GUIDE NO. AERB/NRF/SG/RW-9

GOVERNMENT OF INDIA

AERB SAFETY GUIDE

Remediation of Areas Affected by Radioactive Contamination

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDE NO. AERB/NRF/SG/RW-9

Safety Guide

Remediation of Areas Affected by Radioactive Contamination

Atomic Energy Regulatory Board
Mumbai – 400094 India

May 2019

Price ₹…..

Orders for this ‘guide’ should be addressed to:

The Chief Administrative Officer,
Atomic Energy Regulatory Board
Niyamak Bhavan-A
Anushaktinagar
Mumbai - 400 094
India

FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the relevant provisions of the Atomic Energy Act, 1962. In pursuance of the objective of ensuring safety of occupational workers and members of the public, as well as protection of environment, the Atomic Energy Regulatory Board has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety codes, safety standards and related guides and manuals for the purpose. While some of the documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulatory aspects of these facilities.

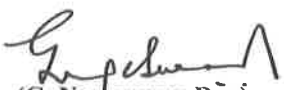
Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific systems, structures, equipment, and components of nuclear and radiation facilities. Safety codes establish the objectives and set minimum requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by Advisory Committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

This safety guide provides guidance for planning and implementing remediation of areas affected by radioactive contamination. It provides guidance for protective and remedial actions that are intended to reduce the existing exposure and to avert potential for the likelihood of such exposure from the related contamination. It addresses the radiation protection criteria, responsibilities of involved organisations / agencies, characterisation and evaluation of affected areas, waste management aspects and criteria for release of remediated area from regulatory control. In drafting this guide, information contained in relevant documents published by the International Atomic Energy Agency (IAEA) under the Basic Safety Standards, Recommendations of the International Commission on Radiological Protection (ICRP 103, 2007) and other international publications have been extensively used. Appendices / Annexure and references are included to provide information that might be helpful to the user.

For aspects not covered in this guide, applicable national and international standards, codes and guides acceptable to AERB should be followed. External dose assessment and industrial safety are not explicitly considered. These aspects are covered in the relevant safety guides.

This safety guide has been prepared by specialists in the field drawn from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Nuclear Power Corporation and other consultants. It has been reviewed by the relevant AERB Advisory Committees on Codes and Guides and the Advisory Committee on Nuclear Safety.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.



(G. Nageswara Rao)
Chairman, AERB

DEFINITIONS

Absorbed Dose

The fundamental dosimetric quantity D is defined as:

$$D = dE / dm$$

where, 'dE' is the mean energy imparted by ionising radiation to the matter in a volume element and 'dm' is the mass of matter in the volume element. The energy can be averaged over any defined volume, the average dose being equal to the total energy imparted in the volume divided by the mass in the volume. The SI unit of absorbed dose is joule/kg ($J.kg^{-1}$), termed the gray (Gy).

Acceptable Limits

Limits acceptable to the regulatory body for radiation exposure under accident (or on potential exposure if they occur).

Accident

Any unintended event, including operating errors, equipment failures or other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

Activity

The quantity 'A' for an amount of radionuclide in a given energy state at a given time is defined as:

$$A = dN/dt$$

where 'dN' is the expectation value of the number of spontaneous nuclear transformations from the given energy state in a time interval 'dt'. The SI unit of activity is the reciprocal of second (s^{-1}), termed the Becquerel (Bq).

ALARA

An acronym for 'As Low As Reasonably Achievable'. A concept meaning that the design and use of sources, and the practices associated therewith, should be such as to ensure that exposures and the probability and magnitude of potential exposures for radiation protection are kept as low as reasonably achievable, with economic and social factors taken into account.

Approval

A type of regulatory consent issued by the Regulatory Body to a proposal.

Assessment

Systematic evaluation of the arrangements, processes, activities and related results for their adequacy and effectiveness in comparison with set criteria.

Atomic Energy Regulatory Board (AERB)

A national authority designated by the Government of India having the legal authority for issuing regulatory consent for various activities related to the nuclear and radiation facility and to perform safety and regulatory functions, including their enforcement for the protection of site personnel, the public and the environment against undue radiation hazards.

Authorised Limit

Limits established or accepted by the Regulatory Body.

Averted dose

The dose prevented or avoided by the application of a protective measure or set of protective measures.

Clearance Levels

A set of values established by the Regulatory Body and expressed in terms of activity concentrations and/or total activity, at or below which sources of radiation may be released from regulatory control.

Committed Effective Dose, E (τ)

The time integral of the whole body effective dose rate following an intake of a radionuclide. The quantity 'E (τ)' is defined as

$$E(\tau) = \Sigma w_T H_T(\tau)$$

where 'H_T (τ)' is the committed equivalent dose to tissue 'T' over the integration time 'τ' and 'w_T' is the tissue weighting factor for tissue T. When 'τ' is not specified, it will be taken to be 50 years for adults and age 70 years for intakes by children.

Conditioning of Waste

The processes that transform waste into a form suitable for handling, transport and/or storage and/or disposal. These may include converting the waste to another form, enclosing the waste in containers and providing additional packaging, if necessary.

Contamination

The presence of radioactive substances in or on a material/the human body or other places in excess of quantities specified by the competent authority.

Controlled Area

A delineated area to which access is controlled and in which specific protection measures and safety provisions are, or could be, required for

(a) controlling normal exposures or preventing the spread of contamination during normal working conditions; and

(b) preventing potential exposures or limiting their extent should they occur.

Decommissioning

The process by which a nuclear or radiation facility is finally taken out of operation in a manner that provides adequate protection to the health and safety of the workers, the public and the environment.

Decontamination

The removal or reduction of contamination by physical or chemical means.

Discharge (Radioactive)

Planned and controlled release of (gaseous or liquid) radioactive material into the environment from nuclear/ radiation facilities.

Disposal (Radioactive Waste)

Emplacement of waste in an appropriate facility without the intention of retrieval.

Documentation

Recorded or pictorial information describing, defining, specifying, reporting or certifying activities, requirements, procedures or results.

Dose

A measure of the radiation absorbed by a target. The quantities termed absorbed dose, organ dose, equivalent dose, effective dose, committed equivalent dose, or committed effective dose are used, depending on the context.

Dose Limit

The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

Effective Dose

The quantity 'E' defined as a summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor:

$$E = \sum W_T.H_T$$

Where 'H_T' is the equivalent dose in tissue 'T' and 'W_T' is the tissue weighting factor for tissue 'T'.

Emergency

A non-routine situation that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment. This includes nuclear and radiological emergencies and conventional emergencies like fires, release of hazardous chemicals, storms, tsunamis or earthquakes. It includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard.

Environment

Everything outside the premises of a facility, including the air, terrain, surface and underground water, flora and fauna.

Equivalent Dose ($H_{T, R}$)

The quantity '$H_{T, R}$' is defined as

$$H_{T, R} = D_{T, R} W_R$$

where '$D_{T,R}$' is the absorbed dose delivered by radiation type 'R' averaged over a tissue or organ 'T' and 'w_R' is the radiation weighing factor for radiation type 'R'. When the radiation field is composed of different radiation types with different values of 'W_R' the equivalent dose is

$$H_T = \sum W_R D_{T, R}. R$$

Exemption

The deliberate omission of a practice, or specified sources within a practice, from regulatory control or from some aspects of regulatory control, by the Regulatory Body on the grounds that the exposures which the practice or sources cause or have the potential to cause are sufficiently low as to be of no regulatory concern.

Exposure

The act or condition of being subject to irradiation. Exposure may be either external (irradiation by sources outside the body) or internal (irradiation by sources inside the body). Exposure can be classified as either normal exposure or potential exposure; occupational, medical or public exposure; and in intervention situations, either emergency exposure or chronic exposure. The term 'exposure' is also used in radiation dosimetry to express the amount of ions produced in air by ionising radiation.

Hazard

Situation or source, which is potentially dangerous for human, society and/or the environment.

Institutional Control (Radioactive Waste)

The process of controlling the radioactive waste site by a national authority or institution designated under the laws of the country. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a nuclear/radiation facility.

Intake

The process of taking radionuclide into the body by inhalation or ingestion, or through the skin, and the amount of given radionuclide taken in during a given period.

Member of the Public

Any individual in the population except one who is subject to occupational or medical exposure. For the purpose of verifying compliance with the annual dose limit for public exposure, the member of the public is the representative individual in the relevant critical group.

Monitoring

The continuous or periodic measurement of parameters for reasons related to the determination, assessment in respect of structure, system or component in a facility or control of radiation.

Near Surface Disposal

Disposal of waste with/without engineered barriers, or below the ground surface with adequate final protection covering to bring the surface dose rate within prescribed limits.

Nuclear Fuel Cycle

All operations associated with the production of nuclear energy, including mining, milling, processing and enrichment of uranium or processing of thorium, manufacture of nuclear fuel, operation of nuclear reactors, reprocessing of irradiated nuclear fuel, decommissioning, and any activity for radioactive waste management and research or development activity related to any of the foregoing.

Off-site Emergency
Accident condition/emergency situation involving excessive release of radioactive materials/hazardous chemicals from the plant to the public domain calling for intervention.

Prescribed Limits

Limits established or accepted by the Regulatory Body.

Projected dose

The dose to be expected if no protective or remedial action is taken.

Quality Assurance (QA)

Planned and systematic actions necessary to provide the confidence that an item, process or service will satisfy given requirements for quality.

Radiation Worker

Any person who is occupationally exposed to radiation, and who in the opinion of the Regulatory Body, should be subjected to radiation surveillance.

Radioactive Material/ Radioactive Substance

Any substance or material, which spontaneously emits radiation in excess of the levels prescribed by notification by the Central Government.

Radioactive Waste

Material, whatever its physical form, left over from practices or interventions for which no further use is foreseen:(a) that contains or is contaminated with radioactive substances and has an activity or activity concentration higher than the level for clearance from regulatory requirements, and(b) exposure to which is not excluded from regulatory control.

Records

Documents, which furnish objective evidence of the quality of items and activities affecting quality. It also includes logging of events and other measurements.

Reference Level

Action level, intervention level, investigation level or recording level established for any of the quantities determined in the practice of radiation protection.

Regulatory Body

(See "Atomic Energy Regulatory Board").

Regulatory Constraints

Restrictions on radiation protection parameters as specified by the Regulatory Body.

Remediation

Any measures that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans. (See also decontamination)

Residual dose

The dose expected to be incurred in the future after implemented protective actions have been terminated (or a decision has been taken not to implement protective actions).

This applies in an existing exposure situation or an emergency exposure situation.

Safety Code

A document stating the basic requirements, which must be fulfilled for particular practices or applications. This is issued under the authority of the Regulatory Body and mandatory to be followed by the respective utilities.

Safety Guide

A document containing detailed guidelines and various procedures/ methodologies to implement the specific parts of a safety code that are acceptable to the Regulatory Body, for regulatory review. This is issued under the authority of Regulatory Body and is of non-mandatory nature.

Safety Manual

A document detailing the various safety aspects/instructions and requirements relating to a particular practice or application that are to be followed by a utility.

Source

Anything that causes radiation exposure, either by emitting ionising radiation or releasing radioactive substances or materials.

Storage (Radioactive Waste)

The placement of radioactive waste in an appropriate facility with the intention of retrieving it at some future time. Hence, waste storage is by definition an interim measure and the term interim storage should not be used.

Supervised Area

Any area not designated as a controlled area but for which occupational exposure conditions are kept under review even though specific protective measures and safety provisions are not normallyneeded.

Surveillance

All planned activities, viz. monitoring, verifying, checking including in-service inspection, functional testing, calibration and performance testing carried out to ensure compliance with specifications established in a facility.

Unrestricted Use

Any release or use of materials, equipment, buildings or site without any restriction imposed by the Regulatory Body

Contents

1. INTRODUCTION

1.1 General

Radioactive contamination of an area may occur due to nuclear or radiological incidents / accidents or activities associated with handling of radioactive materials. Any measure that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans is called ‘remediation’.

Remediation involving cleanup of contamination distributed over wide forest area, agricultural, residential, industrial land and contaminated structures are quite challenging and complex especially following a nuclear accident. Multiple organisations /agencies having varied roles and responsibilities may be involved for the management of remediation activities.. Well defined safety criteria, implementation plans, strategy and procedures facilitate effective implementation of remediation activities. Additionally delineated responsibilities of the involved agencies, availability of resources and effective technologies are equally important. The decisions on remediation should take into account other factors besides radiation protection and in particular the views of those groups of the public that may be affected by the remedial action.

1.2 Objective

The objective of this safety guide is to provide guidance for planning and implementing remediation of areas affected by radioactive contamination. It provides guidance for protective and remedial actions that are intended to reduce the existing exposure and to avert potential for the likelihood of such exposure from the related contamination now and in future. It also gives guidance for minimisation of non-radiological impacts associated with the remediation activities.

1.3 Scope

The scope of the guide includes radiation protection criteria, roles and responsibilities of involved organisations / agencies, characterisation and evaluation of affected areas, waste management aspects and criteria for release of remediated area from regulatory control.

This safety guide is applicable for the remediation of areas affected by radioactive contamination. The term ‘areas’ is used in its broadest sense and could include land, surface & ground waters, residential /industrial site areas and structures thereon. These areas may have been contaminated as a result of, accidental radioactive releases to the environment, nuclear or radiological accidents, nuclear weapon tests, incidents involving releases of radionuclides by users of radioactive material or inadequate practices for radioactive waste management and disposal

It also provides guidance regarding remedial actions such as the removal / reduction of the source of radiation exposure, protective actions involving restriction to access or use of the affected areas including the restrictions on the foodstuffs produced in the affected area. Guidance for radiation monitoring and safety assessment of the contaminated areas at various stages of the remediation programme and the minimization of the adverse impacts associated with these remediation activities is also covered.

In certain situations, non-radiological hazards may be associated with the affected areas or remediation activities. The non-radiological hazards should be assessed in conjunction with radiological hazards to find an optimal remediation strategy. The scope of this safety guide does not include exclusive guidance for assessment of non-radiological hazard. Applicable safety codes and guides of the Regulatory Body should be used for this purpose.

The guidance provided in this document may also be used for clean-up activities of nuclear facility or radiation facility premise during decommissioning. However, guidance for decommissioning of facilities is beyond the scope of this safety guide. Applicable safety codes and guides of the Regulatory Body should be followed in this regard.

2. REGULATORY FRAMEWORK AND RADIATION PROTECTION CRITERIA

2.1 General

The mission of AERB is to ensure that the use of ionizing radiation and nuclear energy in India does not cause undue risk to the people and the environment. The regulatory framework and the radiation protection criteria are evolved from the provisions of:

(i) The Atomic Energy Act.1962
(ii) Atomic Energy (Safe Disposal of Radioactive Wastes) Rules 1987 ; and
(iii) Atomic Energy (Radiation Protection) Rules 2004.

IAEA Basic Safety Standards (GSR Part 3) [1] provides the safety requirements for remediation. The International Commission on Radiological Protection (ICRP) recommends reference levels for emergency and also for existing exposure situation. The reference levels of the existing exposure situation are used as the radiological criteria [2] for remediation of a contaminated environment following a nuclear or radiological accident. The AERB safety codes AERB/NF/SC/RP [3] and AERB/SC/RW [4] provide the regulatory requirements for remediation of a contaminated site. This safety guide takes cognizance of the above.

2.2 Radiological Criteria

The contaminated area may have either short-lived or long-lived radionuclides or combination of both. Radiological survey of the contaminated area should be carried out for its characterization. Based on the initial characterization of the affected area, a detailed inventory of contaminated area should be prepared, This should include the locations, size, extent and properties of the contaminants, environmental characteristics, actual or potentially exposed population distribution and other relevant factors that may affect the remedial activities. The overall objective of remediation is to:

(i) Reduce the radiation doses to individuals or groups of individuals being exposed;
(ii) Avert doses to the individuals or groups of individuals that are likely to arise in the future;
(iii) Minimize the adverse impact of remediation including impact on personnel involved;
(iv) Prevent or reduce spread of contamination of the radionuclides present in the contaminated area; and
(v) Release of areas for restricted or unrestricted use.

Based on the remediation objective, a remediation strategy should be developed. This remediation strategy should consider the:

(i) Environmental monitoring and surveillance data;
(ii) Estimation of projected / actual dose to the public; and
(iii) Evaluation of remediation alternatives.

The scope of remediation should be decided based on the contamination level and

potential of radiological hazard associated with the contaminated area. Remediation should be justified, optimised and graded approach should be followed considering hazard potential of the affected area. The ALARA (As Low As Reasonably Achievable) principle and social aspects should be taken into account while planning and implementation of remediation activities. Based on the potential of radiation exposure to the public and the environment, a graded approach for remediation should be followed considering the application of reference levels.

The responsible organisation / agencies involved in remedial or protective actions should ensure that the practices, measures and duration of remedial actions are optimized. The remedial or protective actions are expected to yield overall benefits to outweigh the associated radiation risk.

2.3 Application of Reference Levels

Reference dose level should be used for screening the potential of radiation exposure and prioritising the need for remediation. The reference levels should be expressed as an annual effective dose to the representative person. The reference levels for radiation exposure in terms of effective dose should be between 1 mSv to 20 mSv per year, for optimisation of remediation [5]. For the long term, remediation should aim to bring down the radiation dose to the representative person to 1 mSv/y (excluding dose due to natural background) in a progressive manner. The public concerned should be informed about the radiation exposure situation of the contaminated areas and also the protective measures needs to be followed for optimising the radiation exposure resulting from the contaminated area. Priority should be given to remediation of those groups of people for whom the dose exceeds the reference level. Areas having contamination / exposure level above 20 mSv/y should be identified and remediated to bring down the radiation exposure to the public and the environment within the reference level. Special attention should be given for remediation of areas having schools / colleges, hospitals, residences, market etc. where members of public, especially the children, have potential of receiving higher radiation exposures.

2.4 Responsibilities of Involved Organisations / Agencies

The licensee is responsible for remediation of on-site environment contamination resulting from nuclear or radiation facilities. The licensee should inform immediately to the Regulatory Body with respect to the onsite or off-site environmental contamination resulting from the licensed facilities. The licensee should also inform the Central / State / Local Government authorities as appropriately in the case of an off-site environmental contamination. The licensee should submit the onsite remediation plan to the Regulatory Body for approval.

The Central / State / Local Government authorities are responsible for the remediation of off-site areas and or identifying the persons or organisations / agencies responsible for remediation. The identified responsible authorities / organisation / agencies should submit the off-site remediation plan to the Regulatory Body for review and necessary regulatory approvals prior to its implementation. The remediation activities of the off-site areas may involve organisations / agencies like NDMA, DDMA, NDRF etc.

The organisations / agencies responsible for remediation should conduct radiological survey of the affected areas through an accredited environmental survey laboratory to ascertain the nature and potential of radiation hazard and further to identify the areas which require remediation and help to prioritise the area according to the potential of contamination hazard. A graded approach should be followed for all remediation activities.

The organisations / agencies responsible for remediation should ensure safe storage / disposal of radioactive waste generated from remediation activities. The criteria for waste management including storage and disposal of radioactive waste generated from the remediation activities should be addressed in the remediation plan. The Central / State / Local Government authorities, as applicable, should provide
designated area for storage / disposal of radioactive waste generated from remediation activities especially in the case for management and disposal of large volume of radioactive wastes.

Radioactive waste having high radionuclide concentration / radiation field should be stored in designated waste storage area with adequate safety measures. The duration of storage and the scheme for final disposal of such waste should be submitted to the Regulatory Body for review and approval. The authorized organisations / agencies should be responsible for radiation monitoring and surveillance of waste storage areas and ensuring safety and security of the stored waste until its disposal.

The Central / State / Local Government authorities as applicable should establish mechanism for providing information to the public about the environmental contamination and radiation safety aspects. The public awareness programme should also include the practices to be followed by the public for optimization of radiation exposure resulting from the affected areas.

2.5 Remediation Plan

Characterisation and safety assessment of the affected area should be carried out prior to designating any areas for remediation purpose. Once the area is designated for remediation, the remediation plan of the designated area should be developed by the responsible organizations / agencies and submitted to the Regulatory Body for approval. The radiological and non-radiological hazards associated with the remedial actions should be assessed and included in the remediation plan. The remediation plan should

address the radiological criteria, reference levels, responsibilities of involved organisations / agencies, radiation protection aspects, waste management / disposal aspects, safety and security of stored waste, end state of remediated area and need for any post remediation monitoring, surveillance and institutional control measures. The remediation plan should include the decision hierarchy / priorities of remediation considering the potential of radiation exposure. Stricter criteria require a more extensive clean-up effort. Options may include access controls, restrictions of individual activities, intervening in food production and food consumption activities / systems and implementing decontamination of inhabited areas and farmland. Non- intrusive and less environmentally disruptive techniques should be used for remediation to the extent possible. Methodologies generally followed for remediation of various environmental contaminations are given in Annexure. The remediation plan should aim for the reduction of radiation dose to the public and environment to an acceptable level at the end of remediation. Typical content of remediation plan is given in Appendix I.

2.6 Radiation Protection of Remediation Workers

All personnel involved in remediation activities should be treated as radiation workers and the radiation dose limit and safety requirements prescribed by the Regulatory Body for radiation workers should be followed. The protection of the workers should be commensurate with the associated radiation risk. Designated Radiological Safety Officer (RSO) should supervise the radiation protection aspects during remediation activities. The radiation dose to the individual involved in remediation activities should be monitored and assessed. The responsible organisations / agencies and the designated RSO should submit periodic report to the Regulatory Body on radiation protection aspects of remediation including doses received by personnel involved in remediation activities. The radiation exposure to the occupational workers during remediation activities should be optimised.

The personnel involved in remediation works should be made familiar with radiation safety aspects, nature of contaminated area, the potential of hazards and the safety procedures for the safe and effective performance of their duties. Adequate training should be given to personnel engaged in remediation activities. The personnel involved in remediation work should use adequate personal protective equipment and follow safety measures.

2.7 Stakeholder's Involvement

All the stakeholders should be involved during the planning and implementation of remediation activities to the extent possible. The involvement of stakeholder fosters positive environment during implementation of remediation activities

Active involvement of stakeholders during the initial phase of remediation helps in the identification of broadly acceptable end-uses of the area (and accordingly the end state), priorities and selection of technologies. Indeed, stakeholders may have a vested interest in retaining certain features and infrastructure elements of affected area. Reuse of

buildings and roads are to be considered in the remediation planning. Stakeholder's involvement from the very beginning may also help to create a sense of 'ownership' in the chosen paths and final uses, thus facilitating the stewardship requirements. Stakeholder's involvement may also facilitate broader awareness of stakeholder perceptions about acceptable and unacceptable end-states for the remediated area

2.8 Safety and Security Aspects

Access control to the affected area should be maintained throughout the remediation activities commensurate with the hazard potential. These measures should be included in the remediation plan. The organisations / agencies responsible for remediation should ensure the safety and security of the waste stored during remediation activities. Necessary barricades, display board / warning sign should be provided in the waste storage / disposal area as necessary.

3. RADIATION MONITORING AND CHARACTERISATION OF AFFECTED AREA

3.1 General

Radiological survey of the affected area is a pre-requisite to initiate any remediation programme. It helps to ascertain the radiological impact on the public and the environment and assists in decision-making process for remediation. Radiation monitoring of the affected area facilitates characterisation and prioritisation of the affected area based on contamination levels and the potential of radiation hazard. Characterization helps to identify the extent of contamination and the features that may assist/ hinder in the remediation process of affected area.

3.2 Environmental Monitoring

The scope of environmental monitoring programme should be commensurate with the potential of contamination level and the associated radiation risk to the public and the environment. The environmental monitoring programme should focus on the measurement of activity levels in various environmental matrices of the affected area. The type, amount and frequency of samples collected and radionuclides measured should be able to assist the decision making process. It should also be representative of the affected area and able to demonstrate the regulatory requirements including reference dose levels.

An accredited environmental survey laboratories should carry out environmental monitoring of the affected area at various stages such as pre remediation, during remediation and post remediation. The objective of pre-remediation environmental monitoring is to ascertain the radiological characteristics of the affected area thereby facilitating the development of a remediation plan. The environmental monitoring programme involves the measurements of ambient radiation and radioactivity levels in air, water, soil, milk and biota (including fodder vegetation). The environmental monitoring programme should also include the assessment of radiation dose to the public from the radioactive contamination of the affected area.

3.3 Characterization and Evaluation

Characterization of affected area is essential to assess the lateral and vertical extent of contamination and threat to groundwater resources, the environment and the public. An area characterization and evaluation report should be submitted to the Regulatory Body along with remediation plan. The characterization and evaluation of the affected area should provide the latest information about the affected area and confirm the need for further evaluation or remediation. The characterisation and evaluation report should address the following:

(i) Nature and extent of radiological contamination and other non-radiological hazards;
(ii) Demographic features;
(iii) Meteorological condition;
(iv) Baseline / natural radiation data;
(v) Identification of receptors;
(vi) Food habits and types of crops/agriculture produce;
(vii) Important exposure pathways;
(viii) Assessment of public dose;
(ix) Options for remediation or alternate;
(x) Suggested remediation technologies and the averted dose;
(xi) Evaluation of environmental, occupational and public health and safety issues expected during remediation; and
(xii) Expected quantity of remediation waste.

Standard monitoring instruments, sampling and measurement techniques should be used for environmental monitoring and characterisation of the affected areas.

3.4 Exposure Pathways

On contamination of the area, the public may get dose from various exposure pathways. The environmental exposure pathways that should be considered for dose evaluation include the following:

(i) External exposure resulting from soil/ sediment/ water contamination
(ii) Internal exposure from;
    (a) Inhalation of re-suspended activity from soil;
    (b) Ingestion of groundwater;
    (c) Ingestion of food items produced from the affected area;
    (d) Ingestion of milk and meat produced from animals grazing the area; and
    (e) Ingestion of fish from the nearby water bodies.

The exposure pathways depend on the characteristics of contaminant and the amount of activity associated, the land / water use, dietary habits and demography. Based on the area characteristics, the important pathways for radiation exposure to the public should be identified and considered for dose evaluation / assessment.

3.5 Public Dose Assessment

Estimation of public dose resulting from the affected area should be carried out for all possible scenarios and important exposure pathways. The areas having potential of radiation exposure above the reference level should be identified and prioritised to facilitate remediation. Approved procedures and standard predictive models should be used for public dose evaluation / assessment [6]. Measured environmental data and area specific parameters should be used for dose assessment to the extent possible. Population distribution and long term radiological impact on the public and the environment should be taken into account for planning and implementation of remediation activities.

3.6 Prioritization of Remediation

The remediation should aim to reduce the radiation dose to the public and the environment taking into account ALARA principle and socio economic aspects. For optimisation of remediation, reference dose levels for existing exposure situation between 1 mSv to 20 mSv per year should be used. For effective implementation of remediation, prioritisation of the affected area should be carried out based on the projected / actual effective dose. To facilitate this, the affected area should be classified into the following groups based on the projected / actual effective dose to the public:

(i) Effective dose > 100 mSv/y;
(ii) Effective dose between 20 to 100 mSv/y; and
(iii) Effective dose between 1 to 20 mSv/y.

The overall objective of remediation is to bring down the radiation dose to the public from the affected area to less than 1 mSv/y (excluding natural background radiation exposure) in a progressive manner with long-term objective. The classification of the contaminated area should be carried out based on the radiological survey data and the dose assessment by accredited environmental laboratories. The prioritisation of the classified area for remediation should consider the population density, use of the contaminated area, measures for averting dose, avertable dose, economic aspects and consideration of social impacts in conjunction with the effective dose to the public.

4. PLANNING AND MANAGEMENT OF REMEDIATION

4.1 General

Remediation of affected area especially in public domain is to be carried out in accordance with the plan approved by the regulatory body. The first step towards this is to identify and evaluate the possible options for remediation considering technical, social and economic aspects. These options may range from partial to complete removal of radioactive contamination from the affected area and release of the remediated area for restricted or unrestricted use.

The nature and type of remediation process may vary depending on specific situations such as contamination levels, size of affected area, nature of area, area topography, population density, approachability, drainage pattern, availability of funds, resources etc. These aspects need due consideration while planning and undertaking remediation.

4.2 Radiological, Non-radiological and Technical Aspects

Various radiological, non-radiological and technical aspects should be taken into account for an effective remediation programme. The organisations / agencies responsible for undertaking the remedial action should consider the following aspects while planning the remediation:

(i) Radiological aspects
   a) Nature of contamination (air/ water/ ground, radio-nuclides involved);
   b) Dose limits and specific reference levels;
   c) Doses to the public and workers implementing the remediation measures;
   d) Avertable doses (individual and collective) to the members of public;
   e) Radiological risks; and
   f) Optimisation of radiation protection;

(ii) Non-radiological aspects
   a) Social disruption arising during and after the implementation of the remedial measures;
   b) Effect on the local produce / market / economy;
   c) Awareness among the public;
   d) Views of interested parties; and
   e) Conventional and non-radiological hazard.

(iii) Technical Aspects
   a) Environmental effects;
   b) Justification and optimisation of remedial measures;
   c) Consideration of all relevant advantages and disadvantages;
   d) Estimated time schedule and results;
   e) Type of machineries and processes required; and
   f) Generation of secondary waste, their collection & transportation and

availability of disposal sites.

4.3 Availability of Funds and Resources

The organizations / agencies responsible for undertaking the remediation should make arrangement for adequate financial, technical and human resource to establish and perform the remediation programme. The cost of remediation and availability of funds/resources for remediation should be addressed in the remediation plan.

4.4 Management Options

The choice of a particular remedial option should be based on the capability to meet the specified remedial objectives. Based on these, the remediation strategy should be developed by considering the following aspects:

(i) Priority to high population density and potential of contamination;
(ii) Characteristics of the affected area;
(iii) Feasibility for imposing control / restrictions over the area (isolating/ boundary marking);
(iv) Inventory and size of the contaminated areas;
(v) Types and properties of the contaminants;
(vi) Consideration of decay of short lived radionuclides;
(vii) Time schedule for undertaking remedial measures;
(viii) Population actually or potentially exposed;
(ix) Radiological impact to human health and the environment;
(x) Awareness among the population;
(xi) Availability of waste disposal / storage facility; and
(xii) Potential effects on neighboring areas.

The criteria and the process used for prioritization of the affected areas should be documented and maintained by the responsible organisations / agencies. If any new area is identified, it should be added to the list and the list of area should be prioritized again and intimated to the Regulatory Body.

4.5 Optimisation

The remedial measures should be optimized by taking account of technical and social aspects so as to obtain an optimized radiation protection and positive societal benefit. Normally, there would be a range of remediation options available which need to be optimised. The following aspects should be considered for optimisation of remediation;

(i) End-state use of the remediated areas;
(ii) Requirements of institutional controls, if any;
(iii) Area characteristics;
(iv) Availability of techniques and feasibility of implementation;
(v) Radiation protection of the workers and the public

(vi) Environmental impact;
(vii) Waste generation and management options;
(viii) Public perception; and
(ix) Information from public.

Options that lead to unrestricted release of the area after meeting the remediation criteria have additional benefit of not requiring institutional control or other regulatory constraints, and so should be favoured. It is recognized that specific features such as topography, size of the area and lack of waste management facilities might limit the feasibility of a remediation option that leads to unrestricted release. Even when the remediation end criteria have been met, some remediation options could involve further restrictions on the use of the area so as to reduce individual and collective doses. Such an option will, however, require institutional control as long as the restrictions are deemed as necessary. Hence feasibility studies of the identified techniques should be carried out by the organisations / agencies responsible for remediation prior to its selection for implementation.

The performance and cost of all remediation options should be assessed and a comparison should be made to determine the optimum option. If this optimum is not obvious, the comparison should be performed using a quantitative decision aiding technique. The optimisation of remedial measures should result in reference levels expressed in terms of a residual activity concentration or dose criteria for the remediated areas.

Remedial measures may remove all of the contamination, or remove only part of it, or may only alter the exposure pathways or reduce the number of people exposed without removing the contamination itself. Depending on the expected residual dose, which can be derived from the expected effectiveness of the proposed remedial measures, associated restrictions should be defined as part of the remediation plan, if necessary. The residual dose, as well as the advantages and disadvantages of the associated restrictions, should be integrated into the optimization process. If the option includes on-site disposal of radioactive waste, the resulting exposure from this disposal option should also be taken into account.

5. IMPLEMENTATION OF REMEDIATION STRATEGIES

5.1 General

Implementation of remediation follows once the regulatory body approves the remediation plan. The implementation of remediation plan is to be carried out by the responsible organisations / agencies within the time frame specified in the remediation plan.

5.2 Remediation Strategies

Strategies for implementation of remediation should be defined and addressed in the remediation plan. The remediation strategy should take into account of the reference dose levels and end-state use of the remediated area. The remediation strategies should also consider the non-radiological hazards to the workers and the public during their implementation.

The remediation plan and strategies should address the end-state use of the remediated area. The unrestricted use or restricted use of the remediated areas including any restriction of access to affected areas should be addressed in the remediation plan and strategies along with timeframe.

5.3 Development of Remediation Plan

A remediation plan should be prepared for the designated area for remediation and got approved by the Regulatory Body prior to its implementation. The plan should demonstrate that the remediation activities can be accomplished safely. Typical content of a remediation plan and various steps to be followed during remediation programme are given in Appendix I and II respectively.

During the planning of remediation, consideration should be given for the size of contaminated areas and the amounts / characteristics of radioactive waste that may be generated from the remediation activities. The quantity and types of waste likely to be generated should be considered during the planning to ensure that the waste management system is adequate of managing the wastes or may have to be augmented accordingly.

The remediation plan and the associated monitoring requirements should be designed and implemented so as to identify the possible effects of contaminants on the public and the environment and thereby optimise protection. The radiation protection of the workers performing the remediation activities, radiation dose to the public and the environment should be taken into account during the development of remediation plan.

The schedule and sequence of the remediation activities; operational data (e.g. instrument readings corresponding to the reference levels); the criteria for the termination of remedial actions; and post- remediation conditions with respect to access

or use of the remediated area should be defined and sequentially addressed in the remediation plan to achieve the desired remediation objective.

The criteria for deciding termination of remedial actions should be clearly defined so that remediation is not unnecessarily continued beyond the point after which it is not justified and optimized. As an integral part of any successful remediation, there should be a clear understanding by the interested parties about the remediation end criteria.

Provisions for the post-remediation state should be addressed in the remediation plan. As remediation progresses, the plan should be updated to reflect any changes or on provisions relating to the conduct, target level of remediation process and progress of the remediation. The changes in remediation plan and strategies should have approval of the Regulatory Body.

The process of designing a remediation plan and strategies should take advantage of lessons learnt from similar remediation projects that have been completed in the past. These lessons provide both positive and cautionary advice. The information on the failure of a particular method of remediation in certain circumstances may help to narrow the choice of feasible remediation strategies when planning new remedial actions. Lessons learnt during the implementation process should also be considered for updating of the plan.

Trained personnel should be used to perform remediation activities. The organisation responsible for remediation should supervise the remediation activities. The organisation / agencies responsible for remediation activities should create adequate awareness among the concerned public by disseminating relevant information.

5.4 Evaluation of Technical Feasibility

Technical feasibility of the identified remediation techniques should be carried out prior to the start of the remediation activities. The technical evaluation should consider the following:

(i) The ability of the technology and associated services to reduce or avert risk to an acceptable level;
(ii) Availability of the technology and associated services;
(iii) Cost for implementing the technology
(iv) The reliability and maintenance requirements of the technology;
(v) Infrastructure available with the organisation to support the technology;
(vi) The environmental impacts of the technology;
(vii) Risk to workers and public safety during the implementation of the technology;
(viii) Public acceptance;
(ix) Organisation structure and trained manpower;
(x) Waste management and disposal aspects;
(xi) Radiation protection aspects and dose consumption;
(xii) Environmental monitoring;

(xiii) Decontamination requirements (mobile/ stationary);
(xiv) Drainage pattern of the affected area;
(xv) Emergency preparedness plan to deal with unforeseen events;
(xvi) Security aspects;
(xvii) Post remediation requirements; and
(xviii) Regulatory requirements and criteria.

5.5 Implementation

Once decision is taken for remediation, the implementation of the remediation activities should be carried out as per the approved plan. Review of the work should be carried out to assess the efficiency and safety of remediation activities. Before undertaking the operation in full scale, a trial run on a limited portion of the affected area may be carried out on pilot scale to demonstrate the effectiveness of plan.

The organisations / agencies responsible for remediation should submit periodic reports to the Regulatory Body at different stages of implementation as defined in the remediation plan. The implementation of remediation activities should aim to achieve the end state as planned. However, if the end state radiation / contamination levels achievable are to be modified due to any reason, it should be done with the approval of Regulatory Body.

5.6 Waste Management

The remediation of contaminated environment may generate large amount of radioactive waste with varying radionuclides concentrations. Generating of radioactive waste during remediation activities should be optimised by selecting suitable waste management options and practices.

The management of radioactive waste should be carried out within the regulatory framework. Approved procedures should be used for pre-disposal management and disposal of radioactive waste. The organisations / agencies responsible for remediation should establish adequate facilities and system for management of radioactive waste and identify / acquire sufficient land for storage / disposal of solid waste. The organisations / agencies should develop waste management scheme / plan in advance considering the following:

(i) Estimated quantity of waste generation;
(ii) Classification, characterisation, categorisation, collection and segregation of radioactive waste based on the radionuclide concentration, radionuclide half-life, surface radiation field of waste package etc.;
(iii) Availability of facilities and options for waste management and disposal;
(iv) Monitoring requirements;
(v) Consideration for re-cycle and re-use of low level radioactive waste;
(vi) Radiological impact on the public and environment, exposure pathways due to storage / disposal of radioactive waste;
(vii) Authorisation for safe storage / disposal of radioactive waste; and

(viii) Safety and security of radioactive waste.

The waste management scheme / plan should have sufficient flexibility to accommodate various types of waste considering the off normal operation / events. The waste management scheme / plan should consider the waste management principles such as:

(i) Dilution and dispersal of low level wastes;
(ii) Delay, decay and dispersal of waste containing short lived radionuclides;
(iii) Concentration and containment of high active wastes containing long-lived radionuclides;
(iv) Compaction of compressible waste;
(v) Controlled incineration of combustible waste; and
(vi) In-situ fixation in suitable matrix.

Segregation of wastes at collection stage should be aimed to ease treatment process. Graded approach should be followed for storage, treatment and disposal of radioactive waste. The criteria specified by the Regulatory Body should be used for exemption or clearance of radioactive waste generated from remediation activities. Any deviation from the exemption or clearance criteria should be carried out with the approval of the Regulatory Body on case-by-case basis.

The potentially active waste generated from the remediation activities should be recycled and re-used to the extent possible. The low active waste may be disposed off to the environment such as natural depressions, excavated trenches, existing excavations, mined cavities etc. Such activity should be performed only after radiological impact assessment confirm that no adverse radiological impact to the public and the environment and also with the approval by the Regulatory Body. The organisations / agencies responsible for remediation and subsequent waste storage/management should ensure the following:

(i) Radiation monitoring;
(ii) Safety surveillance;
(iii) Maintaining records and documents; and
(iv) Provision for transfer of information to future needs.

Management of radioactive waste and residual materials generated from remediation activities should consider the radiological and non-radiological hazards including physical hazards, if any, to the human health and the environment. It should be addressed in the remediation plan.

5.7 Management of Residual Material

The remediation of contaminated area may generate large amounts of residual materials contaminated with various radionuclides. Such residual materials may be generated during the different phases of the remediation process. The clearance for reuse or recycle of residual materials and equipment, if any, from the remediation activities should be carried out in accordance with the clearance criteria established by the Regulatory Body.

6. POST REMEDIATION MANAGEMENT

6.1 General

The post remediation management includes the evaluation of remediated area with specified end-state criteria, post remediation monitoring and surveillance, need of institutional controls and release of remediated area for use based on the regulatory decision considering residual contamination or dose level. The post remediation management plan is important for ensuring compliance with respect to the regulatory requirements and developing confidence of public with respect to remediation activities and radiation safety aspects.

6.2 Evaluation of Remediation Effectiveness

The effectiveness of remediation of a contaminated area should be evaluated based on the residual activity levels and resultant effective dose to the public after completion of the remediation activities. The residual dose to public should be benchmarked with respect to the specified end state criteria and reference dose levels specified for the remediation activities. The evaluation of remediation should consider monitoring data, long-term surveillance requirements and control measures that may be required to be imposed for long-term stability of radiological condition.

6.3 Post Remediation Monitoring

A monitoring and surveillance plan should be prepared for the remediated areas especially where restrictions are maintained after remediation has been completed. The plan should be reviewed periodically based on the monitoring data and modified, if required, with the approval of the Regulatory Body.

The extent of monitoring and surveillance plans of the remediated area should be based on the residual contamination / risk and the need to verify the long-term stability of radiological conditions. The monitoring and surveillance programmes should include, as necessary, the environmental monitoring (dose rates, activity concentrations in soil, water and air, biological indicator species and foodstuffs), whole body monitoring ,if applicable, and dose assessment. The results of the monitoring and surveillance programmes should be documented and made available to the Regulatory Body including interested parties to maintain public confidence.

6.4 Release of Remediated Area

The remediated area may be released for specified use to the general public or to any authorized facilities
/ organisations / agencies after satisfying the regulatory requirements and also considering social aspects. The remediated area may be released for (a) Un-restricted use, (b) Restricted use and (c) Restricted Access as specified by the Regulatory Body. The

monitoring and surveillance should be carried out to confirm the radiological conditions of the remediated area and also to assess the requirement of any additional controls need to be imposed on the remediated area.

(a) Un-restricted Use:

The prevailing radiological conditions of the remediated area are considered to be the residual background conditions for a new practice or for use of the land for habitation. Approval for the release of remediated area for unrestricted use should be obtained from the Regulatory Body on a case-by-case basis considering the residual activity level and radiological impact.

(b) Restricted Use:

Release of remediated area for 'restricted use' implies reliance upon continuing existence and retention of institutional controls. Such 'control' may take the form of signs warning to the public against trespassing or other activities, fencing and imposing of restrictions at local level to prevent and control alternate use of the remediated area. The approval for restricted use of the area should be obtained from the Regulatory Body on a case-by-case basis considering the residual activity level, radiological impact and the proposed use.

(c)Restricted Access:

The term "restricted access" means limited access to contaminated area. Restriction of access to contaminated areas should be determined on the basis of potential of residual contamination level. Depending on the type and levels of residual contamination, access control measures may vary from the placing of warning signs, fencing and restriction of access using guarded control stations. The organisations / agencies responsible for remediation should have adequate administrative authority and power for implementation of access control to the remediated area.

6.5 Long Term Management

The long-term management including monitoring and surveillance required for the remediated areas should be addressed in the final report of remediation. The organisations / agencies responsible for long-term management of the remediated area should be identified and intimated to the Regulatory Body. The responsible organisations / agencies should submit periodic reports to the Regulatory Body with respect to general status and radiological condition of the area.

The organisations / agencies responsible for remediation should have adequate infrastructure and resources for long-term management of the area. They are responsible for implementation of institutional controls and other safety measures stipulated by the Regulatory Body from time to time.

6.6 Removal of Regulatory Control

After completion of remediation, the organizations / agencies responsible for remediation should submit detailed report to the Regulatory Body. The report should address the radiological status of the remediated area, the institution controls and monitoring programme required, if any. The release of remediated area from regulatory control should be done on a case-by-case basis considering residual activity and associated potential hazard. Before removal of regulatory control, ongoing monitoring practices and surveillance programme should be taken into account to assess the long-term effectiveness of remedial measures and the public confidence for the same.

Similarly in considering the long-term effectiveness of remedial measures, the environmental influence of physical, chemical, geological and other factors needs to be evaluated. In particular, contamination of groundwater may not become apparent for some time and may do so at some distance from the source of the contamination. Such considerations and other lessons learned during implementation of the programme should be documented for future reference / use, if any.

7. QUALITY ASSURANCE

7.1 General

Quality Assurance (QA) is necessary to provide adequate confidence and credibility that the basic objectives of remediation are being met. This needs to be established at all stages of remediation e.g. planning, implementation of remediation plan and strategies, storage of radioactive materials, development of criteria and for management of radioactive waste. Implementation of a quality assurance programme (QAP) requires organisational and administrative set up, training of the personnel and adequate quality control (QC).

7.2 Staffing and Training

Adequate and qualified manpower should be available for carrying out remediation work. Appropriate training in radiation protection, radioactive waste management and other operational aspects should be imparted to them before engaging in job. The training programme should include fundamental as well as practical aspects of radiation protection, environmental aspects, waste management, regulatory requirements, quality control aspects and operational procedures relevant to their role in the remediation activities. Refresher training should be provided periodically and/or whenever procedures are revised.

7.3 Organization and Administrative Control

Organisational structure for remediation should provide for sufficient independence of the quality assurance function. The responsibilities and authority of personnel involved in QAP should be delineated. The organisations / agencies responsible for remediation may delegate to other organisations the work of establishing and implementing all or part of the programme, but retain the responsibility for its overall effectiveness, without prejudice to the contractor's obligations and legal responsibilities. The agency performing QA activity should not come under the control of organization / agency actually performing the remediation work. The organisations / agencies should be responsible for the safe operation of all the remediation activities to minimise all radiological and non-radiological hazards and devise strategies and methods to protect the workers, members of the public and environment from any harmful effect.

7.4 Environmental Monitoring Record

The purpose of remediation activities is to bring down the radiological conditions of the affected area to an acceptable level as specified by the Regulatory Body. To facilitate this, an environmental monitoring programme should be implemented. The frequency of environmental monitoring and surveillance should be established based on the nature and type of environmental contamination to meet the requirements set by the Regulatory Body. Approved procedures should be used for environmental monitoring. The facility should implement approved quality assurance programme for sampling, monitoring and

analysis to ensure reliable data. The periodic environmental monitoring and surveillance reports should be submitted to the Regulatory Body for review.

7.5 Dose Assessment Record

The responsible organisation / agencies should establish external and internal radiation monitoring and dose assessment programme including dosimetry services for the workers involved in remediation activities. Appropriate and adequate number of dose monitoring/assessment instruments should be available for measurement of radiation exposure. Approved methods and procedures should be used for assessment of both external and internal exposures.

Dose records must be kept up-to-date and procedures should be established to ensure that dose assessments for any monitoring period reaches the individual's dose records promptly. These records must be made available to the worker, Regulatory Body and National Occupational Dose Registry System (NODRS) at DAE. The retention period of records should be as specified by the Regulatory Body.

7.6 Reporting and Documentation

The responsible organisation / agencies should maintain appropriate documentation on various aspects of remediation activities. These should be updated and reviewed periodically. Appropriate information should be communicated to the Regulatory Body and other relevant agencies. Documents should be easily identifiable, retrievable and should include time periods for which the relevant information is recorded.

The following records should be maintained by the organisations / agencies responsible for remediation:

(i) Approved remediation plan and procedures;
(ii) Affected area plan and methods of remediation adopted;
(iii) Records on inventory of waste generated, it's characteristics and data pertaining to its storage, treatment and disposal;
(iv) Environmental monitoring data;
(v) Personnel exposure related data;
(vi) Data pertaining to training and qualification of the personnel involved;
(vii) Data pertaining to QA and QC related checks;
(viii) Reporting of death or serious injury, if any;
(ix) Completion report of remediation activities;
(x) Photographs showing affected area before and after remediation work;
(xi) Approval from the Regulatory Body for releasing the remediated area for restricted/ unrestricted use;
(xii) Specifications of any areas that remain restricted and restrictions that apply;
(xiii) Approval/authorisation for storage/transfer/disposal of radioactive waste; and
(xiv) Statements of lessons learnt during the remediation.

Organisations/ agencies responsible for remediation should have the responsibility for the retention of records and their maintenance in multiple retrievable forms/places. Mechanism should be established for transfer of information about the remediated area for future use. Security during retention and disposal of these records should be ensured.

Appendix-I

TYPICAL CONTENT OF REMEDIATION PLAN

Sr. No	Information to be Furnished	
A.	**Name and address of the organisations / agencies applying for remediation**	
B.	**General Description**	
1	Name and Address of the facility from where environmental contamination originated	
2	Brief description, date and time of the accident / event resulting in environmental contamination	
	Scope and objective of remediation	
3	Estimation of activity releases / disposal	Gaseous route (Bq)
		Liquid route(Bq)
		Terrestrial route (Bq)
4.	Location of the affected area	
5.	Size of the affected area	
C.	**Characterization of affected area**	
1.	Type of terrain, soil/ rock/ water body	
2.	Hydrogeological characteristics (Type of aquifer and its extent, groundwater depth, velocity, direction, details of ground water utilization, water table fluctuations with season etc.)	
3.	Total population	
4.	Population density	
5.	Nature of area utilization by public	
6.	Details of cultivable land	
7.	Industries, markets, educational institutions, roads & alternate roads, hospitals etc.	
8.	Water reservoirs	
9.	Vegetation, milk and other produce	

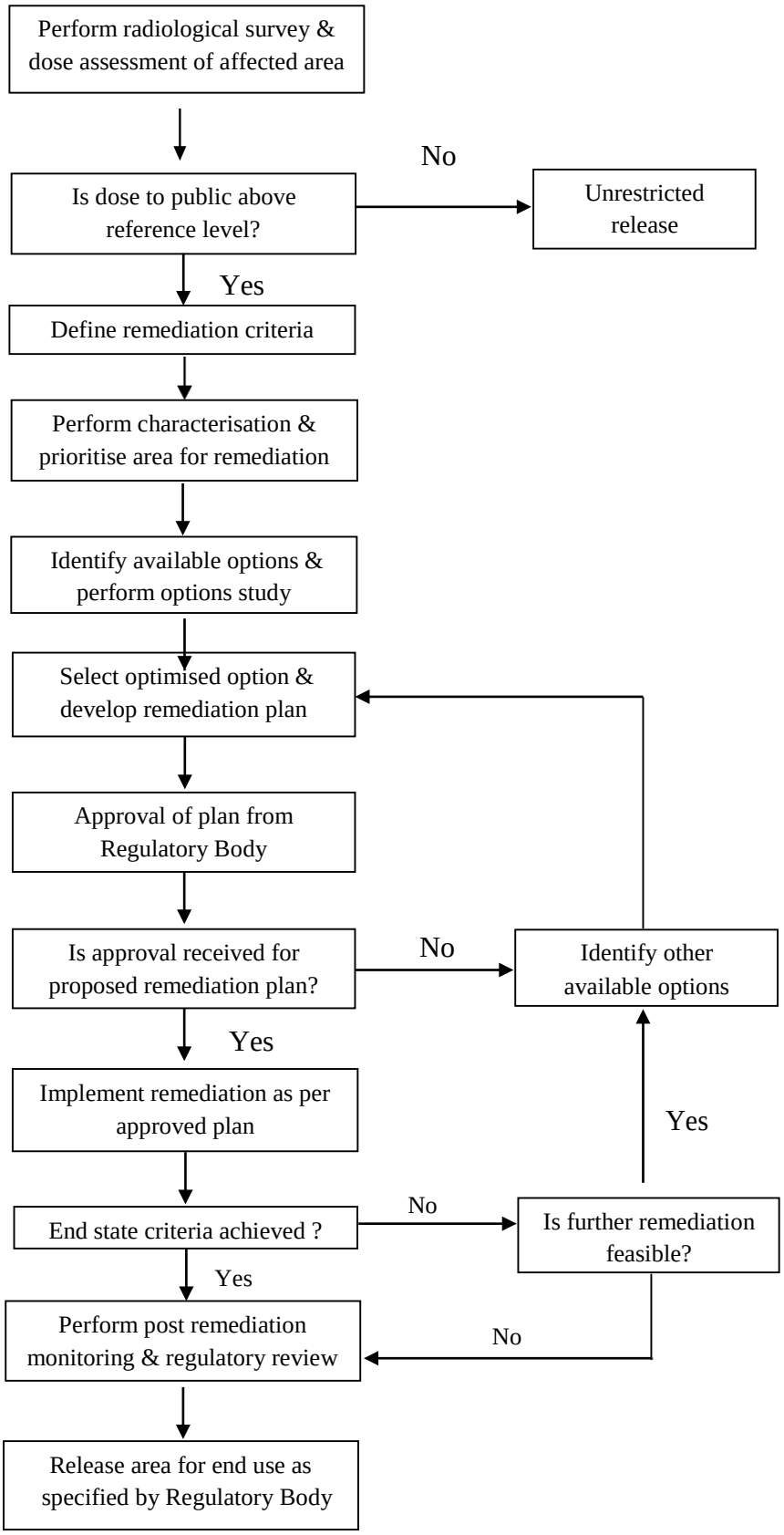
10.	General meteorological condition	
11.	Wind speed and direction	
12.	Air temperature	
13.	Air humidity and precipitation	
14.	Rainfall	
D.	**Radiological Characterization of affected area**	
1.	Important radionuclides present	
2.	Background radiation level before the incident/ accident	
3.	Radiation field after the incident/ accident (dose rate at contact surface/ at 1 metre distance)	
4.	Total (Bq) and Specific activity(Bq/g or Bq/ml) of each radio-nuclides	
5.	Physicochemical characteristics of radionuclides	
6.	Area affected (m^2) having actual or projected effective dose to the public.	≥ 100 mSv/y
		20 to 100 mSv/y
		1 to 20 mSv/y
7.	Characterization and prioritization of affected area based on contamination level	
E.	**Dose assessment for member of public in affected area**	
1.	Effective dose to public (mSv/y)	
2.	External exposure dose (mSv/y)	a. Plume shine
		b. Ground shine
3.	Internal exposure dose(mSv/y)	a. Inhalation of re-suspended activity from soil
		b. Ingestion of ground water
		c. Ingestion of food items produced from affected area
		d. Ingestion of milk and meat produced from animals grazing the area
		e. Other, if any

F.	Description of remediation plan	
1.	Available remediation options and the avertable dose	
2.	Best suitable remediation option identified and the avertable dose (with reason):	
	Detailed plan of action for the proposed remediation option: - Man power - Major machineries - Protective wears - Temporary power supply - Vehicles - Decontamination equipment - Estimated fund and resources	
3.	Estimated time schedule for remediation	
4.	Organisations / Agencies identified for carrying out remediation activities including their roles and responsibilities	
5.	Alternate arrangement planned till the completion of remediation activity	
6.	Estimated dose for carrying out remediation	a. Collective dose(mSv/y)
		b. Average individual dose(mSv/y)
		c. Maximum dose to an individual (mSv/y)
7.	Management plan for waste generated during remediation	a. Estimated volume and category of total waste generation (m^3) Solid: Liquid: Gaseous:
		b. Estimated activity of total waste generation (MBq) Solid: Liquid: Gaseous:
		c. Treatment process planned in-situ/ other place
		d. Estimated volume of waste to be disposed (m^3) Solid: Liquid: Gaseous:
		e. Estimated activity of waste to be disposed (MBq) Solid:

		Liquid: Gaseous:
		f. Location for waste disposal and types of waste disposal modules
		g. Planning for waste storage and types of waste storage modules
		h. Volume and activity of waste to be stored Solid: Liquid:
		i. Location for waste storage
		j. Security arrangements for waste storage
		k. Impact on persons involved in the remediation
		l. Steps to prevent spread of contamination during remediation process
8.	Management plan for residual materials	
G. Description of end state		
1.	Predicted activity concentration in soil, water body and other material after remediation	
2.	Predicted annual effective dose to member of public after remediation	
3.	End state of the affected area	Restricted use
		Unrestricted use
H. Post remediation management		
1.	Post remediation environmental monitoring and surveillance plan	
2.	Frequency of monitoring and surveillance	a. Land
		b. Water body
		c. Air atmosphere

Appendix II

STEPS TO BE FOLLOWED DURING REMEDIATION PROGRAMME

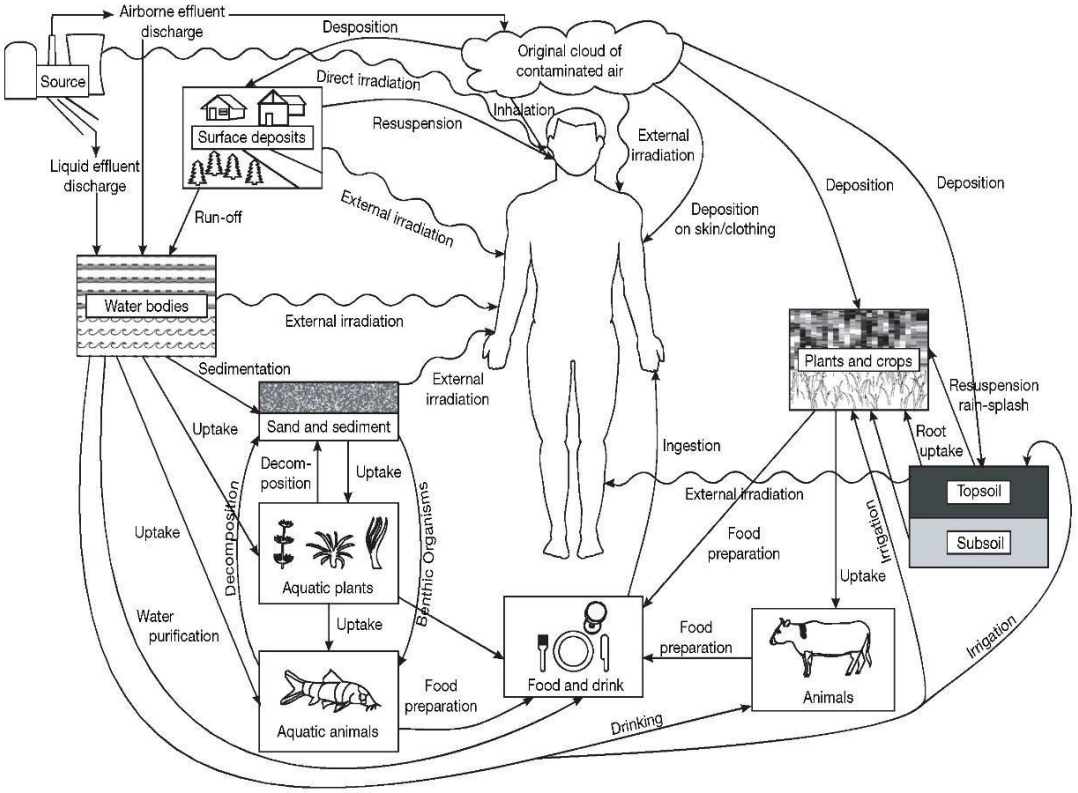


Annexure

METHODOLOGIES FOR REMEDIATION OF RADIOACTIVE CONTAMINATED AREAS

1. Introduction

An area may be contaminated with radioactive materials due to nuclear or radiological accident or activities associated with handling of radioactive materials. Radiation exposure of human from contaminated areas may occur in different pathways and can be either due to external radiation from contaminated surface / land or internal radiation by intake of contaminated plant and animal food items produced in that areas. The possible pathways of exposure to the members of public as a result of radioactive material discharges to the environment are given below [7];



Radiation exposure of human from contaminated areas can be prevented or minimised by taking different remedial measures. Remedial measures are largely designed to reduce ingestion doses from the consumption of contaminated foodstuffs and drinking water, external doses from surfaces contaminated by deposited radionuclides and inhalation doses from re-suspended material. A large number of remediation options have been developed especially since the Chernobyl and Fukushima events. Some of the remediation options are listed below [8].

2. General applicable options

The following are the general remediation options that may be applicable irrespective of type of contaminated area depending upon the other factors such as feasibility, cost, demography and social aspects.

Topsoil removal or replacement: Top portion of the contaminated land retains most of the radionuclides as it acts as a sorbing media. A few centimeter of topsoil removal by using graders, bulldozers, frontend loaders, excavators and scrapers or a turf harvester may be good remediation option. The removal of much of the contamination at the surface will greatly reduce radionuclide uptake by plant roots, external exposure and resuspension of radionuclides from the soil. The removal of the surface layer forms a large volume of contaminated waste and needs special attention for management and disposal. Treatment process of such soil depends on its specific activity and volume.

Covering the area by a layer of a clean material: A layer of a clean material like soil, sand, clay, rubble, asphalt, concrete etc. over the contaminated surface will reduce external exposure, radionuclide resuspension and lateral migration of radionuclides. Effectiveness of the measures will depend upon the characteristics of the material used, water permeability, radionuclide activity concentration in the clean covering materials, rooting depths of different crops etc.

Phyto-extraction: Phyto-extraction, also called phyto-accumulation, refers to the uptake of metals from soil by plant roots into aboveground portions of plants. Certain plants, called hyper accumulators, absorb unusually large amounts of metals in comparison to other plants. After the plants have been allowed to grow for some time, they are harvested and either incinerated or composted. This procedure may be repeated, as necessary, to bring soil contaminant levels down to allowable limits. Metals such as nickel, zinc, and copper are preferably removed by phyto-extraction because the majority of the approximately 400 known plants t absorb unusually large amounts of metals with high affinity for accumulating these metals.

In situ leaching to remove radionuclides: In situ biological and chemical leaching techniques may be applied for remediation of contaminated land, trees or building structures. In situ leaching may include washing, flotation, chemical extraction and bio leaching. Requirement of specialised equipment, large amount of leaching substance and high amount of secondary waste generation are the drawbacks of this process.

Processing of food items: Ways of processing of food items may also reduce the activity concentration. There are many ways to process crops, vegetables, milks, meats and other food product to reduce radionuclide activity concentrations. Washing, peeling, fermentation, distillation, blanching and canning of vegetables and crops may reduce activity concentration of many radionuclides in the foodstuff. Processing raw milk into butter and cream can reduce the activity concentrations of

radiocaesium and radio strontium. Boiling and pickling wet, and soaking in salt (salting) or acid solution (marinating) are the most effective types of meat or fish flesh processing. Removal of bones from meats will reduce radio strontium intake. However, degradation of food quality and nutrition value in processed food is a major problem in this process.

3. Agricultural System

Human obtain most of the food from agricultural food chain. Agricultural workers and the public may be exposed to external and internal radiation from the contaminated fields, agriculture produce or animal products. Therefore, the remediation of agricultural areas may be based on management of soil, crop, fodder production and animal. Soils constitute the main long-term reservoir of radionuclides in terrestrial ecosystems. In view of this, remediation strategies are mostly aimed to decrease the incorporation of radionuclides into the food chain through uptake from the soil by plants. Such remediation methodologies are applied at the soil scale, aiming to modify the soil parameters that affect radionuclide mobility.

Ploughing: Mechanical ploughing can decrease radionuclides concentration in the rooting zone by a dilution effect by mixing the contaminated topsoil layer with deeper soil layers, which have lower radionuclide content. Ploughing also has positive effect in remediation to minimise radiation dose by dilution of radionuclides in rooting zone, decrease in the re-suspension of contaminated soil and decrease of external dose to the agricultural worker. Effectiveness of ploughing in dose reduction depends on the type of soil, type of crops, extent of ploughing etc. The external dose may be reduced by a factor of 2 to 20 with the complete inversion of soil.

There may be the side effects of ploughing. Deep ploughing may (i) substantially change the landscape;
(ii) cause changes in the physical characteristics of the soil and in the structure of the surface horizons, such as enhanced mineralization of organic matter and changes in nutrient status resulting in decrease in fertility of the agricultural land etc.

Application of lime to arable soils: Liming of soil is part of conventional agricultural practice and applied as an ameliorant to soils with a low pH or low Ca status. But application of lime is also effective for reduction of both radiocaesium and radio strontium concentration in crops if used, as part of a remediation strategy. Lime ($CaCO_3$) can be applied in a variety of different forms including dolomite powder, calcareous tuffs and marlstone. Liming may reduce ^{90}Sr and ^{137}Cs transfer to farm products by a factor of 2 to 4 and 1.5 to 4 respectively, depending on factors, such as original soil pH, CEC (Cation Exchange Capacity) and calcium status, hydrological regime of the soil, productivity and type of crops. Side effects of liming are that it can change soil nutrient status and soil microbiology, potentially leading to associated changes in flora and fauna diversity.

Application of organic materials to arable soils: Organic materials are normally

applied to soils with a low organic content and of light granulometric texture. Organic material applied may be of different origins and may include manure, straw and plant derived fertilizers peat and sapropel (bottom sediments in natural lakes).Organic fertilizers increase plant production by enhancing the nutrient and microelement content of treated soils which result in decrease in concentration of radionuclides in crops. The application of organic materials may reduce ^{90}Sr, ^{60}Co and ^{137}Cs transfer to plants by a factor of 1.3 to 3 depending on plant and soil properties.

Application of mineral sorbent to arable soils: Mineral sorbents added to soil enhance the sorption capacity of the soil Sorbent used for remediation of contaminated land should have a much higher sorption capacity for the target radionuclide than that of untreated soils. Bentonites, palygorskite, zeolites etc. can be used as sorbents, as these materials have a high sorption affinity for h certain radionuclides. Radiocaesium transfer to crops can be reduced up to 2.5 fold depending on the soil texture by adding mineral sorbents. However, application of mineral sorbents can change the nutrient status and ultimately fertility of agricultural lands.

Application of mineral fertilizers: Application of mineral fertilizers as a remedial option involves a change in both ratio and application rates of the individual elements (i.e. N, P and K) in the NPK mix applied on contaminated land. As potassium is a chemical analogue for cesium, its application in elevated rates can reduce the accumulation of radiocaesium in crops. Application of phosphates can reduce radio strontium availability to plants because strontium phosphate is relatively insoluble. However, increasing N application can increase radiocaesium and radio strontium transfer to crops due to soil acidification.

Selection of crops with lower accumulation of radionuclides: Different crops have different rates of accumulation of radionuclides due to differences in metabolic and biochemical mechanisms of radionuclide uptake by plants. Therefore, crops with lower rate of accumulation of specific radionuclide present in the contaminated agricultural land can be used. Rate of accumulation of cesium and strontium can vary up to 100 times for different crops.

Management of animals: Animal's food products are important sources of internal dose in many circumstances. Internal exposure can be minimised by reducing radionuclides concentration in milk, meats and other animal food products. Thus one of the options is clean feeding of animals i.e. providing uncontaminated or low levels of contaminated feed to the animals. Other option in animal management could be changing the slaughter time to a season of the year when the contamination level is at its lowest, administration of additives to animal feed to minimise gut uptake by animals (for example administration

of stable Cs to prevent absorption of radiocaesium and administration of calcium to prevent absorption of radio strontium), administration of prussian blue to reduce gut uptake of radiocaesium by livestock, administration of alginates to reduce the transfer of ingested radio strontium to milk by binding it to tissue can be adopted.

4. Aquatic ecosystems

Aquatic ecosystems include lakes, rivers, groundwater and marine waters etc. The main exposure pathways from aquatic sources are from their use as drinking water supplies, for irrigation and as a source of aquatic foodstuffs. Contaminated water bodies may also lead to external exposure from contaminated bottom sediments but, due to self-shielding provided by water, the exposure is often relatively low. Intervention in aquatic systems resulting in reduction of exposure to general population includes reducing contamination reaching the water body, altering the water chemistry to reduce uptake of radionuclides by the aquatic species, diluting the water body with additional water supply etc. Different options available for remediation of radioactively contaminated water body are as follows:

Addition of lime**:** There is considerable experience in application of lime in relation to acidification. Radiocaesium and radio strontium uptake of freshwater fish can be reduced by lime. Effectiveness of this process depends on initial Ca concentration, pH, total P concentration, amount and type of Ca applied, and water retention time. This process is more effective in water bodies with long water retention time.

Addition of potassium**:** By adding potassium to water, the radiocaesium activity concentration in freshwater species may be reduced by chemical dilution as potassium is chemically similar to cesium. Effectiveness of this process also depends on the water chemistry and amount of potassium addition and retention time of water. A two to three fold reduction in radiocaesium activity concentration in fish can be achieved by increasing concentration of potassium by factor of 10 in water.

Construction of dykes or barriers**:** Long term decrease in radionuclide transfer to rivers or lakes can be achieved by construction of dykes or barriers between rivers and floodplains by preventing the remobilization and runoff of contaminants. However, dyke construction is not effective for areas highly prone to flooding. Seepage of contaminants through water cannot be prevented by this method.

5. Forest ecosystems

Human usually use forest areas for forestry, grazing livestock, recreation and as source of wild food. External exposure may occur from the forest floor and contaminated trees, handling of contaminated forestry material and industrial production using contaminated wood. General public may receive internal exposure from inhalation of radionuclides following forest fires or combustion of contaminated wood but more common source is due to consumption of forest foods. Only a few effective and practical remedial measures are available that can be carried out in forest ecosystems.

Forest soil treatment with fertilizer**:** Similar to agricultural area remediation, addition of NPK or only PK fertilizer reduces radionuclides uptake by forest trees. However, the effectiveness of this process is highly area specific and a typical reduction factors of 1.5–2 can be achieved.

Modification of tree felling schedules**:** Changes in the timing of tree harvesting and intermediate felling may be remediation options to minimise dose from forest ecosystems. For mature or nearly mature trees, early felling, soon after the time of contamination is the most suitable while delayed felling is the most suitable for young trees reaching maturity after about 20 years of contamination. Effectiveness of this process depends on type of radionuclides, their activity concentrations, age of trees, productivity, forest soil characteristics etc. Other available remediation options are selective harvesting to avoid the most contaminated wild foods and wood, preventing fires in forest areas, control on use of wood ash etc.

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LIST OF PARTICIPANTS

EXPERT COMMITTEE FOR DEVELOPMENT OF SAFETY GUIDE FOR REMEDIATION OF AREAS AFFECTED BY RADIOACTIVE CONTAMINATION

Dates of meeting: November 27 & 28, 2014
April 9 & 10, 2015
August 20 &21, 2015
September 14 & 15, 2017
March 15, 2019

Members and Invitees of Expert Committee:

Shri K.K. Chandraker (Chairman)	:	AERB(Former)
Shri S.A. Hussain	:	AERB(Former)
Shri M. Ramasomayajulu	:	NPCIL
Dr. P.M. Ravi	:	BARC
Dr. Ravi Ranjan Rakesh	:	BARC
Dr.(Smt). Kitheri Joseph	:	IGCAR
Shri R.Ananda Narayanan	:	NPCIL
Shri J.P.N. Pandey	:	BARC
Dr.P.Vijayan (Member Secretary)	:	AERB
Shri Vikas Shukla (Invitee)	:	AERB
Shri Nishikant Tyagi (Invitee)	:	AERB
Shri Haradhan Ghosh(Invitee)	:	AERB
Shri Ashish Jaiswal (Invitee)	:	AERB

ADVISORY COMMITTEE ON NUCLEAR SAFETY (ACNS)

Dates of meeting: March 6 & 7,2014

Members and Invitees of ACNS :

Dr.Baldev Raj (Chairman)	:	IGCAR (Former)
Shri S.A. Bhardwaj	:	NPCIL (Former)
Shri K.K. Vaze	:	BARC (Former)
Shri S.G. Ghadge	:	NPCIL
Shri Rajnish Prakash	:	HWB
Dr. P. Chellapandi	:	IGCAR
Dr. D.N. Sharma	:	BARC
Prof. J.B. Doshi	:	IIT, Bombay (Former)
Shri R. Bhattacharya	:	AERB
Shri A.J. Gaikwad	:	AERB
Shri S.A. Hussain	:	AERB
Shri K. Srivasista (Member-Secretary)	:	AERB

ADVISORY COMMITTEE ON NUCLEAR AND RADIATION SAFETY (ACNRS)

Dates of meeting: July 8, 2017

Members and Invitees of the committee:

Shri S. S. Bajaj	Chairman	Former Chairman, AERB
Shri D. K. Shukla	Member	Chairman, SARCOP, AERB
Dr. N. Ramamoorthy	Member	Chairman, SARCAR, AERB
Dr. M. R. Iyer	Member	Former Head, RSSD, BARC
Shri U. C. Muktibodh	Member	Director (T), NPCIL
Shri V. Rajan Babu	Member	Director (T), BHAVINI
Prof. C.V. R. Murthy	Member	Director, IIT, Jodhpur
Shri H. S. Kushwaha	Member	Former Director, HS&E Group, BARC
Shri K. K. Vaze	Member	Former Director, RD&D Group, BARC
Shri S. K. Ghosh	Member	Former Director, CE Group, BARC
Dr. S. C. Chetal	Member	Former Director, IGCAR
Shri A. R. Sundararajan	Member	Former Director, RSD, AERB
Dr. A. N. Nandakumar	Member	Former Head, RSD, AERB
Shri S. T. Swamy	Member- Secretary	Head, RDS, R&DD, AERB, Mumbai