131}I with foodstuffs, kBq	55.5	555
Max concentration of I-131 in fresh milk, kBq L^{-1} or in daily diet, kBq d^{-1}	3.7	37
Ground deposition density of I-131 on pasture, kBq m^{-2}	25.9	259

Countermeasures in the early phase included sheltering, evacuation and/or the ingestion of stable iodine to block uptake of radioiodine by the thyroid. For adults and children over 2 years, a dosage of 250 mg of potassium iodide was recommended whereas for children under 2 years, the recommended dosage was 40 mg of potassium iodide.

Immediately following the Chernobyl accident, sheltering was only applied to residents of Pripyat town, located 4 km from the damaged reactor, with evacuation taking place from the day after the accident. Within 10 days of the accident, villages within a 30 km zone of the damaged reactor were then evacuated with some villages outside this zone being evacuated in the months following the accident. Overall, 116,000 people were evacuated in 1986. Stable iodine was administered to the inhabitants of Pripyat town within the first two days and it was an effective countermeasure. However, administration of iodine was delayed for those outside Pripyat to early May onwards and was not therefore an effective countermeasure.

Following the Fukushima accident, approximately 6,000 residents within 3 km of the damaged reactors were evacuated within around 12 hours of the accident. The evacuation zone was extended to 20 km within the next 24 hours, with 85,000 people being evacuated. Orders to shelter were given to people within an area between 20 and 30 km of the accident and for people to take stable iodine. A further 10 days on and residents in the 20 to 30 km zone were directed to evacuate if located within the main plume direction. The initial evacuation orders were not based on radiation criteria, but were rather based on the expected dose outcome. By April 22, a deliberate evacuation area and an evacuation prepared area had been established (Figure 37). The deliberate evacuation area was based on consideration of recommendations by the ICRP and the IAEA according to which a reference level should be selected from a range from 20 to 100 mSv. Finally, it was decided to select the lowest value of the recommended range of the reference levels for decision to provide evacuation, in other words if a total estimated dose is expected to exceed 20 mSv in the first year then a decision on evacuation is taken. In the evacuation-prepared areas, it was recognised that there was no control over the damaged reactors and that, should there be any deterioration in radiation conditions, people should either shelter or evacuate.

Figure 37. Evacuation areas established following the Fukushima accident. The deliberate evacuation area is depicted by the red line; the evacuation-prepared area is depicted by yellow lines.

Following the Chernobyl accident, about 400,000 direct thyroid measurements to assess the I-131 thyroidal content were taken between beginning of May and the end of June 1986. The individual doses derived from direct thyroid measurements for Belarusian residents (Table 12) were much lower than those calculated on the basis of environmental contamination. Experience shows that when estimated from environmental information, doses to the public are commonly overestimated by around a factor of 10. Direct measurements however showed that more than half of the youngest children (aged up to 3 y) in the Belarusian most affected areas (three southern regions of Gomel Oblast) had thyroid doses greater than the level B, when immediate countermeasures should have been applied. The median thyroid absorbed dose derived from direct thyroid measurements of evacuated Belarusian children aged up to 6 y was 2 Gy.

Table 12. Individual doses derived from direct thyroid measurements for Belarusian residents.

Area	**Age-group**	**Thyroid dose, Gy**		
		<0.3	**0.3-2.5**	**>2.5**
Evacuated villages from three southern regions of Gomel Oblast	0-3y	5.6%	39.8%	54.6%
	Adults	32.5%	60.0%	7.5%
Non-evacuated villages of three southern regions of Gomel Oblast	0-3y	14.5%	55.8%	29.8%
	Adults	65.3%	33.7%	0.9%
Contaminated territories of Mogilev Oblast	0-3y	61.1%	37.1%	1.9%
	Adults	94.0%	6.0%	0.02%

In the Fukushima prefecture, over 1,000 children aged up to 15 y had thyroid measurements taken within the third week following the accident. Additional measures were taken from over 60 people evacuated from other areas in April 2011.

According to UNSCEAR (2014), individual doses of a few hundred mGy could have occurred with the average dose in the Fukushima prefecture being around 80 mGy, reducing to between 1 and 10 mGy in the other prefectures. Those thyroid dose estimates were done by using radio-ecological models with assumptions regarding radioiodine intake. Comparison of thyroid dose derived from direct thyroid measurements and those based on radio-ecological models for several settlements in the Fukushima Prefecture confirmed the above mentioned fact that the thyroid doses to the public based on radio-ecological models overestimate actual thyroid doses derived from direct thyroid measurements. Thyroid doses derived from direct thyroid measurements following the Fukushima accident were much lower than those estimated from the thyroid measurements following the Chernobyl accident.

In comparing responses, it is evident that a large scale monitoring of the I-131 thyroidal content in over 400,000 members of the public initiated following the Chernobyl accident provided the basis for reliable estimates of individual thyroid doses and provided support to the development of models to assess thyroid doses in people that had not been monitored. Only a small number of people (less than 2,000) were subject to direct thyroid measurements following the Fukushima accident to support validation of radioecology models for assessing thyroid doses. The dominant pathway for I-131 intake following Chernobyl was from the ingestion of fresh cows' milk whereas at Fukushima the dominant intake pathway was inhalation. This led to very different ranges in thyroid doses, with doses up to 50,000 mGy occurring following the Chernobyl accident and up to a few hundred mGy occurring following the Fukushima accident.

Lessons learned from the comparison include:

- The strategy for the introduction, implementation and withdrawal of countermeasures must be driven by relevant national radiological criteria.
- The early notification of people and immediate introduction of emergency plans are extremely important.
- Large-scale monitoring of thyroidal iodine content among the public is a solid basis for reliable estimates of thyroid doses. Measurement in the early phase of an incident allows the use of data to support decisions on the time and scale of countermeasures.
- Timely implementation of urgent countermeasures in the early phase of a radiological emergency is the most effective means to avert radiation doses to the population.

- Preventing ingestion intake of radioiodine's by the public (Fukushima accident) is an effective measure for mitigation of exposure to the thyroid that might be several orders of higher if an ingestions intake had not been precluded (Chernobyl accident).
- In the intermediate and late phases of accident response, the decision on the selection of specific countermeasures should be based on cost-benefit analysis while taking into account public perception and acceptance of those strategies.

6.6 Points from discussion

During the response to the finding of radioactively contaminated objects at Dalgety Bay and the beaches around Sellafield, body burdens in the local populations were not measured, but rather desk top evaluations of doses were made coupled with continued monitoring of the environment and recovery of any found objects. This was largely to avoid adding to the intrusion that monitoring machines for detecting objects in the environment had had on the local population and a desire to provide reassurance rather than increasing public concerns.

The use of a 3 mSv/y reference level was largely based on judgement, having been selected prior to the ICRP recommending a band between 1 and 20 mSv. The dose limit of 1 mSv is used in the UK for practices but a higher value was considered appropriate for intervention in this case[4], However, it is recognised that there is little practical safety difference between these two values, given the overall uncertainties. If remediation were to be undertaken on a building that would be opening a business, e.g. premises affected following the Litvinenko incident in London, a 1 mSv criterion for the workers would be applied, as a planned exposure situation. Guidance for clean-up following accidents is currently being prepared in the UK.

Optimisation is used in recovery situations in the UK with 3 mSv/y value being applied as a reference or guidance value. Clean up of contaminated land should be optimised to achieve contamination levels lower than this value. However, in the case of contaminated objects, there can be no fixed target.

The decision against on-site disposal of wastes was a site-specific decision, driven by negative public attitudes from past experiences of the site. The perception is that locals are living with non-radioactive pollutants and this should not be made worse through the addition of radioactive waste disposal sites.

[4] It is understood that the planned implementation in the UK of the concepts of planned, emergency and existing exposure situations, as set out in the revised European Basic Safety Standards Directive (Council Directive 2013/59/EURATOM) is the 6th February 2018. The government plans to consult on its implementation proposals late 2016/early 2017.

7 Session 5: Assessments and Communication of Results

7.1 Quantification and interpretation of doses and risks in relation to legacy sites

John Harrison (PHE) presented.

The objective of the ICRP radiation protection framework is to prevent deterministic effects (gross tissue damage occurring above a dose threshold) and limit stochastic effects (cancer and hereditary effects for which a linear no threshold dose response is assumed). Deterministic effects at doses above around 100 mGy, but lower than 1,000 mGy, are unlikely to be manifested immediately with cancers potentially developing years after exposure. Links between effects and exposure very much rely on epidemiology. At doses greater than 1,000 mGy, effects are much more likely to be clinically observable within days to weeks following exposure and can be clearly linked to exposure. Below 100 mGy, the link between deterministic effects and radiation exposure becomes very uncertain and biological plausibility contributes to evaluation (Figure 38). It is, nonetheless, commonly assumed for protection purposes that the likelihood of effects diminishes proportionally with dose down to zero.

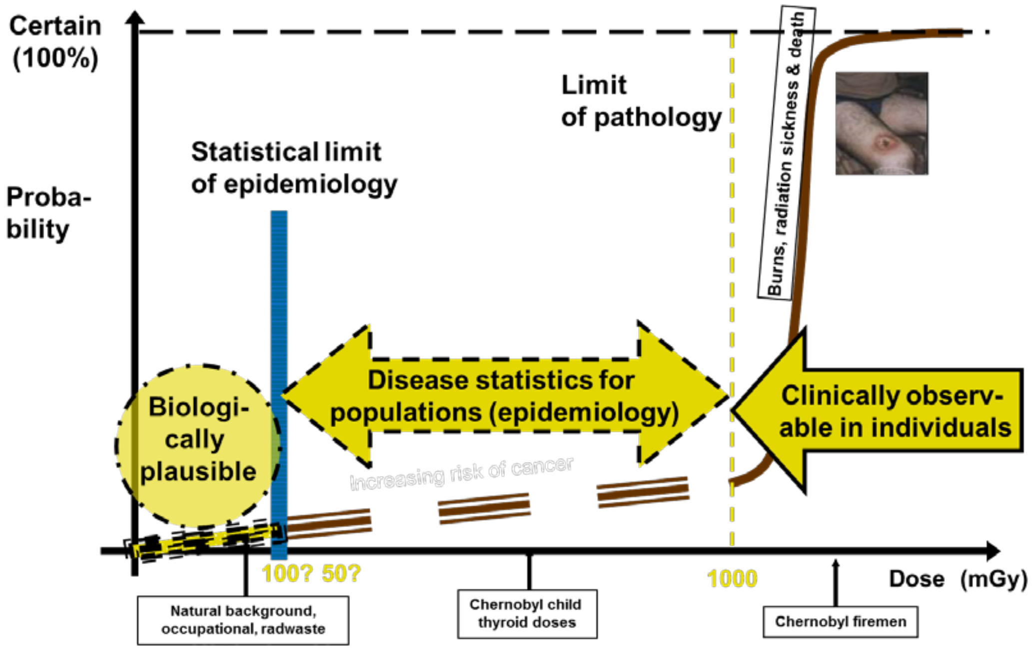


Figure 38. Probability of radiation effects with exposure.

There have been various studies to evaluate cancer risks in workers, including protracted exposures experienced by 'A' bomb survivors as well as occupational exposure studied. A particularly interesting study (Muirhead et al, 2009) was undertaken in the UK based on data from the national registry of radiation workers. The study considered over 170,000 workers with an average cumulative dose of 25 mGy and the incidence of solid cancers. Comparison of the results of this study with a dose response for 'A' bomb survivors shows there is consistency between risk estimates for acute exposures and chronic exposures. A similar trend is observed for leukaemia.

More recently, this UK work has been brought together with additional data from the US and France, within the INWORKS project (see for example Richardson et al., 2015; Leuraud et al., 2015). The project served to significantly increase the number of workers analysed (a total of over 300,000). A similar picture in terms of dose response was observed, but greater knowledge was gained on risks associated with low dose exposure, around a few tens of mGy. Extrapolation and biological plausibility are still required when considering risks associated with lower doses for which risk is has to be inferred. There is no direct evidence of risk at doses below around 1 mGy and it is not possible to attribute a particular cancer to radiation exposure as a cause. Taking into account scientific information and a need for a clear basis for management of protection, the ICRP has derived nominal risk coefficients for stochastic detriment (Table 13).

Table 13. ICRP Nominal risk coefficients (x 10^{-2} per Sv) for stochastic detriment.

	Cancer	Hereditary	Total
Publication 60 (1991)			
Worker	4.8	0.8	**5.6**
Public	6.0	1.3	**7.3**
Publication 103 (2007)			
Worker	4.1	0.1	**4.2**
Public	5.5	0.2	**5.7**

Effective dose, Sv, is used as a protective quantity that allows for the summation of all radiation exposures by risk adjustment using simplifying weighting factors to relate exposure to health detriment. Effective dose applies to a sex-averaged reference person rather than individuals and assumes a linear no threshold dose response and that chronic and acute exposures, and internal and external exposures are equivalent. These assumptions are supported by data for higher doses and data that provide some assurance of the equivalence per unit dose on effect once relative biological effectiveness for different radiations is taken into account.

Effective dose is applied by the ICRP rather than absorbed dose. The simple risk adjustment used to derive effective dose relates principally to cancer, but does allow for hereditary disease. There is currently a discussion ongoing as to whether other diseases should be considered in terms of detriment. For internal emitters, committed effective dose is used. This quantity takes account of radiation dose delivered over a lifetime rather than that associated with the dose delivered in the year of intake. Doses can be calculated or estimated with reasonable reliability, although the risk at low doses is uncertain.

ICRP Committee 4 is considering the benefits and detriments of radiation exposure on people in relation to the source of exposure and its amenability to control and exposure pathways and actions that can be taken to reduce exposures. There is a distinction to be made between amenability to control under planned, emergency and existing exposure situations. For existing situations, the source already exists when a decision on control has to be taken and in emergency situations control over the source has already been lost. In terms of the benefits of exposure, these fall into three broad categories – occupational exposure, medical exposure and public exposure. For occupational exposures there is the benefit of employment whereas there is a clinical benefit to medical exposures. Public exposure relates to all other exposures other than occupational and medical and relates to societal benefits, such as they availability of techniques that are associated with ionizing radiation. In controlling the use of radiation, the ICRP system of protection requires these benefits to be weighed up. The use of constraints and limits are recommended for planned situations whereas constraints and reference levels are recommended for use under existing and emergency situations; limits are not applied to these situations. The use of constraints and reference levels is an integral part of optimisation, which should be applied under all exposure situations to reduce exposures.

Constraints or reference levels are set in terms of bands of concern (Table 14). Under existing exposure situations, a distinction is made between occupational and public exposures. Occupational exposures arising in remediation work should be controlled on the basis of planned exposures, even while the public doses are controlled as existing exposure situations. In planned situations, the objective is to control the working environment rather than the risk to the individual. For public exposures under existing situations, control is again achieved through the use of reference levels, optimisation and ALARA, but with the reference level being set toward the lower end of the 1-20 mSv/y band. This is higher than criteria for planned situations, recognising that the key difference between planned and existing situations is the amenability to control. Furthermore, reference levels are not intended as dose limits.

Table 14. Bands of concern and reference levels.

BANDS OF PROJECTED DOSE	CHARACTERISTICS AND REQUIREMENTS
Greater than 20 - 100 mSv	Exceptional situations. Benefit on a case-by-case basis. Information, training and individual monitoring of workers, assessment of public doses.
Greater than 1 - 20 mSv	Individual direct or indirect benefit. Information, training and either individual monitoring or assessment.
1 mSv or less	Societal benefit (not individual). No information, training or individual monitoring. Assessment of doses for compliance.

The ICRP has published effective dose coefficients to enable dose to be calculated for a range of reference phantoms (new-born, 1, 5, 10 and 15 year old children and adults). The coefficients have been calculated using reference biokinetic and dosimetric models under standard assumptions for exposures and intakes. However, where better data is available for a particular exposure type and its use can be technically justified then the ICRP recommendation is for such data to be applied.

There may be situations where both existing and planned exposure situations occur together. Under such circumstances, it is suggested that effective doses from existing contamination should be distinguished from those relating to planned exposures since different control criteria apply and optimisation and ALARA will differ. For planned exposure situations, there is a requirement for an operator to set constraints and ensure that any discharges are appropriate in terms of public exposure. For existing situations, stakeholder engagement is required in setting reference levels and determining appropriate actions in response to potential risks.

Different approaches are used to control exposures to chemical mutagens and carcinogens. Generally there are poorer data available for chemicals. As with radiation, there is difficulty in extrapolating risks to low levels of exposure and, with a greater sparsity of data, extrapolations tend to be less reliable than those for radiation. There is also the lack of an international body for chemicals, equivalent to the ICRP, to ensure consistency in approach to exposure and risk assessments. Some national programs are available to consider such issues however. For example, in the UK there is a Committee on Carcinogenity that considers the use of minimal risk levels and margins of exposure.

There is a proposal in the UK for a 3 mSv dose criterion to be applied to a critical group, below which the classification of land as contaminated may not be warranted. This recommendation came before the publication of ICRP publication 103.

In summary, health effects of radiation are well understood at higher doses, but are uncertain at low dose levels[5]. The use of effective dose is a protection tool rather than a scientific quantity and is used to evaluate doses over a range of exposure situations. Occupational protection in existing and planned situations can be controlled in the same way. Public protection is treated differently in existing and planned situations. For existing situations, reference Levels are for use in conjunction with Stakeholder consultation; for planned situations, constraints are set by regulators and applied by operators.

7.2 Application of radiation protection principles to the area affected by historic releases from Mayak PA

Sergey Romanov (SUBI) presented.

In terms of legacy sites, the focus of radiation protection is primarily on the population living in long-term contaminated areas. The cumulative effective doses of exposure for adult populations in two towns near Mayak PA in the period 1948-1994 have been evaluated (Table 15). The most important impact relates to I-131 dose, but doses from long-term radionuclides are also relevant.

Table 15. Cumulative effective doses (mSv) of exposure for adult populations in Novogorny and Ozersk towns over the period 1948-1994, indicating source of exposure.

	Novogorny	Ozersk
Distance	7 km, SouthEast	8 km, NorthWest
I-131	120.20 (79.3%)	59.20 (81.3%)
Nobel gases	2.58 (1.7%)	1.85 (2.5%)
External exposure	4.83 (3.2%)	1.61 (2.2%)
Long-term radionuclides	23.96 (15.8%)	10.14 (13.8%)
Total	151.60 (100%)	72.80 (100%)

ICRP Publication 111 gives recommendations on the application of protection principles to people living in long-term contaminated areas after nuclear accidents or radiation emergencies, but the circumstances for the area around Mayak PA are different. Whilst exposures are long-term, they have arisen more as a result of the cold war and a lack of technology during the time of early operations at Mayak PA.

A s part of a continuing radiation monitoring program in the area around Mayak PA, a collaboration project was established between the NRPA and the SUBI. In the period between 2011 and 2014, tissue samples (lung, liver, bones) were collected during the autopsies of 107 non-occupationally exposed residents of 6 settlements at different distances from Mayak PA. The data were used to estimate committed effective doses to that population (Table 16).

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[5] It may be noted that different authors use the terms high dose and low dose differently, and dose-rate also plays a role, as discussed in Wakeford and Tawn (2010). It may be noted that the commonly adopted public dose-limit of 1 mSv/y and the dose range below that to which optimization is recommended to be applied are in the range where the associated risks are sais to be very uncertain.

Table 16. Committed effective dose (mSv) accumulated over the period 1949-2013.

Town	Committed Effective dose E (50), mSv				
	Sr-90	Cs-137	Pu-239	Am-241	Total
Ozyorsk (8 km, NW)	2.0 (15%) * 5.2 (32%) **	7.3 (57%) (45%)	3.0 (24%) (20%)	0.5 (4%) (3%)	12.8 16.3
Novogorny (8 km, SE)	3.0 (20%)	11.3 (72%)	1.0 (6.5%)	0.2 (1.5%)	15.5
Chelyabinsk (80 km, S)	1.4 (20%)	5.2 (73%)	0.4 (5.6%)	0.10 (1.4%)	7.1

* compound type is M, ** compound type is F

The most important radionuclide in terms of dose was Cs-137. In 1992-1994; the Cs-137 body burden in Novogorny residents was about 500 Bq. Comparison of estimated body content (on the basis of diet) against actual body content of Cs-137 (from whole body counting) has shown that actual body burdens tend to be lower than those estimated, but general agreement is good (Figure 39).

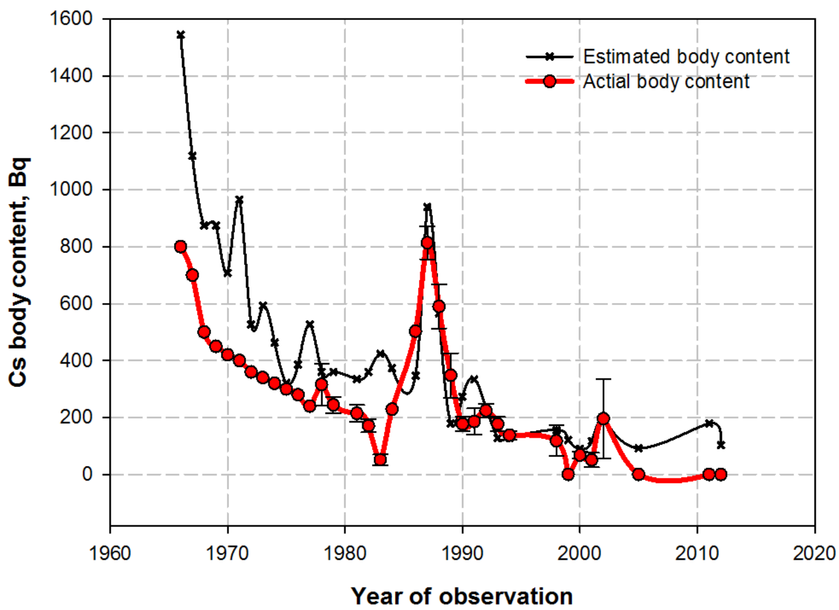


Figure 39. Comparison of calculated and measured Cs-137 body burdens.

For Sr-90, body burdens have changed by a factor of 3 or 4 over the last 20 years and a large discrepancy is observed between actual and estimated body burdens (Figure 40). The discrepancy is considered largely due to variable absorption from the gut. The highest Sr-90 body burden (250 Bq) in Ozyorsk residents was measured in 1967.

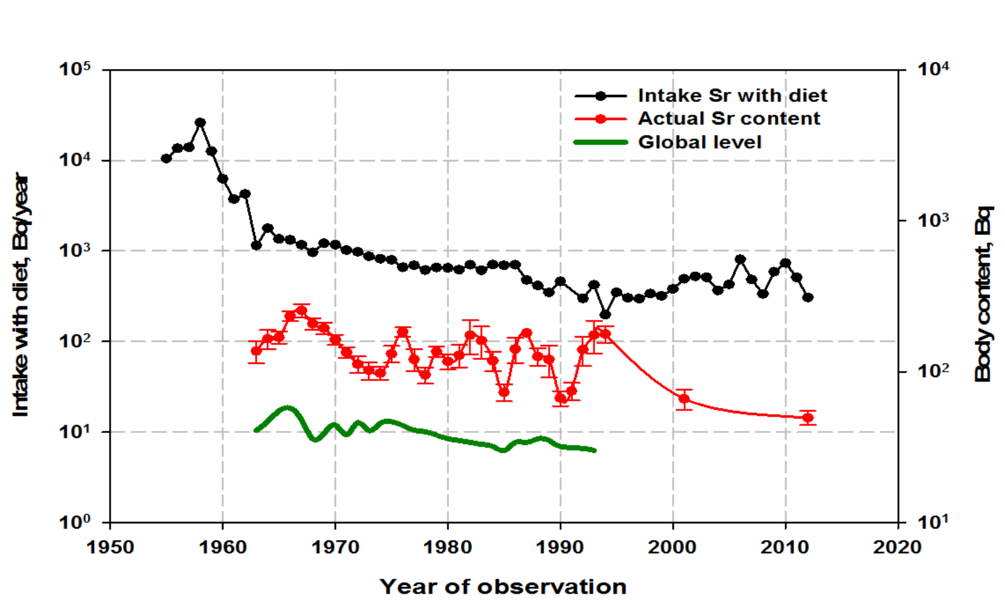


Figure 40. Dynamics of ingestion intake and body burden of Sr-90 in Ozyorsk residents that died between 1963 and 2013.

Plutonium alpha and Am-241 body burdens have reduced considerably over time, with the greatest body burdens at autopsy being recorded in people arriving in the area between 1948 and 1959, corresponding to higher inhalation intakes during this period.

There are some very important dynamic factors to take into account in assessing doses based on monitoring programs: seasonal fluctuations can occur and this variation must be recognised. For example, plutonium air concentrations are variable with season with resuspension rates being greater during the summer months but also peaking differently from year to year (Figure 41).

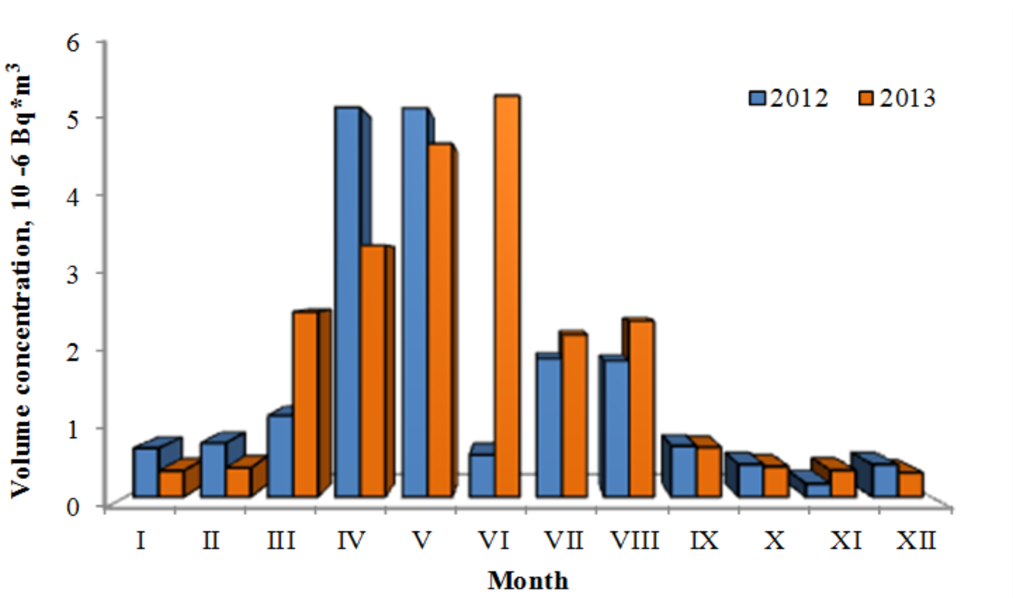


Figure 41. Seasonal fluctuation in plutonium air concentrations in Ozyorsk in 2012 and 2013.

Scientific assessment has shown that there is no significant issue with Cs-137 and Sr-90 as there has been large reductions in body burdens over time. The same trend is evident for plutonium. Annual effective doses have reduced for adults in the Ozyorsk population to below 0.1 mSv. However, if plutonium in soil and air and Sr-90 in water are measured then the area would be classified as contaminated. Whether or not the area really is contaminated can be questioned when doses are taken into account[6]. The results of this study are reported further in Suslova et al (2015),

Noting the above, it is suggested that the dose for a population affected by an existing exposure situation (excluding radon) should be within the dose band of 1 to 5 mSv/y. The provision of standard medical care should also be obligatory, but criteria for additional medical care are not available and should be developed. In the early 1950’s the population was subject to high external exposures and medical evidence showed the presence of chronic radiation disease. Obtaining this information was the driver for resources being made available for actions to reduce external exposures and, as a result, no chronic radiation disease is now evident. Provision of additional medical care in this instance therefore resulted in action being taken. However, provision of additional medical care for small populations can also create concern in a population[7].

7.3 The Techa River: scientific grounding of the regulatory measures on provision of radiation safety of the environment and population

Galina Tryapitsyna (URCRM) presented.

Protective measures and monitoring have been required to protect the local population and the environment resulting from discharges from the Mayak PA site into the Techa River (Figure 1).

Three main categories of protective measures include:

- Technical measures to reduce radioactive contamination of the river;
- Technical, organizational and other measures to ensure prevention or reduction of exposure of riverside residents to the contaminated river; and
- Measures to monitor the radiation situation in the riverside area and the health status of the population.

More recent surveys have been undertaken to evaluate how effective these activities were and to better understand the behaviour and effects of radiation in the environment.

The actual measures used included, amongst others, terminating radioactive releases to the river, construction of a reservoir, and relocation of riverside settlements from the upper reaches of the river. Overall, around 7,500 people from 19 riverside villages were resettled, equating to around 30% of the overall inhabitants along the river. Residents living in close proximity to the river were resettled in the lower reaches. A ban on the economic use of the river and floodplain was also instigated in 1951. The ban was not fully effective however as local residents were not explained the reason behind the ban nor understood what radiation was. People do now understand that they are inhabiting a contaminated area, but still fish and swim in the river and have ducks and geese for food. The river and the floodplain were contaminated while the territories adjacent to them were clean, but residents still believe it is the land that is contaminated rather than the river. The contamination prevents economic development in the area with investors leaving when hearing of the contamination in the river.

The removal of people from the most contaminated areas of the river was the correct measure. However, dose reconstruction indicates that the measure was introduced too late since the highest doses related to 1951, with relocation occurring in 1956. Dosimetric surveys have been undertaken since the 1950’s allowing a database to be produced on public health risks. The excess relative risk

[6] See practical discussion of this issue in Koenig et al (2014) including points raised in Gonzalez (2013).
[7] Even when limited to individual monitoring, as mention in section 6.1.

of leukaemia incidence has been calculated as 2.2 per Gy (Krestinina et al, 2013a) and for solid cancer mortality the excess risk has been calculated as 0.61 per Gy (Schonfeld et al, 2013). In relation to mortality from all circulatory system diseases, an excess relative risk of 0.36 per Gy has been determined (Krestinina et al, 2013b).

The most effective measure undertaken has been the construction of reservoirs. Prior to construction, still water bodies did not exist along the river, but understanding that radionuclides may sink to sediments led to the creation of new dams to isolate water and radionuclides and prevent the radionuclides from entering the lower river system. Two canals were also constructed to direct clean water from other lakes into the river. Whilst these measures have been highly effective, the river is still not clear of radiation due to marshes and sediments forming sinks for radionuclides prior to the measures being undertaken. Secondary desorption of radionuclides from marshes and sediments provides a continued input of radioactivity to the river.

Some 60 years after these remediation actions were undertaken, a comprehensive survey program was undertaken that included chemical analysis of water, radionuclide content of sediments, plants, phytoplankton, zooplankton, zoobenthos and fish and the community composition, abundance and biomass of phytoplankton, zooplankton and zoobenthos. Dose rates were calculated for biota in reservoirs using the ERICA assessment tool. Dose rates significantly higher than the ERICA screening value were calculated (Table 17). The locations of the different reservoirs are illustrated in Figure 42. The highest dose rates were calculated for phytoplankton and zooplankton. Reservoir R-9 was associated with the highest dose rates, but this reservoir no longer exists. In November 2015 the open water area of the reservoir was completely closed out. No fish were present in reservoir R-17.

Table 17. Estimated dose rates (µGy/h) for aquatic biota in reservoirs.

	Reservoirs				
	R-11	R-10	R-4	R-17	R-9
Phytoplankton	2.3E+02	8.1E+02	4.6E+03	6.9E+04	1.5E+06
Zooplankton	2.7E+01	4.4E+01	1.6E+02	1.3E+03	5.0E+04
Zoobenthos	2.3E+02	6.8E+02	5.7E+03	4.6E+04	-
Fish	3.3E+01	2.1E+02	7.9E+02	-	-

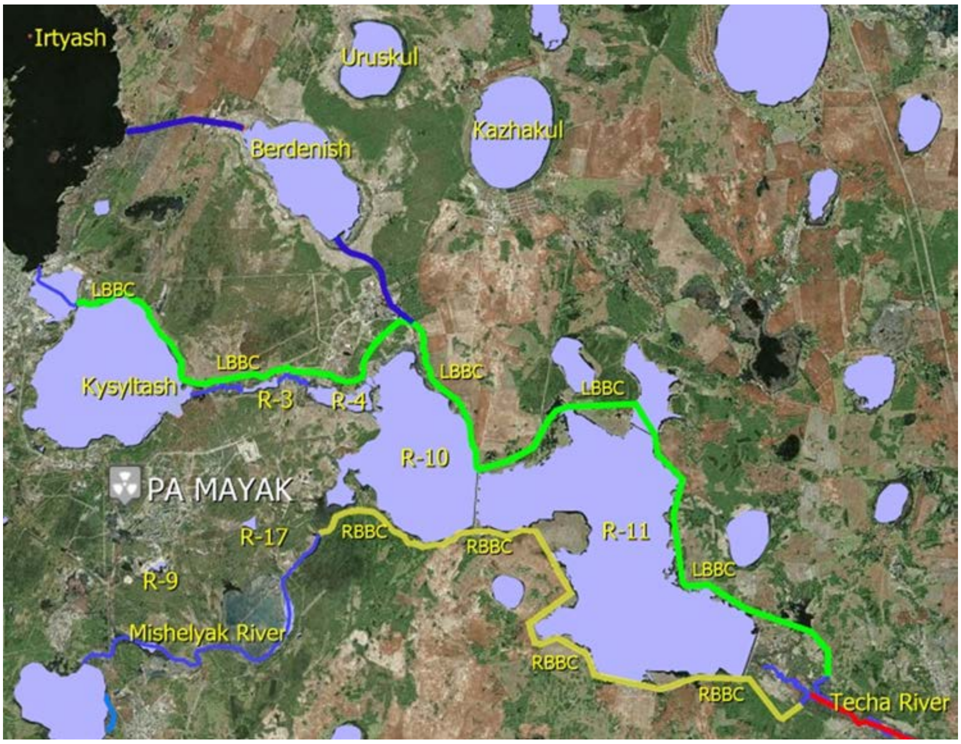


Figure 42. Location of reservoirs relative to Mayak PA and the Techa River.

With the exception of R-17, the fish species present and their size and weight were typical for the region. The frequency of erythrocytes with micronuclei, frequency of erythrocytes with morphological abnormality and comet assay tail moment were significantly different from a control reservoir (Table 18). Autopsies of fish also revealed tumours of the gonads in fish inhabiting radioactively-contaminated reservoirs. Such tumours were registered in fish aged over 7. There were few animals of this age in the catches from the control reservoir (due to the fish capture by the population). The fish were all older than 7 years and so it was not possible to relate the tumour presence to radiation.

Table 18. Indices of peripheral blood cells of roach from studied reservoirs (average ± SE)

Indices	ShR	R-11	R-10	R-4
Comet assay tail moment (peripheral blood cells)	0.71 ± 0.17	0.57 ± 0.08	* 1.52 ± 0.22	* 1.45 ± 0.29
Frequency of erythrocytes with micronuclei, ‰	0.25 ± 0.04	* 0.51 ± 0.06	* 0.52 ± 0.06	* 0.53 ± 0.06
Frequency of erythrocytes with morphological abnormality, ‰	64 ± 8	*133 ± 13	*131 ± 16	*180 ± 17

* - significant differences as compared to indices of roach from Shershnevskoye Reservoir (Mann - Whitney U-test, $p < 0.05$).

For environmental protection, biodiversity is a key endpoint of interest. The number of species present in each reservoir was therefore of interest. Studies on the number of species present as zooplankton, phytoplankton and zoobenthos were undertaken and biodiversity in samples related to the dose rate in the reservoir for those organisms. In most reservoirs, biodiversity was consistent with that for the region for phytoplankton and zooplankton. Biodiversity was however greatly reduced in R-17 and R-9, which had the highest dose rates (Figure 43).

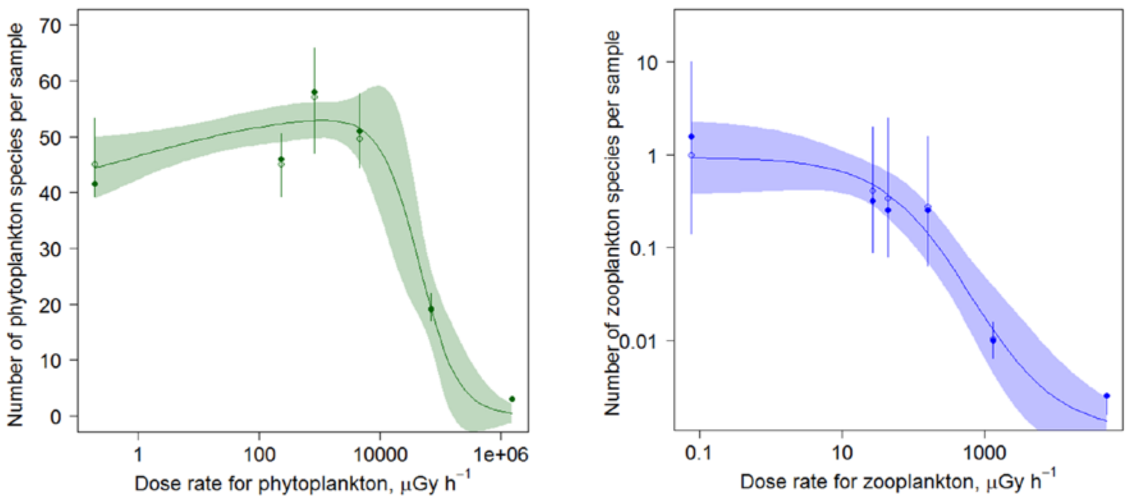


Figure 43. Dependency of phytoplankton (left) and zooplankton (right) biomass on dose rate.

Zoobenthos were the most exposed due to their contact with sediments and biomass of major groups of zooplankton were reduced in the most contaminated reservoirs. This was particularly evident for bivalve molluscs. Whilst the species present in sediments were similar to those found throughout the region, individuals were very small with size being most notably reduced in the reservoirs corresponding to the highest dose rates (Figure 44).

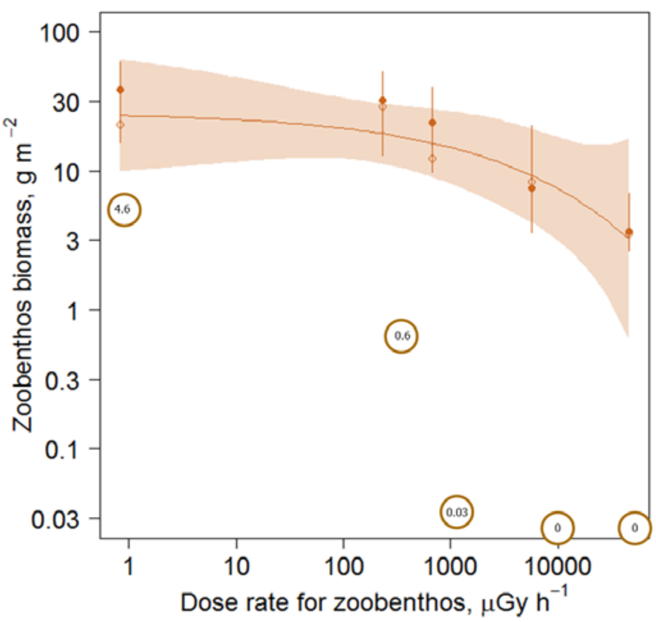


Figure 44. Dependency of zoobenthos biomass on dose rate, with large open circles indicating bivalve biomass.

Three monitoring stations were established in the Techa River, in the upper, mid and lower sections. Caesium and strontium concentrations were measured at each station with concentrations decreasing with distance downstream. Dose rates were calculated for fish at each station. All dose rates, whilst being above background dose rates, were below the ERICA screening value. Results of the comet assay, performed on roach peripheral blood cells, indicated a significant impact in the upper reaches of the river. The number of erythrocytes was also decreased in fish in the upper and mid sections of the river.

A study was undertaken whereby fish from a clean river were transplanted in cages to the Techa River and Zyuzelga clean river and vice versa. Stress factors were investigated in both populations. Little difference was observed in fish transplanted to the clean river, but those transplanted to the Techa River showed increased stress factor responses, including lower blood cell count. This suggests that under chronic exposure animals demonstrate decrease in adaptive capacity to other factors.

In reservoir R-11 no significant differences in the biota characteristics were revealed at the eco-system level. The biocenoses of the reservoirs R-1- and R-4 showed changes in the structure of the benthic communities. Signs of considerable degradation of the biocenosis were registered in reservoirs R-17 and R-9. The general condition of fish, at a population level, in the Techa River is satisfactory, although adverse biological effects are observed in individuals at a chronic radiation exposure above 100 µGy/d. The effects observed on individuals were nonetheless compensated for within the overall population.

During one sampling campaign, fish in the downstream sampling area were found to have higher strontium concentrations that had occurred during previous sampling campaigns, indicating the migration of fish between upper and lower regions. The migration of the more contaminated fish to the lower reaches is of concern with regard to fishing by communities inhabiting these reaches. Further study of the migration of fish is suggested, along with study of the amount of fish consumed by the population and resultant doses. Both dosimetric and epidemiological data may be used to evaluate health risks.

7.4 Remediation of radioactive residues: An interdisciplinary study on a case in Hanover, Germany

Claudia König (University of Hanover) presented.

There are a number of legacy sites in Germany, the main ones being the Wismut uranium mining residues, for which remediation activities are currently in the monitoring stage, and the Asse II salt mine that was used as a research deep geological repository for low and intermediate level waste that has been affected by water intrusion. Asse II site issues have had a large impact on the siting process for disposal of high level waste in Germany. At the moment authorities assess the technical feasibility of its remediation.

A rather different legacy was the De-Haën TENORM (technologically enhanced NORM) residues that were discovered unexpectedly in an urban area in Hanover in 2009. A risk assessment was undertaken for this TENORM legacy in 2010-2012, requiring an interdisciplinary approach with a large focus on risk communication. The discovery of the residues led to high media coverage that illustrated a gap between risk assessment and risk perception. The situation allowed a study to be taken to identify the factors characterising the area of conflict between expert risk assessment and lay-person risk perception of TENORM contamination and of the different understanding of risk and safety. The specific obstacles to implementing radiation protection measures, particularly in terms of TENORM remediation were also studied. (See Koenig et al, 2014).

Hanover is the capital of the federal state Lower Saxony and has a population of over 500,000. The List district of Hanover was built between 1920 and 1930, has a population of 44,500 and is characterised by five-storey buildings, each housing around 8 to 10 flats, with inner courtyards and front gardens. Many of the flats are owner-occupied. Historically (from 1865 to 1902), uranium and thorium products were processed within the De-Haën chemical plant. The plant was abandoned in 1902 when processing was moved to a neighbouring city. Since the 1930's the area has been used for residential purposes. Initial radiological measurements were first made in the summer of 2008, with elevated ambient gamma dose rates being indicated in some areas, indicating patchy contamination (Table 19).

Table 19. Radiological contamination measured in and around residential properties in the List district of Hanover.

Parameter	Investigation results
Ambient gamma dose rate	75% of open area < 0.15 µSv h^{-1} 8.3% of open area > 1.00 µSv h^{-1} 80% of gardens < 0.15 µSv h^{-1} 1.2% of gardens > 1.00 µSv h^{-1}
Radon indoor	Values between 22 and 1530 Bq m^{-3} in basements Values between < 100 and 560 Bq m^{-3} in apartments
^{238max}U + ^{232max}Th in soil samples	Minimum: 0.18 Bq g^{-1} Maximum: 159.6 Bq g^{-1}
^{238}U in water	In drinking water: < 0.004 Bq L^{-1} In groundwater: 0.2 – 0.5 Bq L^{-1}

Under the German Radiation Protection Ordinance, a dose constraint of 1 mSv/y is given for the exposure of a member of the public to NORM residues. An activity constraint of 1 Bq/g is also stipulated[8]. The Table 19 data indicate the scope of exceedance of these criteria, depending on how averaging is done and upon occupancy and other behavioural factors relevant to dose assessment.

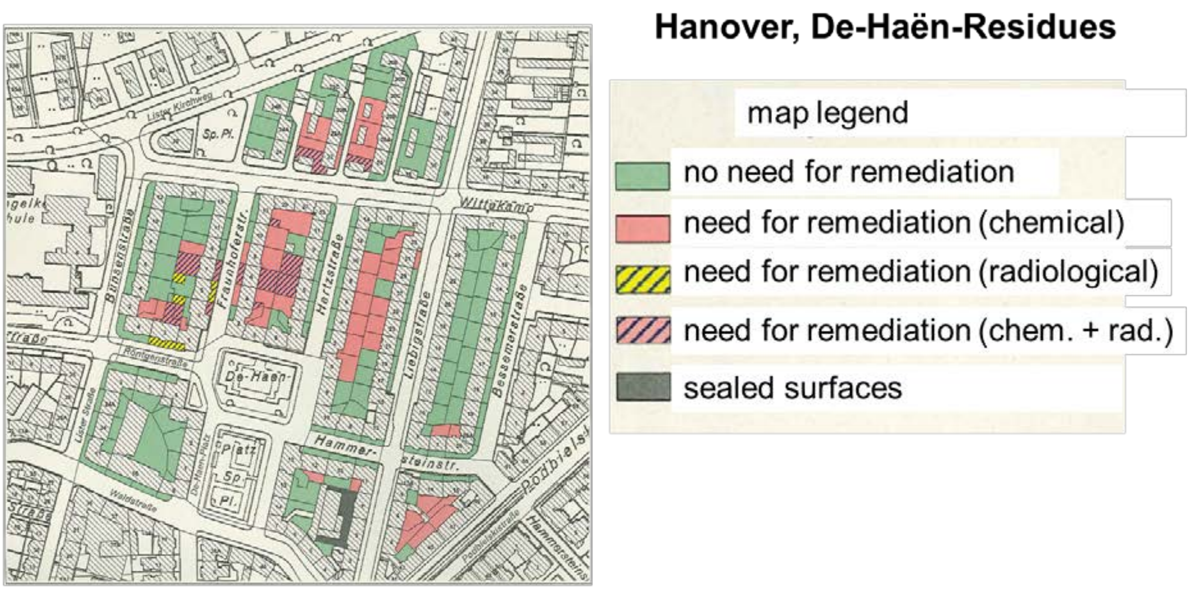
The De-Haën plant was a chemicals plant and many other chemicals were present, giving rise to a possibly greater health risk than that associated with the radiation (Table 20). A number of exceedances of the regulatory guidance values were evident, indicating that remediation actions were required.

Table 20. Data for chemical contaminants and comparison against regulatory guidance values.

Parameter		Investigation results Min. – Max. (mg/kg dry matter)	Regulatory guidance values for children's playgrounds	Regulatory guidance values for residential areas	Exceedance factor
Lead		1.1 – 5,900	200	400	30 – 15
Mercury		0.1 – 250	10	20	25 – 12
Arsenic		2.6 – 560	25	50	22 – 11
Antimony		1.5 – 1,200	50	100	24 – 12
Cyanide		1 – 190	50 (acute exposure)	50 (acute exposure)	4
Benzo(a)pyrene		0.05 – 11.4	2	4	6 – 3
Chromium		8.1 – 320	200	400	1.6
Barium		16 – 6,600	1,500 (acute exposure)	1,500 (acute exposure)	4.4

[8] German Radiation Protection Ordinance: Part 3: Protection of man and environment against natural radiation sources from activities, §§ 93-104

A map of required remediation areas is given in Figure 45. A total of 45 plots required remediation, with round about 15 owners affected at each plot. Under German soil protection regulations, owners are required to pay for remediation if the causer of the pollution does no longer exists.



Affected areas around De-Haën-Square (Source: IFUA, 2009)

F*igure 45. Areas affected by chemical and/or radioactive contaminants and need for remediation.*

Interviews were conducted with residents, gardeners, journalists, a lawyer and experts from Lower Saxony and Saxony using interview guidelines. All interviews were tape-recorded and later transcribed and anonymised. Around 550 pages of empirical material was generated as a result of these interviews, which were analysed to develop risk communication guidelines for crisis situations, the crisis being related to unexpectedness and not radiation, with people being required to change their perception of their living environment. Additional findings from the study were that scientific knowledge and terminology used were complex issues for the public to grasp, particularly concepts such as Sv/Bq. A regulatory gap was also evident along with a mismatch in the understanding of residents' values. A positive factor was the introduction of an external mediator that was very experienced and engaged.

There are a number of differences between risk communication and crisis communication. Risk communication is very message centred and time can be taken to ensure that information is controlled and structured. Information dissemination also tends to be proactive, providing information on the possibilities of negative consequences and risk avoidance from technical experts and scientists. Crisis communication on the other hand needs to be very situation centred and reactive. Messages largely focus on the current situation or conditions and required actions, and can be spontaneous and unstructured and issued by different regulators or other authorities. From the study, it was evident that those involved in the initial communication were trained to discuss the risk, but not crisis communication.

The different levels of background knowledge of the local people had a significant effect on how long it took for them to understand and absorb the information disseminated by those in authority. This was compounded by the fact those people in authority had little idea either, for example having no experience or procedures for dealing with radiation and chemical contamination issues simultaneously. Where people do not have an adequate background to understand the facts and numbers presented, peripheral evaluation of information can become more important. In communicating, it is important to show awareness of concerns and understanding at a level that gains trust from those affected.

One of the main issues identified from the discovery of the contamination was the gap in regulations. The Radiation Protection Ordinance provides no regulation for the remediation of residues from former practices and activities, but does provide for protection of people and the environment from natural radiation resulting from activities. The Soil Protection Ordinance provides no regulatory guidelines for radioactive contaminants. The residues at the site were identified around 100 years after operations at the plant ceased and those responsible were no longer present. Those organisations given the responsibility were familiar with non-radioactive pollution but had little experience of managing radiation issues. Once the presence of radiation was identified, those responsible for remediation were unsure what 'higher than background' meant or what to do. As such, radioactively contaminated areas identified were marked so they could be addressed at a later date. The marking of areas (see for example Figure 46) provided for a non-verbal form of risk communication. The overall communication between radiation protection and soil protection communities was not good and improvement is required.

Dose criteria for radiation protection were not transferable to soil criteria and the time and media pressure did not help the situation. Those undertaking remediation activities were under considerable pressure to complete work due to the residents being responsible for the costs.

Figure 46. Example of non-verbal risk communication through the marking of radiologically contaminated areas.

Health risk assessment and remedial management, as set out the Soil Protection Ordinance, is a multistage process comprising of characterisation to determine the amount of contaminants present and evaluating mobility and bioavailability. Feasibility and cost are then considered. Four different land use scenarios are considered (industrial, parks and leisure facilities, residential areas and playgrounds).

The values of residents had also not been fully anticipated such as peoples concern over health risks to children, even if they had none. There were also considerable concerns with financing the works and feelings of injustice at having to pay for remediation of contamination caused by others. The use of an experienced mediator was very valuable in helping to explain issues from a neutral position.

Overall, the study identified pitfalls on various levels (regulatory, communication and ethical) of the remediation process, with the regulatory issues presenting the largest issue. On a practical level, the lack of, or inconsistency in regulations was a large issue, as was the lack of funds for the remediation of industrial legacies. If the contamination had occurred in a different state, funds would have been available to fund the remediation, which added to the feeling of injustice that people had. Finally, the need to develop coordinated action plans for environmental protection disciplines was identified.

7.5 Points from discussion

Cancer risk estimates from atomic bomb survivors and comparison with risk estimates from other exposed groups could potentially result in differences due to the non-radiation effects in atomic bomb survivors such as heat and stress resulting from the bombing. However, risk estimates for solid cancers and leukaemia resulting from gamma exposure in other groups are similar. The Mayak PA study also provided information relating to internal plutonium exposure and risks were again in line with expectations, when individual cancers are allowed for. The incidence of lung cancer cases in Mayak workers and 'A' bomb survivors are also broadly in line, although uncertainties in plutonium dose estimates need to be taken into account. The results these different studies adds confidence that the risk estimates are reasonably accurate.

Overall recommendations arising from lessons learned are due to be published by relevant authorities in the summer of 2016.

In all remediation situations, a balance needs to be made between costs incurred and potential benefits. Risk informed guidance is not always adopted, depending upon the circumstances. For example, further monitoring of beaches near Sellafield was not considered necessary for radiation protection purposes following the study undertaken by PHE on behalf of the Environment Agency. Nonetheless, the Environment Agency took the decision to continue monitoring. Both science and values need to be considered in making decisions with discussions being held with local people to inform on risks and impacts that actions, such as evacuation, could have. In some instances, greater health risks may be associated with countermeasures. Drawing the appropriate people together to allow values to be incorporated within the regulatory and decision process is therefore important.

A particular issue with public communication and risk perception lies with the different approaches applied. In planned situations, a 1 mSv dose limit for the public may be used, but for other exposure situations the ICRP recommends a reference level of between 1 and 20 mSv. The difference between limit and reference level is not always understood and the different values applied can lead to confusion and concern. Applying the same risk standards to different exposure situations and for chemicals and radionuclides would appear to be both logical and avoid some of the confusion.

8 Session 6: International Perspectives

8.1 Status of ICRP Task Group 98

Mike Boyd (US EPA) presented.

ICRP Task Group 98 (TG98) on the '*Application of the Commission's Recommendations to exposures resulting from contaminated sites from past industrial military and nuclear activities'* is a TG of ICRP Committee 4 which advises generally on the practical application of the Commission's Recommendations, most particularly ICRP Publication 103, the most recent overarching recommendations document. The terms of reference for TG98 are to describe and clarify the application of the ICRP's Recommendations on radiological protection of workers, the public and the environment at sites contaminated from past activities. These were approved by the ICRP Main Commission in November 2014. The sites considered by the task group include those affected by past industrial, military and nuclear activities, but does not include sites contaminated as a result of nuclear and radiological accidents. Nuclear and radiological accidents are covered by ICRP TG93. ICRP Task Group 76 is specifically considering NORM and consultation between the all current TGs will be required to ensure consistency.

The scope of the report to be produced includes characterization of sources, exposure pathways, dose distribution, categories of exposure, protection of the environment and the setting of reference levels for sustainable protection strategies. Stakeholder involvement will be considered in all steps. In choosing protection objectives, the ICRP position is that these should be justified and optimised and residual doses must be acceptable. Management of waste arising from remediation activities is not specifically included in the scope of TG98 although it may be appropriate to take it into account.

Several ICRP publications (see http://www.icrp.org/publications.asp) are being considered as input to theTG98 report.

- Publication 82 on Protection of the Public in Situations of Prolonged Radiation Exposure (1999).

In this report the scope is broader, including accidents and areas of high natural background, and it is based on the 1990 ICRP main Recommendations in Publication 60 (1991), i.e. practices and interventions, alongside emergencies.

- Publication 111 on Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency (2009).

This report falls directly in the scope of TG93 and takes account of the more recent main Recommendations in Publication 103 (2007), i.e. planned and existing exposures situations alongside emergencies. However, both TGs need to have a common understanding of existing exposure situations.

- Publication 126 on Radiological Protection against Radon Exposure (2014).

TG 98 needs to decide whether radon exposure needs its own section; can it be incorporated into guidance for individual public and worker exposure, and whether it is a concern for biota.

Account is also being given to parallel on-going work in the IAEA and thoughts and inputs are being shared. Relevant issues have also been raised in Committee 4 during the recent ICRP Symposium in

Seoul (see http://www.icrp.org/page.asp?id=186). For example, appropriate levels for protection of workers during remediation (see also section 7.1) and whether it is possible to set a lower bound on optimization for remediation. (See also related discussion of uncertainties at low doses in section 7.1)

Noting all the above, there has also been good progress to date on development of the content and scope of the report and a rough outline has been developed. The first meeting of the Task Group is to be held in the days following this workshop, with a number of topics tabled for discussion.

A draft TG98 report is due to be presented to Committee 4 within a year.

8.2 Existing exposure situations and legacy management

Ted Lazo (NEA) presented.

The ICRP recommends that protection options be justified and optimised and that residual doses should be in the range of those tolerable with protection optimised to ensure residual doses are acceptable. The question is what this means in practice for legacy management

There are a number of different approaches to defining what constitutes a legacy site. Such sites have no identifiable owner and were either operated under historical regulations that do not meet current standards or was never regulated. Since legacy sites already exist, the ICRP suggests they be considered as existing exposure situations, whereby the situation already exists and has generally done so for some time such that it is not possible to control the source, but control of exposure pathways and the exposure of individuals is possible. In managing legacies, the choices made relating to protection need to appropriately address prevailing circumstances; protection options are therefore a site-specific consideration. A framework of tools to optimise radiological protection is provided by the ICRP, but the framework could be considered too rigid.

The ICRP framework aims to support protection decision making in relation to addressing stakeholder concerns and protection of the public, but decisions will vary according to the wider on-gong situation. The prevailing circumstances encompass a broad range of physical, environmental, social, economic and political issues. Science is needed to support the application of the framework.

In terms of prevailing circumstances for legacies, the situation has generally existed for some time and exposures are normally low to moderate, but could be relatively high. Worker exposures are normally short-term, but may be received over a working lifetime, whereas public exposures are generally chronic and relatively constant over time. The social and economic history of a legacy site can be a very important factor; what is considered intolerable under some circumstances may be tolerable in others. The circumstances of the ICRP exposure situations that drive the tolerability of risk are outlined in Table 21. The optimum solution will depend upon where people are in relation to the legacy site and their protection and other expectations and concerns.

The ICRP frequently refers to tolerability and equity. In planned exposure situations, the tolerability of risk is embodied in the selection of the numerical value of the dose limit and equity is embodied in the selection of the numerical value of the dose constraint. In existing and emergency exposure situations, both tolerability and equity of risk are embodied in the selection of the numerical value of the reference levels.

Optimisation should be framed by the level of risk tolerability associated with the exposure situation. Protection should be implemented such that all exposures are, or are working towards being, as far below the circumstantial tolerability level as reasonably achievable. Optimisation should be applied to meaningfully manage exposure situations in a graded fashion. The choice of dose limits or reference levels and the level of tolerability should be at least partly consider the controllability of the source, the variability of personal exposures, and the importance of personal behaviour in terms of exposure.

Table 21. Circumstances of ICRP exposure situations that drive tolerability of risk.

Exposure situation	Driver	
	Source	Exposure
Planned	– Well characterized – Controllable – Well regulated	– Well characterized – Easily manageable – Public and occupational management depend on source and pathway control
Existing	– Can be characterized – Largely unchangeable – Already present	– Can be managed – Somewhat uncertain – Public management depends mostly on behavior control – Graded occupational management
Emergency	– Very uncertain – Uncontrollable	– Extremely uncertain – Hard to manage – Public and occupational management is urgently needed and depend mostly on behavior control

The prevailing circumstances can have a significant effect on the tolerability of risks and on the identification of an acceptable optimum protection solution. A first and essential step is to listen to and understand stakeholder concerns with regard to the prevailing conditions. The location of sites relative to populations will drive perceptions and culture can play an important role in affecting public viewpoints. Whether dose limits and constraints and/or reference levels are applied should also be driven by the prevailing circumstances, not some preconception.

The key elements of the ICRP system of radiological protection are the application of the principles of justification, optimisation and the application of dose limits (or restriction of dose) according to the exposure situation and the type of exposure (occupational, public or medical). How the framework varies under planned and existing exposure situations is illustrated in Figure 47. Dose constraints do not apply under existing exposure situations. In deciding upon remediation options, dose restriction comes into play. It was suggested however that dose limits rather than dose restriction should be applied for existing situations. For example, where workers are being managed within a planned exposure situation, dose limits are applied, whereas in emergency situations a reference level is applied which may be higher. Activities in both instances are nonetheless planned. The use of a dose limit may therefore be conceptually more appropriate in existing situations where activities for remediation are planned.

In conclusion, there are many different aspects to be taken into account in managing legacy issues. The management of legacies can be strongly influenced by stakeholder concerns and views, which are themselves strongly influenced by the prevailing conditions. Flexibility is essential to appropriately managing such situations and an essential first step to legacy management has to be the development of a thorough understanding of all aspects of the prevailing circumstances.

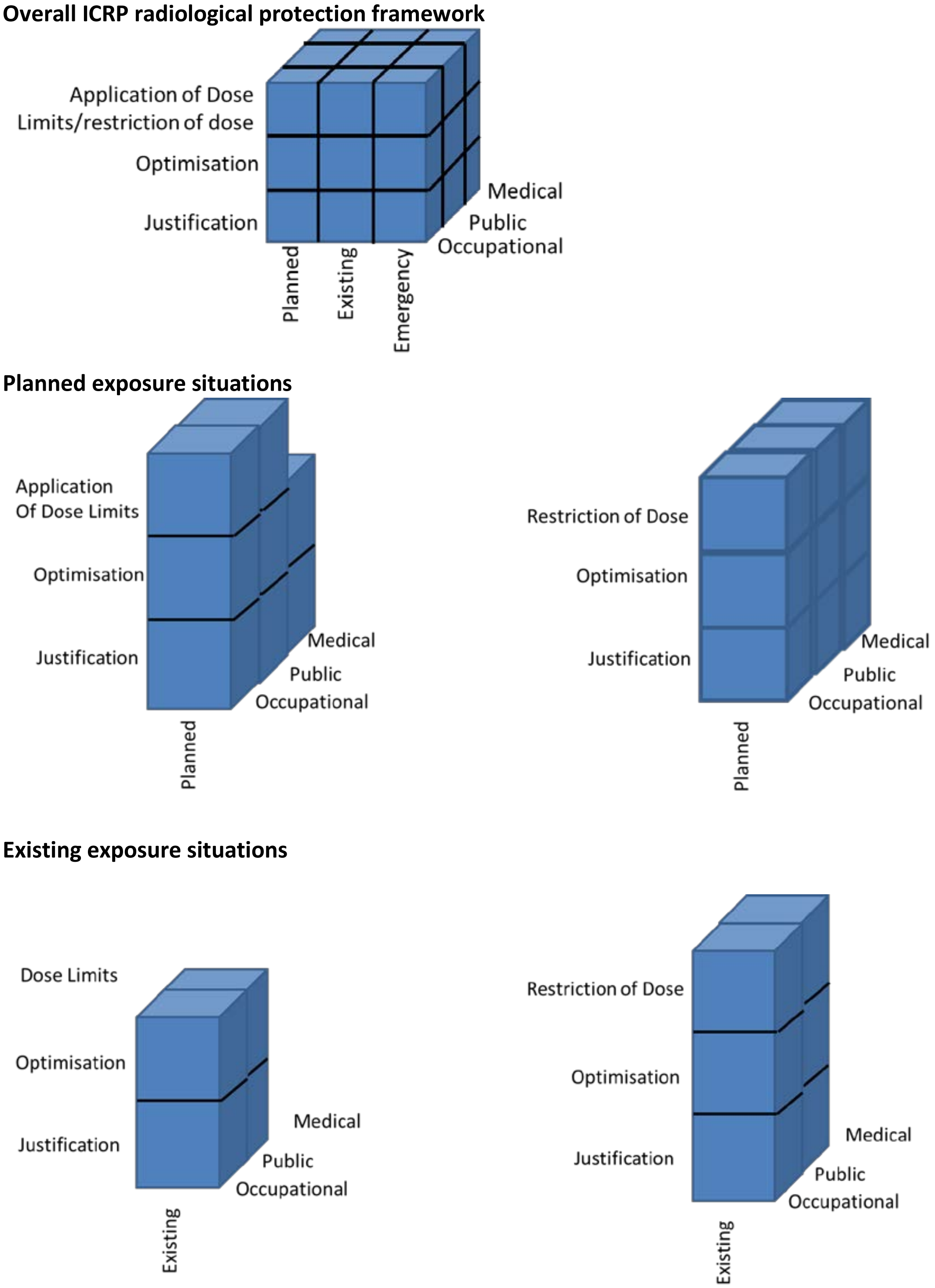


Figure 47. The overall ICRP radiological protection framework (upper figure) and its application to planned (middle) and existing (lower) exposure situations.

8.3 IAEA activities for the safe management of legacy sites

Gerhard Pröhl (IAEA) presented.

The IAEA 2006 Safety Fundamentals detail 10 principles for radiological protection (IAEA, 2006). Those particularly important to legacy site management are Principle 1 (responsibility for safety) and Principle 10 (protective actions to reduce existing or unregulated radiation risks). The 10 principles are the high level requirements of the IAEA. The International Basic Safety Standards (IBSS) provide more specific information and represent an international consensus on radiation protection, based upon ICRP Publication 103, and approved by all Member States (IAEA, 2014).

The IBSS cover a range of exposure situations. In terms of relevance to remediation programs, the IBSS defines responsibilities for government and regulatory bodies and the relevant planning and implementing bodies, and sets out the key radiation protection principles of justification, optimization and limitation. Radiological criteria are also stipulated in terms of reference levels for the dose of the representative person (1 to 20 mSv/y), exposure due to commodities (1 mSv/y) and limits for remediation workers (20 mSv/y). The IAEA considers that remediation work is a planned activity where the source cannot be controlled, but the activity of workers can be controlled. The IBSS also calls for the involvement of stakeholders and development of strategies for the management of radioactive waste arising from remediation.

The safety requirements are supported by a range of documents, including safety assessment for facilities and activities that relates to any human activity that may cause people to be exposed to radiation risks, including the remediation of legacy sites. A 2007 safety guide (IAEA, 2007) for remediation of affected areas is currently under review. The current version provides guidance on regulatory infrastructure and responsibilities and addresses all the key issues associated with the remediation of contaminated sites, including post-remediation management.

A system for the management of radioactive waste generated as a result of remediation activities is required and relevant information on exemption and clearance and the classification of radioactive wastes is available in a number of IAEA publications, including:

- 2009 General Safety Guide GSG-1 on Classification of Radioactive Waste
- 2005 Safety Guide RS-G-1.7 on Application of the Concepts of Exclusion, Exemption and Clearance
- 2004 Safety Reports Series No.44 on Derivation of Activity Concentration Values for Exclusion, Exemption and Clearance

There is also a safety guide (WS-G-5.1) on the release of sites from regulatory control on termination of practices although this is more related to planned activities and their termination. Nonetheless, topics and points raised in the guide are relevant and should be taken into account in the management of legacy sites. However, some aspects, such as dose criteria are not relevant to existing situations.

The IAEA undertakes a number of activities to support the implementation of safety standards. The assessment of exposure is a prerequisite of radiation protection; exposure levels and time dependence are required to be known if exposures are to be managed. A series of activities has been supported by the IAEA in relation to dose assessments and the exchange of knowledge and experience. The most recent has been the MODARIA (Modelling and Data for Radiological Impact Assessments) program that ran from 2012 to 2015. The program was aimed at improving capabilities in radiological impact assessment through testing and comparison of assessment models and analysing and compiling relevant assessment data. A follow on program, MODARIA II, is planned with the first Technical Meeting taking place from 31 October to 4 November 2016. Such programs also provide a forum for the exchange of knowledge and experience.

Within the MODARIA program, there were 10 working groups (WG). Of particular relevance to legacy site management was the work of WG1 and WG3.

WG1 focussed on remediation strategies and decision aiding techniques. The scope included lessons learned in terms of social, economic and environmental considerations and support in decision making. Existing decision aiding models were reviewed and compared and consideration given as to how to improve decision making for remediation planning.

WG3 was focussed on models for assessing radiological impacts at NORM and other radioactively contaminated legacy sites and support in the management of remediation activities. A program was specifically developed, NORMALYSA, which is publicly available and has a multi-language interface. The models in NORMALYSA are illustrated in Figure 48.

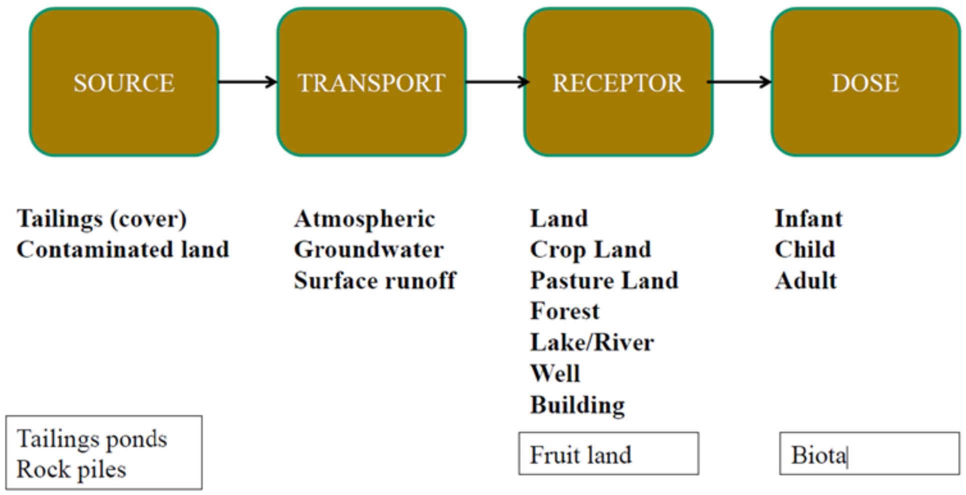


Figure 48. Models in NORMALYSA.

Dissemination of knowledge and training is required throughout Member States and the IAEA has developed a program, supported by the EU, to develop training material for preventative and remediation issues in legacy sites. The program is specifically focussed on African countries and includes both development of training materials and implementation of training. The overall objective is to provide support and assistance in implementing regulatory requirements on radiation protection at uranium mining and milling legacy sites.

Other management activities for legacy sites include a Coordination group for Uranium Legacy Sites (CGULS) for which the IAEA was asked in 2010 to provide a coordinating role. The main focus is on uranium legacy sites in Central Asia, Mongolia and Ukraine. A range of activities is undertaken, including assisting countries to develop regulatory documents and remediation strategies. Expert missions are organised to support cooperation.

An international working forum for Regulatory Supervision of Legacy Sites (RSLS) was established in 2010. The forum holds annual meetings and has the objective to support better regulation of existing sites and facilities and to avoid the creation of new legacy sites through strong, independent regulatory oversight. More than 40 Member States are participating in the forum and the work from the first 3 years is due to be published as an IAEA TECDOC. A number of workshops and site visits have been held to allow issues in the field to be experienced. A technical meeting is planned for 2016.

Further projects of the IAEA open to all Member States include:

- ENVIRONET, a network of environmental management and remediation to promote the adoption of good practice in environmental management and remediation; and
- CIDER (constraints in decommissioning and environmental remediation) that aims to examine global constraints and facilitate the implementation of decommissioning and environmental remediation projects.

There was also a Contact Experts Group for international nuclear legacy initiatives in the Russian Federation that ran from 1996 to 2015. The overall objective of the group was to support the safe and secure management of legacy objects, including:

- Defueling and dismantlement of decommissioned nuclear submarines and vessels;
- Retrieval of all radioactive thermo-electrical generators; and
- Remediation of contaminated areas and facilities of the former navy bases.

Through the work programs undertaken, key challenges in legacy site management have been identified. The key challenges are:

- Liability. An operator may no longer exist, or may never have existed and responsibilities therefore need to be assigned. The funding route for management of legacy issues must also be decided.
- Nature of contamination. Both radioactive and chemical hazards may be involved requiring health impacts for mixed contamination to be evaluated. This is a relatively young field and, whilst work has been undertaken in the last decades, there has been no real breakthrough in terms of evaluating mixed contamination impacts. The application of criteria is also an issue.
- Management and remediation of legacies. Legacy sites relate to past activities and large areas can be affected. Remediation efforts can take time and long-term efforts and commitments, and the cooperation of different agencies and interested parties.
- Implementation. Legacy sites are often complex situations, requiring solutions that are tailored to the prevailing conditions. There is no general recipe that can be applied across all legacy sites.

8.4 Points from discussion

The ICRP is concerned with the classification of exposure situations, but there are times when it is difficult to categorize a situation. For example, the Sellafield particles are an existing situation and the source is unknown. However, the approach applied to address the situation is not one that relates to an existing situation since monitoring has been incorporated within the Sellafield site license conditions, which could lead to the situation being classified as planned. This is similar to the case of contamination around Mayak PA. Contamination exists in the area, but that contamination arose both from emergency situations and from planned discharges. It is therefore suggested it is not the classification of the exposure that matters so much, but rather the provision of advice on best practise to address the prevailing exposure conditions. The development of a roadmap describing the management and regulatory process was considered useful in this regard. The procedure or process described in the roadmap could identify the appropriate criteria to apply to situations and the most important aspects to be considered and addressed, without being overly prescriptive. The procedure would need also to consider what is meant by optimisation in the case of legacy site management and account for the involvement of stakeholders in the entire process.

The ICRP task group 98 remit includes protection of the environment from radiation associated with past activities. Radon was also identified as an area of particular concern. Consideration of environmental protection and radon with regard to legacy site management needs to be approached with care as neither radon nor wildlife can be controlled. If aspects cannot be controlled then they cannot be managed. Optimisation, in terms of options assessment, can however take account of costs and benefits in relation to environmental protection and radon.

9 Overall Discussion

The following text summarizes issues raised and various comments made in response.

A key obstacle to the design and implementation of legacy site remediation has been risk communication. This in part relates to the language used in relation to radiation and to the lack of clarity in the definition of protection objectives and the application of protection standards. Past management activities have commonly led to mistrust of the authorities, which can be further fueled by conflicting advice from different scientists and environmental groups. Social and cultural differences can also impact on risk communication.

A major issue for impacted communities has been their health and assurance that their health is being protected. To achieve the required trust, there is a need to begin with a clear endpoint in mind and to build credibility through implementing effective outreach and educational programs alongside clean up, resettlement or other mitigation measures and long-term monitoring programs. Much work is being done to address these issues and to learn from the past. For example, the US DOE is planning a workshop, jointly with the IAEA, to be held in the next few years to revisit what has been done to address the legacy issues at the Marshall Islands.

A common understanding of what a legacy means in the nuclear and radiation context would be useful in explaining matters to affected stakeholders, along with advice would be useful on how the definition should be applied. It may be most helpful if this understanding is expressed in general terms, without embedded detailed prescriptions, since the word legacy already has different meanings in different jurisdictions.

Clarification of criteria to apply to workers at legacy sites would be useful since their work relates to an existing exposure situation, but could also be considered as planned, affecting whether dose constraints or reference levels are applied. In part, the solution depends on whether the remediation workers are considered as radiation workers. This in turn should be dependent upon the extant radiation conditions (dose rates and contamination levels), but also upon how they are ascribed within the system of radiation protection, i.e. which exposure situation is evident.

The transition from an emergency to an existing exposure situation has been discussed for some time and it can be hard to communicate the distinctions between planned and existing exposures. The lack of a clear distinction between exposure situations has been acknowledged by the IAEA[9]. Clarification is required so that decisions can be made as to whether dose limits and constraints are applicable or whether reference levels should be applied. It would also be very useful to have a clear basis for declaring when an emergency if over.

It can also be recognized that when a legacy is discovered, or even when an old site is re-recognised as requiring regulatory supervision, there may be a need for urgent action, albeit not on the scale or type of a major accident emergency. Further advice would be useful on how to recognise that a legacy and/or existing situation exists, and what the following appropriate response might consist of.

Stakeholder engagement has been identified as a key requirement for legacy site management. It may not be possible to achieve a consensus opinion among all stakeholders on all issues, but involvement should be encouraged nonetheless so that people affected by the legacy issue and how it is managed have a feeling of owning the solution. It should remain clear to all who is responsible for making decisions and why it is their responsibility. At the same time, the process should allow any conflicts of interest or trade-offs between options to be made transparent.

[9] Para 1.21 of IAEA (2014).

There is substantial guidance and experience on the conduct of dose assessments. Such assessments inform decisions at each stage of a remediation program, recognizing that the focus of assessment may need to be updated to address the different factors that become relevant at each stage. People living in the area are likely to be familiar with locally relevant assessment information as well as being among most likely to be affected. Taking their advice may therefore support the assessment itself as well as lend credibility to the results.

Similar extensive experience exists for the assessment of non-radioactive pollutants. However, there is less experience in combined and coherent assessment of mixed contamination and waste. There is correspondingly less international guidance on relevant standards that are consistent and coherent for chemical and radiological hazards, and in methods for compliance assessment. The protection endpoints and details of assessments made in each case are also notably different, although there are some exceptions, as in the case of the US EPA Superfund remedial program's approach for risk harmonization when addressing chemical and radioactive contamination[10].

Much experience exists in the radioactive waste management community concerning in long-term assessment of radiological and chemical impacts, including environmental change, landscape evolution and treatment of unlikely but high consequence disturbing events. This experience may have application for the long-term planning for management of major legacy sites, particularly where the strategy has no fixed timeframe, as in the case of long term custodianship, or stewardship. Development of a clear closure plan at the inception of projects (lifecycle planning) is likely to improve confidence in a remediation plan, but this may need to be supported by long-term surveillance for assurance of compliance. Examples have arisen where measures have been expected to be sufficient and then later monitoring shows they were not. This is a separate issue from where the standards have been revised so that further actions are necessary and costs arise. In both cases however, this can complicate the funding of long-term strategies. In this context it may be convenient not to rely solely on an engineered barrier control philosophy, but to adopt in parallel an ecosystem-type approach that incorporates local plants and soils, leading to self-sustaining covers.

Dose can usually be estimated with reasonable confidence, even at low exposure levels, but the risks associated with low doses and dose rates (as discussed in Wakeford and Tawn, 2010) are very uncertain. Although there remain concerns over this uncertainty, the data supporting a linear no threshold approach is in almost all cases better than data available to support chemical risk assessments.

Discussing uncertainty during stakeholder engagement may give rise to an impression of lack of necessary knowledge; however, this might be addressed by acknowledging that the risks at the relevant dose levels are extremely low compared to many day-to-day risks, as well as those associated with aspects of remediation strategies, e.g. stress from being excluded from an area. It may be useful to distinguish the threshold of observable effects from the threshold of relevance for protection purposes, and from the threshold of ability to assess risks in particular circumstances. Further guidance in this context could support communication efforts and this in turn may help stakeholders reach their own opinion on remediation actions and options.

Protection of people will always be the key focus but the optimisation process also includes consideration of protection of the environment and resources, alongside human health. Protection of wildlife may be especially relevant if people are absent from a site. Remediation activities can in themselves do damage e.g. to farmland or water supplies due to physical or other disturbance, or to wildlife through habitat destruction. For wildlife, populations and biodiversity are the protection endpoints, not individuals. Overall, it is therefore important to understand the relevant resources and wildlife populations of protection interest, and what counts as damage to them, from both

[10] These issues have been discussed further in NRPA (2015).

technical and wider stakeholder perspectives. Another factor is that wildlife may provide a mechanism for transport of contamination.

Further international guidance on the application of international recommendations, standards and guidance to legacy sites would be useful. Whether or not it would be possible to develop a single document that covers a wide range of legacy types was considered questionable. Even what might be considered one type of legacy, e.g. uranium mill tailings, can require very different consideration in different circumstances. A starting point may be to consider a range of examples for major types of legacy and then evaluate whether approaches for each of these can be combined, rather than starting with a combined approach and hoping it will be applicable to a range of situations.

The key issues with legacy site management and regulation depend in practice upon the prevailing circumstances. There is however a lot of information available on the overarching issues that apply at legacy sites generally and on the principles for managing those issues. Distinguishing features, from a radiation protection point of view, are connected with the emissions, chemistry and half-lives of the particular radionuclides present, the extent and depth of their distribution in various environmental media, and current and planned land use, in so far as that affects the potential for radiation exposure. The source of contamination is itself not relevant to protection, though it may be connected with availability of resources to address remediation and historic information may help in the characterisation process. A step wise procedure was suggested, including site characterization, exposure assessment, options appraisal, implementation and confirmation of completion. Information could be collated and guidance given on how these concepts could be applied in practice, supported by the experience presented.

Expanded guidance on the application of international recommendations etc., on legacies should not to set rigid criteria, e.g. since each legacy site will have its own individual characteristic such that, for example the optimum reference level may differ from site to site, as was intended in the recommending a range of reference levels in the first place. It was noted that bringing the levels in Russia in line with those of the EC would require the revision and acceptance of the regulatory basis on radiation safety, and would, in principle, reduce the standard of radiation protection of the public achieved in Russia. Harmonisation would however in practice allow the return of most contaminated areas in Russia and Belarus to normal life with almost all local foods complying with EC levels and very little impact on exposures and risks actually experienced while having a large and positive impact in allowing the economy and agriculture of the affected regions to develop. International harmonisation of practice (as opposed to standards) may also present advantages in terms of simplifying movement of materials.

There was a general consensus that all environmental consequences of proposed remediation actions should be considered. Apart from dealing with chemical hazards alongside the radiological, many disciplines may need to be involved. For larger projects, it can be constructive to set up a technical review panel headed by a project manager and consisting of other appropriate technical experts from the fields of radiation protection, hydrogeology, geotechnical engineering, surface water hydrologists and geomorphology.

10 Conclusions and Recommendations

It is evident from the presentations and discussions that many countries are working to address the latest international recommendations, standards and guidance from ICRP, IAEA and NEA. It is also evident that there is a great deal of practical experience in legacy management and regulation in many countries. Nevertheless, many countries have very limited resources or capacity to address scientific and technical aspects of legacy site remediation. Lack of guidelines on remediation and a regulatory process for return to normal unrestricted land use is a stumbling block in many cases.

Learning lessons from the past is very important: to help avoid future mistakes and creation of new legacies; to ensure that legacy management strategies are appropriate to the site of interest, meet protection and safety objectives and address a wide range of stakeholder interests; and to ensure that they are practically achievable. There is continuing scope for sharing of experience. This can be mutually effective at national and bilateral levels, as well as supporting the development of guidance on the application of international recommendations, standards and guidance to legacy sites.

Both chemicals and radiation should be considered at legacy sites to facilitate proportionate risk management, act as a guide to appropriate allocation of resources for remediation and inform a wide range of stakeholders, including those with ultimate responsibility for taking decisions. However, further work is required to address technical issues around assessment and management of mixed contamination to allow this area to move forward.

Key points and challenges in moving from legacy recognition to resolution include the following.

- Every legacy is different and presents a complex variety of relevant prevailing circumstances.
- Technical methods for remediation and regulatory supervision are quite well developed and there is a lot of useful experience, but there is scope for improvement and advantages from harmonisation of methodologies and practice, while acknowledging that their implementation, including the results of optimisation procedures, may lead to different solutions at different sites, according to the prevailing circumstances.
- For successful legacy management, it is important to engage a wide range of stakeholders and seek to obtain their support in a transparent and traceable process. Effective risk communication is a very important part of the engagement process.
- There is a substantial gap between theory and practice and further international guidance on practical application would be valuable. This includes clarification of the application of the concept of emergency, existing and planned exposure situations, and the boundaries between them.
- A holistic approach to proportionate management of different risks is to be encouraged. This may require the review of protection objectives and standards that are applied to different contaminants in different contexts.
- Arising from this, it would be useful to identify common needs of further research and/or technical development based on current experience, including the results of assessments that have already been made.

- Prognostic assessment methods related to legacies that present common relevant features, such as the nature and extent of contamination are available. However, scope exists to improve assessments and bring them into alignment within a common framework of protection objectives. This would then support the consistent application of the principle of optimization.
- Strategically there is a need to link national strategies for legacy site remediation and waste management, including radioactive waste management.

Noting the above factors, the development of a common methodology for legacy management and regulation would be useful. This should be based firmly on the current international framework, with additional guidance provided on moving from the general framework to address site-specific issues. The development of a road map covering all possible legacy issues may however be difficult and an alternative may be to list the questions that should be addressed and provide qualitative criteria for when actions should be taken, what they should address and how they might be implemented. Practical experience on risk identification and risk management could be provided as examples to support the practical application of the methodology.

Remediation needs to be managed as a stage process and the methodology should reflect that process with a focus on overall optimization that integrates all the stakeholders and responsible organizations, as illustrated in Figure 49.

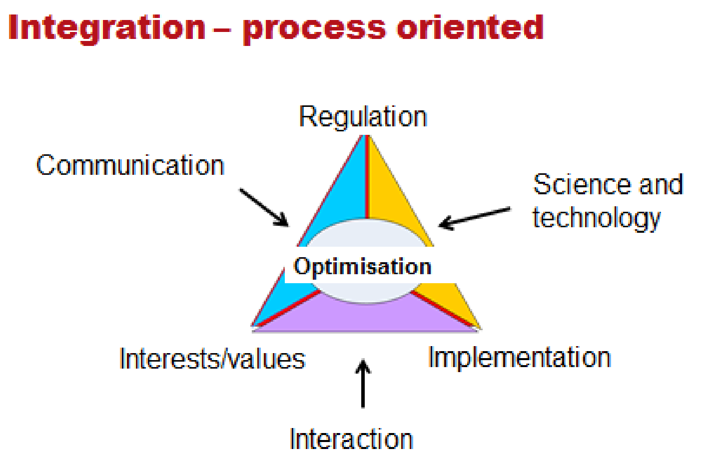


Figure 49. Diagram illustrating the interactions between different functions and factors in an integrated approach to legacy management and regulation

In conclusion, international cooperation plays a vital part in paving the way for legacy sites to be addressed successfully. Discussion of approaches to addressing legacy site issues promotes the sharing of resources, knowledge and lessons learned. This sharing is a key aspect in moving forward.

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Appendix A. List of Participants

The workshop participants and their affiliations are detailed in the following table.

Surname	First name	Organisation	Country
Long	Stephen	Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)	Australia
Proehl	Gerhard	International Atomic Energy Agency (IAEA)	Austria
Riabushkin	Oleksii	ENCO	Austria
Mannaerts	Koen	Federal Agency for Nuclear Control (FANC)	Belgium
Lazo	Edward	Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (NEA)	France
Vaillant	Ludovic	Centre d'Etude de la Protection Nucléaire (CEPN)	France
Koenig	Claudia	University of Hannover	Germany
Hashizume	Haru	Obayashi Corporation	Japan
Higashihara	Tomohiro	Nuclear Regulation Authority of Japan	Japan
Takeda	Seiji	Japan Atomic Energy Agency (JAEA)	Japan
Espeland	Maria Kim	Interpreter	Norway
Frogg	Kristin	Norwegian Radiation Protection Authority (NRPA)	Norway
Harbitz	Ole	Norwegian Radiation Protection Authority (NRPA)	Norway
Holmstrand	Marte	Norwegian Radiation Protection Authority (NRPA)	Norway
Jensen	Louise Kiel	Norwegian Radiation Protection Authority (NRPA)	Norway
Larsen	Stein	Interpreter	Norway
Popic	Jelena	Norwegian Radiation Protection Authority (NRPA)	Norway
Skipperud	Lindis	Norwegian University of Life Sciences (NUMB),	Norway
Sneve	Malgorzata	Norwegian Radiation Protection Authority (NRPA)	Norway
Kiselev	Sergey	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Koloss	Maxim	Embassy of the Russian Federation	Russia
Romanov	Sergei	Southern Urals Biophysics Institute (SUBI)	Russia
Salynkin	Sergey	Federal Medical Biological Agency (FMBA)	Russia
Samoylov	Alexander	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Seregin	Vladimir	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Shandala	Nataliya	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Shcheblanov	Victor	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Shinkarev	Sergey	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Simakov	Anatoly	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Titov	Alexey	Burnasyan Federal Medical Biophysical Centre (FMBC)	Russia
Triapitsyna	Galina	Urals Research Center for Radiation Medicine (URCRM)	Russia
Cabianca	Tiberio	Public Health England (PHE)	UK
Harrison	John	Oxford Brookes University	UK
Smith	Karen	RadEcol Consulting Ltd	UK
Smith	Graham	GMS Abingdon Ltd	UK

Sotnikov	Oleksandr	State Nuclear Regulatory Inspectorate of Ukraine (SNRIU)	Ukraine
Boyd	Michael	U.S. Environmental Protection Agency (US EPA)	USA
Gillen	Daniel	Consultant US Nuclear Regulatory Commission	USA
Norato	Michael	U.S. Nuclear Regulatory Commission (US NRC)	USA
Rood	Arthur	K-Spar Inc	USA
Walker	Stuart	U.S. Environmental Protection Agency (US EPA)	USA
Worthington	Patricia	U.S. Department of Energy (US DOE)	USA

Appendix B. Workshop Programme

17 November 2015

*W*elcome – Ole Harbitz, Director NRPA, Norway

Participant Introductions and Background Presentations

Malgorzata K Sneve, NRPA, Norway

- NRPA Background of International Cooperation on Regulatory Supervision of Legacies

Natalya Shandala, FMBC, Russia

- Regulatory challenges in legacy supervision in Russian Federation

Session 1: Technological and Past Practice Operational Legacies *Chair: Natalya Shandala*

Patricia Worthington, US DOE, USA

- Lessons Learned from the Marshall Islands: A Nuclear Legacy

Stephen Long, ARPANSA, Australia

- Remediation of Contaminated Lands: The Maralinga Experience and Lessons Learned

Sergei Kiselev, FMBC, RF

- Regulatory development and application to address abnormal conditions at Andreeva Bay Site for Temporary Storage of spent fuel and radioactive waste

Session 2: Legacies Following Accidents *Chair: John Harrison*

Hashizume Yoshiharu, Obayashi Corp. Japan

- Cleanup Endeavour after Misfortune at Fukushima NPP – Activities at Work Front

Anatoly Simakov, FMBC, RF

- Regulatory lessons following the accident at the Chernobyl NPP: 30 years after

Seiji Takeda, JAEA, Japan

- Dose estimation for reuse of material contaminated by Fukushima Daiichi NPP Accident

Alexey Titov, FMBC, RF

- Emergency limitation of radionuclide concentrations in foodstuffs: from temporary permissible levels to normal practice

Review of the day's presentations and discussions

18 November 2015

Session 3: Uranium Mining and Processing Legacies *Chair: Ludovic Vaillant*

Michael Norato, US NRC, USA

- Overview of our program for the decommissioning of US uranium mill tailings sites and non-military radium sites

Alexander Sotnikov, SNRIU, Ukraine

- Experience of Ukraine in implementing rehabilitation and decommissioning programs for uranium facilities

Sergei Kiselev, FMBC, RF

- Regulation of uranium legacy in Russian Federation

Dan Gillen, for US NRC, USA

- Criteria, Process, and Technical Approach for Remediation of Uranium Processing Legacy sites in the U.S.A

Session 4: Other Legacies *Chair: Sergey Shinkarev*

Tiberio Cabianca, PHE, UK

- Radiation protection for legacy sites; a prospective from the UK

Koen Mannaerts, FANC, Belgium

- FANC experience dealing with chemical and radionuclides on one legacy site at same time: use of a decision support tool

Stuart Walker, US EPA, USA

- U.S. EPA Superfund Remedial Program's Approach for Risk Harmonization when addressing Chemical and Radioactive Contamination

Jelena Popic, NRPA, Norway

- Regulation of the Norwegian mining legacy

Session 5: Assessments and Communication of Results *Chair: Dan Gillen*

John Harrison, ICRP, PHE, UK

- Application of protection principles to legacy sites in different situations

Sergey Romanov, SUBI, RF

- Application of radiation protection principles to areas affected by historic releases from Mayak PA

Galina Tryapitsyna, UCRCM, RF

- Characteristics of the radiation incident on the Techa River: measures to protect people and the environment

Claudia Kønig, University of Hannover, Germany

- Remediation of radioactive residues: risk communication in practice

Review of the day's presentations and discussions

19 November 2015

Session 6: International Perspectives *Chair: Patricia Worthington*

Mike Boyd, ICRP and US EPA

- Radiation protection and legacy management

Ted Lazo, NEA-OECD

- Existing exposure situations and legacy management

Gerhard Prøhl, IAEA

- IAEA guidance on regulation of legacy sites

Discussion, Conclusions and Recommendations on Meeting Regulatory Challenges

Appendix C. Highlights of Previous Workshops

The following highlights of previous workshops are provided as background material to the current workshop and to consolidate the comments and suggestions made, especially as regards the scope for continued international cooperation in the area.

C1: Emergency Preparedness and Response, with Special Focus on Exercise and Training, Oslo, December 2013, hosted by NRPA

The meeting was designed to consolidate the results of the previous workshops and to discuss Emergency Preparedness and Response (EPR) in a wider forum. Participants included experts from regulatory authorities from Norway, Finland, the RF and the USA. Specific objectives included review of current EPR arrangements and identification of activities to improve them through joint cooperation and exercises.

Several comments and suggestions for joint activities were made including some relating to the regulation of the longer- term consequences of major accident and other incidents, notably:

- Improved training in planning of emergency exercises and reliable methods for evaluation of successful training.
- Improved guidance and training on what information needs to be communicated in relation to implementation of emergency and at later stage countermeasures, to whom, by whom, and how.
- Improved procedures for enhanced notification processes, regionally and internationally to support closer country cooperation in EPR, for actual releases and in pre-cursor situations.
- Sharing underpinning scientific information which supports assessment, which in turn supports decision making on introduction and ending of countermeasures, remediation techniques and waste management.
- Development of an exercise for training in the application of monitoring and assessment information and development of corresponding guidance, in an international context.
- Workshop on justification and selection of later stage mitigation options with focus on how to compare the options.
- Exercises to practice communication processes for each stage of response.
- Decision making in the transition from emergency exposure to existing exposure situation and transition from emergency to intermediate and late stages.

The scope was recognised for international cooperation to address these issues.

C2: Coordination of Regulatory Arrangements for Nuclear and Radiation Emergency Preparedness and Response: Early and Later Phases Analysis, Washington, April 2013, hosted by the US EPA

The key objective of the workshop was the exchange of information on challenges to regulatory authorities and related national agencies in implementing their roles in EPR. Participants included experts from regulatory authorities from Norway, the RF and the USA. Many issues of mutual interest were raised in discussion during the workshop. The critical issues identified were noted as follows, which took account of national experience and also the experience from the accident at the Fukushima Dai-ichi nuclear power plant.

Response Procedures:

- Need to involve and coordinate all national authorities and agencies working in the risk management process within one country, and in the context of accidents with an international dimension.
- International coordination of emergency response. An important issue is to clarify what information needs to be shared in 'early notification', taking account of the differences in national procedures.
- Understanding of the separation of regulatory functions from other functions.
- Dealing with confliction between countermeasures for chemicals, radioactivity and other threats.
- Need to address risk management at all stages of response to nuclear incidents together, not separately.
- Clarification of the boundary between emergency response and recovery, taking into account local conditions and circumstances in making decisions about moving from early to later phases, i.e. emergency to planned or existing situations.
- International guidance from the IAEA and others on application of international recommendations should be extended to be more effective at the national and regional level.

Assets:

- Lack of adequate monitoring equipment and trained staff.
- Development of tools for risk communication which explain patterns of contamination and distribution of doses, and how these map onto social and economic impact, telling people what they want to know and what they need to know.
- Improving arrangements for sharing of resources in a major emergency.

Agency Coordination and Communication:

- How to get people to act upon advice on countermeasures?
- How to stop the unaffected public acting as if they were affected?
- How to convey the issues in non-technical terms?
- How to create credibility?
- Avoid creating confusion with multiple acronyms.
- Language and translation issues.

Scientific Under-pinning:

- Dosimetric monitoring and dose-effect relationships for humans and the environment.
- Conceptual models for dose assessment.
- Quality of data for assessment tools.
- Clarity in results, to support clear decisions.

- Procedures if the information is simply not good enough.
- Confidence in results: avoiding over-caution without putting people at risk, and understanding the consequences of being wrong.

Additional issues:

- Advance regulatory contingency planning is needed to support decision making for remediation, waste management and return to normality.
- Criteria for ending emergency and backing off preparedness, and mechanisms for updating advice in the light of new information.
- Development of long-term trusting relationships among all the organizations involved in ERP with other stakeholders and among countries.
- How to manage the unanticipated? All accidents have unique features.
- Managing the link between safety and security.

Participants agreed that the workshop had provided a major opportunity for sharing information on arrangements in the respective countries for emergency preparedness and response. It also resulted in the identification of several areas for possible future international cooperation.

- Procedures for enhanced notification processes, regionally and internationally to support closer country cooperation in EPR, for actual releases and in pre-cursor situations.
- Sharing underpinning scientific information which supports decision making on introduction and ending of countermeasures, remediation techniques and waste management.
- Sharing legacy site management criteria.
- Exercises to practice communication processes for each stage of response.
- Decision making in the transition from emergency exposure to existing exposure situation and transition from emergency to intermediate and late stages.
- Arrangements for sharing monitoring equipment and trained staff among agencies and among countries.
- Coordination of communication strategies during emergencies, and in explaining arrangements at later stages.

C3: Radioecology and Assessment Research in Support of Regulatory Supervision of Protection of the Environment and Human Health at Legacy Sites, Barcelona 2014

This workshop was held on 6 September 2014, in conjunction with the 3rd International Conference on Radioecology and Environmental Radioactivity (ICRER) in Barcelona, 7 - 12 September 2014. The key objective of the workshop was to exchange and discuss information on the results of projects designed to provide radio-ecological information and wider scientific understanding of remediation options, to support regulatory supervision of legacy sites. A key focus will be the areas affected radiologically by Mayak PA operations and related facilities in the Chelyabinsk oblast. Attendance included a wide range of organizations and presentations were provided on:

- Strategic Issues for Radioecology in Support of Legacy Supervision (Brit Salbu, NMBU, Norway)
- Role of radioecology and radiological impact assessment in the implementation of IAEA Safety Standards on remediation and management of sites affected by enhanced levels of natural or man-made radionuclides (Gerhard Proehl, IAEA)

- Russian National and International Efforts in Nuclear Legacy Regulation (Vladimir Romanov, FMBA of Russia)
- US NRC Research in Environmental Remediation (Stephanie Bush-Goddard, US NRC)
- Derivation of Environmental Reference Values for Uranium in River Water and Sediments (Laureline Fevrier, ISRN, France)
- Dose Estimation on Contaminants by the Fukushima Daiichi NPP Accident (Tadao Tanaka, JAEA, Japan)
- Regulatory Supervision and Assessment of the Radiation Situation at Former Military Technical Bases (Nataliya Shandala and Sergei Kiselev, FMBC of Russia)
- European SOLO Project: Informing Assessments of Radiation Risks at Nuclear Legacy Sites (Joanne Brown, PHE, England)
- Update of US EPA Assessment Methods for Contaminated Sites, (Stuart Walker, US EPA)
- Internal Exposure Levels due to Protracted Exposure to Long-lived Radionuclides in Population Residing in the Vicinity of the Mayak PA Area (Sergey Romanov, SUBI, Russia)
- Characterization of the Current Status of Icthyofauna in the Techa River, (Evgeny A Pryakhin, URCRM, Russia)
- Natural and Anthropogenic Treatment of Surface Water Bodies Contaminated by Radioactive Substances due to Releases from FSUE Mayak PA (Malgorzata Sneve, NRPA and Yuri Mokrov, Mayak PA, Russia)

Regulatory questions and issues identified included:

- Justifying clearance levels for contaminated areas: can an existing situation be eliminated?
- Demonstrating compliance: monitoring – how to do that efficiently and with an appropriate level of confidence?
- Regulations and procedures that work for chemicals and radioactivity at one site.
- Practical interpretation and application of international recommendations at the national and site level.
- Addressing uncertainties in a regulatory context.
- Continuing need for improved regulatory documents (rules and guidance) and procedures to address abnormal conditions at legacy sites.

A complex range of scientific issues was recognized and it was noted that many different disciplines, including radioecology, are involved, involving different environments at different, and even within, sites. It was noted as important to understand the connections between: the radioactive sources terms; the dispersion and distribution of radionuclides in the environment; the potential for radiation exposure; relevant in each case dosimetry and metabolic modelling, and implications for human and environmental health. Within the context of overall legacy management, these aspects might be better considered together and not treated as separate issues. In particular, from a regulatory perspective, there is a continuing need for greater coordination across all four areas, to avoid duplication and share resources to resolve common key issues.

It was suggested that abnormal conditions typically arise legacy sites. These might include the following:

- Previous absence of, or loss of, effective control of radioactive material, such that current standards for radiation and nuclear safety and security are not met, and they therefore should attract the attention of regulatory authorities.

- Non-compliant status of control measures for radiation conditions, including physical containment, as well as institutional measures, e.g. control of access to areas.

It was also noted that new or lost information can come to light, and standards for protection evolve as well as regulation of those standards, so that a site that was previously not a legacy may have to be newly recognised as such.

Distinguishing factors affecting legacy management were recognised as:

- Radionuclides involved in all cases are relatively long-lived, else there is no legacy. However, some legacies are manageable within a socially manageable time-frame without need for off-site disposal, while others require consideration of disposal off-site.
- Some legacies involve large areas and volumes of material, while others are small.
- Large are legacies are not usually highly radiologically hazardous to individuals, but have potential to affect a lot of people; small ones may present a serious hazard, though in that case, only a small number of people is likely to be affected.
- Some involve radioactivity mostly at the surface, which is relatively easy to measure; but some are opposite, or involve radionuclides which are not easy to detect.
- Some involve lots of different radionuclides with different radiative, chemical and physical properties; some, only one or a few radionuclides, which are then easier to analyse.
- Some involve physical and chemical hazards, while others only present a radiological hazard.
- Some have a linked social or political legacy which complicates decision making; some do not.

These factors affect the legacy risks and therefore should comprise the focus of legacy regulation and management, not the cause of the legacy.

Overall conclusions included:

- Regulatory development and application needs continued and enhanced interaction with the science base.
- Not all legacies are the same. The distinguishing features identified in the list above can support the organisation of, and provide the focus to, different research aspects.
- The scope of concerns and preparedness includes not only old legacies, but also the possibility for new ones; future accidents and other events including those related to security concerns.
- There is a need a prompt and effective procedure for response when a potential legacy is reported.
- Environmental Impact Assessments, Safety and Risk Assessments should include consideration of uncertainties. This process will help identify the priorities for scientific research.

C4: Application of Radioecology to Regulation of Nuclear Legacy Management, Bergen 2008

A major “International Conference on Radioecology & Environmental Radioactivity” was held 15–20, June 2008 in Bergen, Norway. In conjunction with the Conference, a workshop titled: “Application of Radioecology to Regulation of Nuclear Legacy Management” was held 14 – 15 June 2008. Representatives of regulatory authorities and technical support organizations from 6 countries took part. The aim was to promote cooperation among all these organizations, and to investigate the challenges in the application of good science within the regulatory process for nuclear legacy management.

- For operational safety, and day to day site management, radiation monitoring can be used directly to confirm compliance with standards. By contrast, for long-term legacy management, it is necessary to rely on an understanding of the site combined with 'assessment models'. Together, these allow us to make prospective assessments of alternative options for site management and plan responses to possible future accidents. There are many complex issues relating to interpretation of radio-ecological data within the context of specific eco-systems, and how they are coupled with engineered features of sites and facilities. Questions arising at the workshop included:
- How do we interpret the measurements for use in the assessments, taking account of the uncertainties?
- Can we learn from the waste repository community, which has been studying the longer term for many years?
- Can we develop a common and documented understanding of the priority issues which deserve further attention to resolve uncertainties?
- Can we do more to share existing information?
- Should there be a wider regulator's forum on nuclear legacy management?

There was a wide range of presentations made at the workshop, offering different perspectives from different countries. These prompted substantial discussion and the following points of consensus emerged.

- Regulatory decisions should be supported by science. However, there are significant uncertainties in scientific information relating to management of emergencies, routine present day situations and long-term site management and waste disposal, all of which are relevant to nuclear legacy management.
- These uncertainties relate to different radionuclides and on different relevant temporal and spatial scales. There is no single solution, but a broad range of scientific and other factors to address.
- Factors associated with large possible impacts that may affect the progress of strategic plans and absorb large resources are clearly more important than those which do not.

It was recommended that regulators should:

- maintain an understanding of the operational strategy;
- make Regulatory Threat Assessments to support regulation of the major hazards;
- maintain regulatory development to provide:
    - adequate and relevant norms and guidance,
    - an efficient regulatory review process, and
    - compliance monitoring;
- maintain an independent Environmental Impact and Risk Assessment capability; and
- be aware of the weaknesses in those assessments and account for uncertainties.

It was suggested that uncertainties can be managed most efficiently through a tiered approach to assessments, as illustratively outlined below:

Tier 1. This involves simple models with limited data requirements and robust, conservative assumptions. They are not resource intensive. If the results suggest that the impacts meet regulator and other requirements, then this is a sufficient level of assessment.

Tier 2. If Tier 1 assessment raises some concerns, then closer analysis of the local situation: source, pathway receptor etc., may be called for. More source and site specific data is required to support more detailed process orientated, dynamic models used in such analysis.

Tier 3. If Tier 2 still raises concerns then site specific measurements and experiments to support the a third Tier of assessments may be necessary, including where appropriate, development of new models. The specific research needs will be identified by uncertainty analysis component of the Tier 2 assessments.

This approach, combined with Threat Assessments, helps to ensure that the research resources are applied to problems which impact most heavily on people and the environment.

Specifically challenging issues identified included:

Responsibility: Regulatory bodies should contribute to their national strategy for legacy management and take account of all the steps in the wider radioactive waste management strategy.

Knowledge Management: The entire community should learn from past events, and maintain records not just for immediate events management but also for the future, and make use of the memory of older or retired staff.

Uncertainties: Knowledge of important uncertainties comes from properly implemented safety assessments. If these assessments have not been done, this becomes the first priority.

Training: We should provide training courses for younger persons to develop the necessary skills. Competence levels in radioecology and other assessment skills need to match needs for managing the legacy, but also to support new developments in nuclear power and other uses of radioactive material.

Regulatory Functions: We should improve the integration of regulatory branches, to support application of the optimization principle and achieve a balanced approach.

Data Resources and Management: It was recommended to:

- make data acquisition and interpretation an integral part of environmental impact and risk assessments; and
- make wider use of data resources at the IAEA and other organizations, such as the International Union of Radioecology (IUR), and provide our own experiences and inputs to such international initiatives.

Coordinated Research: Some of the challenges are very fundamental and very complex, e.g. multi-stressors. The funding for resolving such issues needs combined funding systems, to produce core competence and sufficient resources.

Communication: Better communication strategies are needed to explain: international recommendations, the national policy in each country, the strategy to deliver the policy, what the safety standards mean, and how regulatory supervision is applied to ensure the standards are met. Risks and uncertainties identified by the assessment process need to be better communicated to risk managers and other non-specialist stakeholders.

Sharing Experience: There is a need for improved mechanisms for sharing experience on: data acquisition, site generic data, assessment methods, regulatory processes such as licensing and compliance monitoring, communication etc., for legacy site management. Exchange of information among research groups and with regulators is to be encouraged.

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Årsrapport

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