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Planning for Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1991

PLANNING FOR CLEANUP OF LARGE AREAS CONTAMINATED AS A RESULT OF A NUCLEAR ACCIDENT

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FOREWORD

During the last thirty years, the development of commercial nuclear power and its supporting nuclear fuel cycle facilities has in general been associated with an excellent record of nuclear safety. All nuclear facilities are sited, designed, constructed, operated and decommissioned according to strict requirements and regulations to protect the environment and ensure the safety of the workers and the public. In spite of all precautions, the possibility of an accident which results in the release of unacceptable amounts of radioactive material or unacceptable exposures cannot be excluded. Therefore, it is desirable to plan in advance for emergency action to protect both the facility personnel and the public.

The IAEA has published general guidance and recommendations on emergency planning and preparedness for situations where an accident at a nuclear plant may involve the need for off-site remedial action and the implementation of protective measures. The present report is the second of three IAEA publications dealing with the cleanup of large areas contaminated as a result of a nuclear accident. Technical Reports Series No. 300, which is the first publication, gives an integrated overview of the methods, techniques and equipment available to characterize the radioactive fallout, clean up contaminated urban, rural and forested areas and stabilize the deposited contamination. The subject of the third report (to be published) is the transport and disposal of contaminated material arising from the cleanup of large areas.

This report, which is mainly a planning and management document, outlines the broad strategic and tactical approach to cleanup, the management structure and other key requirements. It also shows how the various subplans interface and interact to ensure that cleanup can be performed safely, efficiently and as quickly as possible under adverse conditions.

At a Technical Committee Meeting (TCM) in Vienna on 12–16 December 1988, 22 experts from 14 Member States discussed and revised a preliminary report on the subject by consultants B. Legrand (France) and R. Meyer (United States of America) and the IAEA Scientific Secretary, M.A. Feraday of the Division of Nuclear Fuel Cycle and Waste Management. After the meeting, the report was revised by the IAEA Secretariat and the final report approved by the participants of the TCM.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

The IAEA and the International Commission on Radiological Protection (ICRP) have published general guidance and recommendations on emergency planning and preparedness for situations where an accident at a nuclear power plant may involve the need for off-site remedial actions and the implementation of protective measures [1–4]. Protective measures that could be implemented to protect the public in the event of an accident at a nuclear facility which results in the release of significant amounts of radioactive material are shown in Table I and range from the sheltering of people to the decontamination of lands and buildings. The implementation of these protective measures involves cost, inconvenience and risk to the public and the workers, so the hazard or social cost associated with a remedial measure should be justified by the resulting reduction in risk [4, 5]. Any intervention will be appropriate only if the resulting detriment to health and social life is less than that resulting from further radiation exposures.

One of the protective measures which could be implemented in the intermediate phase (days to weeks after the accident) and the late phase (several weeks to years) is the cleanup of large areas. The purpose of cleanup is eventually to return an area to unrestricted use, but this would be a step by step process. The strategy employed would depend upon the type of accident, as well as other factors such as the original population density, geography and use of the surrounding area. In certain cases, the radioactive material deposited on the ground could represent the main long term radiological consequence to the population if it is not cleaned up. In the Union of Soviet Socialist Republics, the contribution of this external exposure from the Chernobyl accident is expected to rise from 53% in the years following the accident to 60% of the total dose commitment [6]. Therefore, it would seem prudent that some preliminary planning be done for the cleanup of large areas in countries having nuclear facilities which could release unacceptable amounts of radioactive material in the event of an accident.

The term 'cleanup' includes processes that will reduce the potential doses to people such that the area could be reused, and so embraces decontamination, stabilization or isolation of contamination, and transport and disposal of the wastes arising from the cleanup. Decontamination is the removal of radioactive contaminants with the objective of reducing the residual radioactivity level in or on materials or persons or in the environment. Decontamination can occur as a result of actions by humans or as a result of natural processes such as precipitation. Stabilization of the radioactivity means fixing it in some manner so that it is no longer a detriment to the environment, for example by incorporating the radionuclides into an insoluble compound. The radioactivity could be isolated by covering it with a layer of clean material such as concrete or soil, or by deep ploughing to remove the contamination

TABLE I. APPLICABILITY OF PROTECTIVE MEASURES [3]

Protective measure	Phase		
	Early	Intermediate	Late
Sheltering	**	*	—
Radioprotective prophylaxis	**	*	—
Control of access and egress	**	**	*
Evacuation	**	**	—
Personal protective methods	*	*	—
Decontamination of persons	*	*	*
Medical care	*	**	*
Diversion of food and water supplies	*	**	**
Use of stored animal feed	**	**	**
Decontamination of areas	—	*	**

Note: The protective measure of removing domestic animals in the food chain from pasture and putting them on stored animal feed is not an immediate protective measure beneficial to humans; nevertheless, if the situation warrants, the earlier the animals are put on stored feed the greater may be the dose savings at a later point when animal products begin to enter the food chain.

** Applicable and possibly essential.

* Applicable.

— Not applicable or of limited application.

from the upper layer of soil. Also, there may be subregions within the affected area where alternatives to cleanup, such as 'do nothing' or interdiction of the area, would be preferable.

An IAEA report [7] provides an integrated overview of the important methods and equipment available to clean up large areas contaminated as a result of a nuclear accident. The report includes information on the methods and equipment available to characterize the radioactive fallout, clean up contaminated urban, rural and forested areas and stabilize the deposited contamination, as well as a brief discussion on the transport and disposal of the wastes. Considerable information on these topics is available as a result of: cleanup operations carried out at atomic weapons test sites and uranium tailings piles; decontamination activities at nuclear facilities during decommissioning; research related to these topics; etc. The report also includes some generic information on the planning and management considerations for such a cleanup.

The successful implementation, control and completion of such a large scale cleanup require good planning and co-ordination among all subprogrammes and the overall operational plan. The subprogrammes cover items such as the radiological survey plan, data management and laboratory support [7].

The operational plan for cleanup, the topic of this report, outlines the broad strategic and tactical approach to cleanup, the management structure and other key requirements. This plan would be developed by the Cleanup Director under the supervision of the Emergency Director (Section 4), who is responsible for planning and co-ordinating all activities associated with the emergency and for implementing the required protective measures (Table I). The cleanup plan also shows how the various subplans interface and interact to ensure that cleanup can be performed safely, efficiently and as quickly as possible under adverse conditions. Such planning should minimize the detriment to the workers.

If such an operational plan is not available, significant delays and incorrect actions could cause increases in the cleanup costs and the total occupational dose commitment. For example, application of incorrect cleanup procedures could result in contamination being adsorbed onto surfaces and thus more difficult to remove or cause increases in contamination in adjacent water systems or areas. If the throughput of the analytical laboratories is not matched to the expected field sample output, delays in cleanup could occur and equipment and cleanup teams could stand idle awaiting sample results which confirm compliance with cleanup criteria. Also, if the data collection and management system and the geographical co-ordinate grid system are not properly designed and interfaced, changes in contamination levels at selected points would be difficult to validate.

The basic components of an operational plan for the cleanup of large areas are not significantly different from those required to clean up any area contaminated with radioactivity. However, the planning, interaction of subplans and co-ordination of effort for the cleanup of large areas should be very well developed to minimize the costs of such a cleanup and reduce potential impacts to the environment and society as quickly as possible. In addition, such a cleanup should be closely integrated with other planned emergency actions.

2. PURPOSE

The purpose of this publication is to give guidance to those who are responsible for the protection of the public in the event of an accident at a nuclear facility which results in serious off-site radioactive contamination. This guidance relates specifically to the advance preparation of emergency response plans related to the implementation and management of the cleanup of contaminated areas and is intended to ensure that such plans are integrated with the Overall Emergency Plan [1].

The information presented herein should also be useful in planning the cleanup of areas contaminated with non-radioactive toxic chemicals.

3. SCOPE

The operational plan for cleanup outlines the required management structure and shows how to ensure that the subplans are properly interfaced and backed up adequately by other subplans. The guidance in this publication is based on a consideration of conditions which could prevail if a nuclear facility were to have an accident resulting in contamination of surrounding areas. It is directed to the management of cleanup activities within the area which has been declared by the Emergency Director to be a restricted zone and thus not suitable for public use. It is assumed that:

(a) The public has been evacuated from the affected area.
(b) An assessment of the contaminated areas by the emergency response organization indicates that measures should be taken to prevent the spread of contamination and to reduce doses to acceptable levels.

The report does not deal with planning related to the cleanup of areas contaminated by the dispersion of radioactive particles resulting from the destruction of a nuclear powered satellite as it re-enters the Earth's atmosphere. Such an accident could result in the distribution of radioactive particles and components over many thousands of square kilometres. Although the methods and techniques described in Ref. [7] would be applicable, the planning and implementation could be considerably different than for an accident at a nuclear facility.

The report is mainly a planning and management document. The equipment and methods available to implement the plan are reviewed in Ref. [7]. However, a brief review of cleanup methodology and technology is given in Appendix A.

The report presents: an example of an operational plan for cleanup, showing the interfaces and interactions between various subplans; and a possible management structure for cleanup, showing how it could interface with the Overall Emergency Plan.

It is beyond the scope of this report to give complete details of an operational plan since the cleanup after an accident would be site and accident specific. Nor does the report give values for the derived intervention levels (DILs) required to initiate the cleanup of an area, cleanup criteria needed by cleanup teams, or criteria for the final release for restricted or unrestricted use of all or part of the affected area. These criteria are the responsibility of the competent national authorities. However, the IAEA and other international organizations give guidance on some of these problems. For example, Ref. [8] outlines the principles required to calculate DILs, and Ref. [9] examines the factors which should be considered in establishing final release criteria for contaminated areas.

4. RESPONSIBILITIES FOR EMERGENCY PLANNING AND MANAGEMENT

References [1–4] give guidance on the preparations required for emergencies at nuclear plants and outline the responsibilities and required actions of the regulatory body, public authorities and operating organization. Three emergency plans are defined:

Overall Emergency Plan: This applies to a specific nuclear site and covers activities planned to be carried out by all authorities and organizations involved in the case of an emergency leading to, or likely to lead to, a significant release of radioactivity beyond the site boundary. It includes the co-ordinated emergency plans of the operating organization (licensee) and the public authorities (see below).

Operating Organization Emergency Plan: This covers activities planned to be carried out by or under the responsibility of the operating organization in the case of an emergency.

Public Authorities' Emergency Plan: This covers activities planned to be carried out by or under the responsibility of public authorities in the case of an emergency.

The actions taken off-site, including the cleanup of contaminated areas, are the responsibility of the public authorities. The public authorities are those agencies (other than the regulatory body) of national, regional and local government that have jurisdiction in the area in which the nuclear facility is located [1]. They are usually responsible for: protecting public health and the environment; providing public protection (e.g. fire services and civil defence) and medical and social services; and enforcing the law. Within their general responsibilities, public authorities accept specific responsibility for:

— Preparing and updating an emergency plan,
— Establishing and supporting an emergency organization,
— Implementing emergency measures in accordance with the plan,
— Organizing emergency exercises and ensuring proper training and constant readiness of all persons and equipment involved,
— Giving information and instruction to the public as deemed necessary when an accident has occurred.

In view of the technical capability and immediate availability of site personnel and other specialist organizations, public authorities may choose to delegate to these groups certain off-site responsibilities, for example provision of technical advice. If they do, the transfer of responsibility should be regulated by precise legal directives agreed by both parties and drawn up in advance. Although this delegation of authority may be desirable for certain plant locations, there may also be certain disadvantages which should be taken into account in preparing specific emergency plans [1].

In an off-site emergency situation, certain protective measures that may be necessary or desirable require a legal basis to be effective and to avoid later difficulties. In establishing the Overall Emergency Plan, the public authorities should consider in advance, and to the extent possible resolve (by legislation if necessary), the legal problems arising from actions such as:

(a) Requesting or ordering members of the public to take shelter indoors, stay there or evacuate the area;
(b) Offering radioprotective prophylactic drugs (e.g. potassium iodate or iodide) to members of the public;
(c) Efforts to ensure, by seizure, storage or purchase, that contaminated agricultural products and other foods are not used;
(d) Commandeering services;
(e) Closing down public and private facilities (e.g. transportation and industrial plants) in an affected or potentially affected area.

The effectiveness of the emergency measures designed to mitigate the off-site effects of a serious accident at a nuclear facility depends on: the adequacy of the preliminary planning and preparations; the availability of suitable staff, equipment and facilities to carry out the required tasks; and how well the management organization implements and manages the activities required to meet the emergency situation.

Guidance is available to assist authorities in planning for emergencies at nuclear power plants [1–5]. The authorities responsible for planning should put particular emphasis on the management structure and in particular designate one uniquely qualified person, with an appropriate number of specifically nominated substitutes, to have executive authority for directing the public authorities' emergency organization.

With respect to overall direction and control of the emergency organization, three alternatives have been defined [1]: separate Emergency Directors for the public authorities and the operating organization; an officer of the operating organization designated as Overall Emergency Director; or an officer of one of the public authorities designated as Overall Emergency Director.

It would be desirable to have one person to head the entire emergency operation. Such an Emergency Director should have the political, administrative and legal power to control all personnel associated with the response to the emergency. This person should also have the trained personnel, facilities and equipment to implement and control the protective measures deemed necessary to mitigate the effects of the nuclear emergency.

Examples of the duties for which emergency personnel, equipment and facilities should be available to assist the Emergency Director include:

(1) Advice on radiation protection and safety.
(2) Emergency radiological monitoring for the initial assessment, ongoing sampling and recording, and plotting and assessment of results.
(3) Emergency communications for off-site emergency warning, alarm, instruction and control messages to preselected groups (for example, see Fig. 1). To be effective, an emergency communications office should be established close to the Emergency Co-ordination Centre, where telephone, radio and teleprinter messages can be sent and received and where additional equipment and staff can be installed for effective recording and routing of messages.
(4) Public advice, treatment, care and control.
(5) Analysis of radiological samples.
(6) Data management: a separate office should be set up for this function (see Section 6).
(7) Public relations to organize the dissemination of information to national and local authorities, the public and the media and respond to inquiries. The office should have access to experts in public relations, psychology, radiation protection and safety, and medicine as well as a direct line to the Emergency Co-ordination Centre.

This provides only a partial list of the functions, personnel, equipment and facilities described in documents related to the Public Authorities' Emergency Plan [1]. The items described above are, to a large extent, those of interest to the organization responsible for cleanup of contaminated areas if this type of protective measure is implemented. Since the cleanup team is part of the overall emergency organization, some of the items described above could be used by both organizations provided that such sharing does not impede operational efficiency.

5. PLANNING AND MANAGING THE CLEANUP

5.1. INTRODUCTION

To ensure that the protective measures listed in Table I can be quickly and efficiently implemented to mitigate the adverse effects of an accident at a nuclear facility requires good planning, clear strategies and a good managerial team.

As outlined in Ref. [7], preparations for the cleanup should, if possible, be done in two phases: preliminary planning, which should be done as part of normal

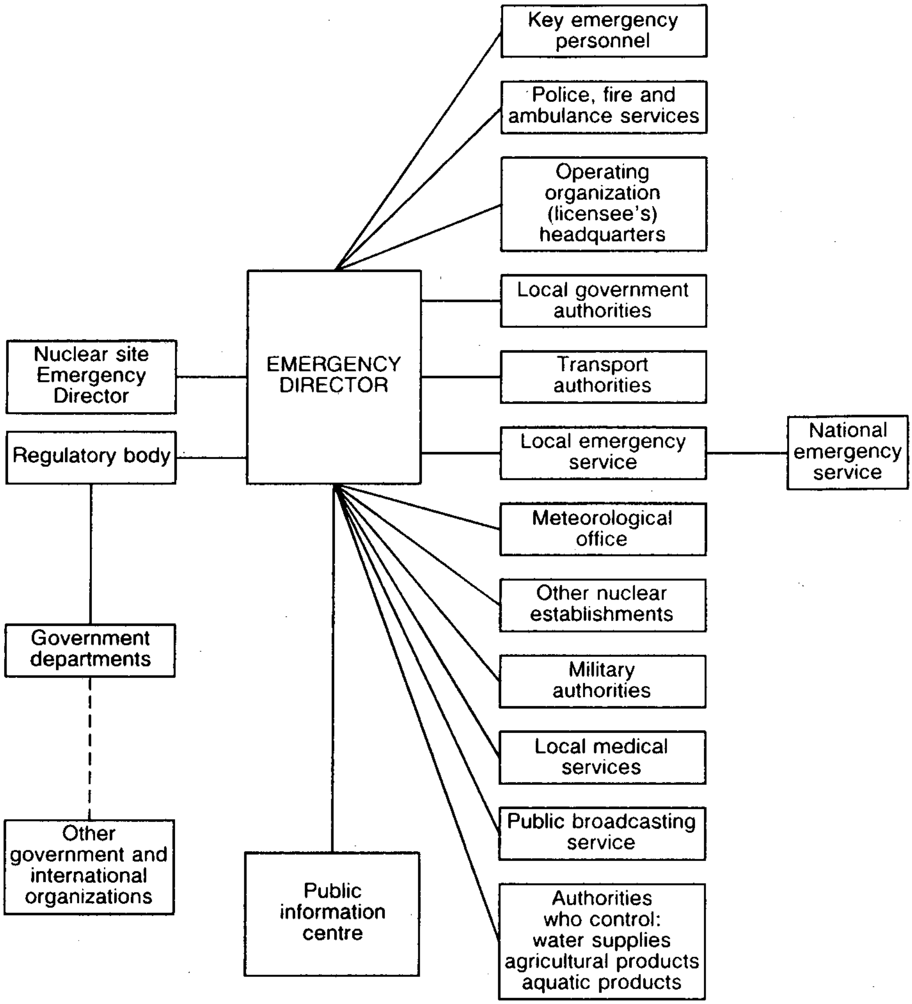


FIG. 1. Example of an off-site warning, alarm, instruction and communication plan network for an emergency at a nuclear facility.

emergency preparedness for each major nuclear facility; and detailed planning, which is initiated at the onset of the accident and takes into account site and accident specific information. The two types of planning are complementary and both are important in minimizing the detriment to society from serious accidents.

The first step in planning is to delineate clearly the overall and local strategies as well as the tactics which are required to achieve specific objectives. Strategy is defined as the science and art of conducting a campaign on a broad scale. A tactic is a manoeuvre to achieve an objective.

For example, the Emergency Director and associated staff would develop the overall strategy required to manage the emergency at a particular facility and to implement those protective measures which might be deemed necessary. The Cleanup Director and staff would, under the supervision of the Emergency Director, define the broad strategy for cleanup and clearly define the key decisions required for such a strategy, e.g. first actions, identification of critical facilities in the area, and division of zones. In addition, the Cleanup Director would establish the broad tactics required to achieve selected objectives. The various cleanup team leaders would, under the supervision of the Cleanup Director, develop the strategic plans required to achieve zonal objectives.

To implement the tactical plans successfully, the cleanup teams for each zone should be fully aware of the equipment and methods which have proved effective in the past and are available locally. They should then decide which are most applicable for their particular situation. The equipment and methods available to clean up areas are reviewed in Ref. [7] and are briefly summarized in Appendix A.

In the following sections, one example of a management structure for cleanup is presented along with some discussion on specific strategies and tactics. These are given only as examples to assist Member States in developing their own country specific approaches to such cleanups.

5.2. MANAGEMENT STRUCTURE FOR CLEANUP

Reference [1] outlines the types of advisers and other staff required by the Emergency Director. Although a senior adviser on cleanup of off-site areas is not included in Ref. [1] as part of the public authorities' emergency organization, it is strongly recommended that such an expert be included in the organization at all stages of planning, whether or not such a cleanup is finally implemented. The reasons for having such an adviser as a senior member of the emergency organization are as follows:

— The adviser on cleanup can direct the development of preliminary cleanup plans and ensure that they are updated as required. Since the adviser would be under the direct supervision of the Emergency Director, the cleanup plan would be fully integrated into overall emergency planning.
— For serious accidents the implementation of cleanup actions could be required within days or weeks of the accident, especially if large urban areas are affected or if urgent remedial actions are required. For example, the spraying of stabilizing solutions may be required to prevent the further spread of contamination.
— The cost of such a cleanup could be enormous. The cost and detriment can be significantly reduced by implementation of an appropriate technical plan developed with full knowledge of actions planned by other parts of the emergency organization.

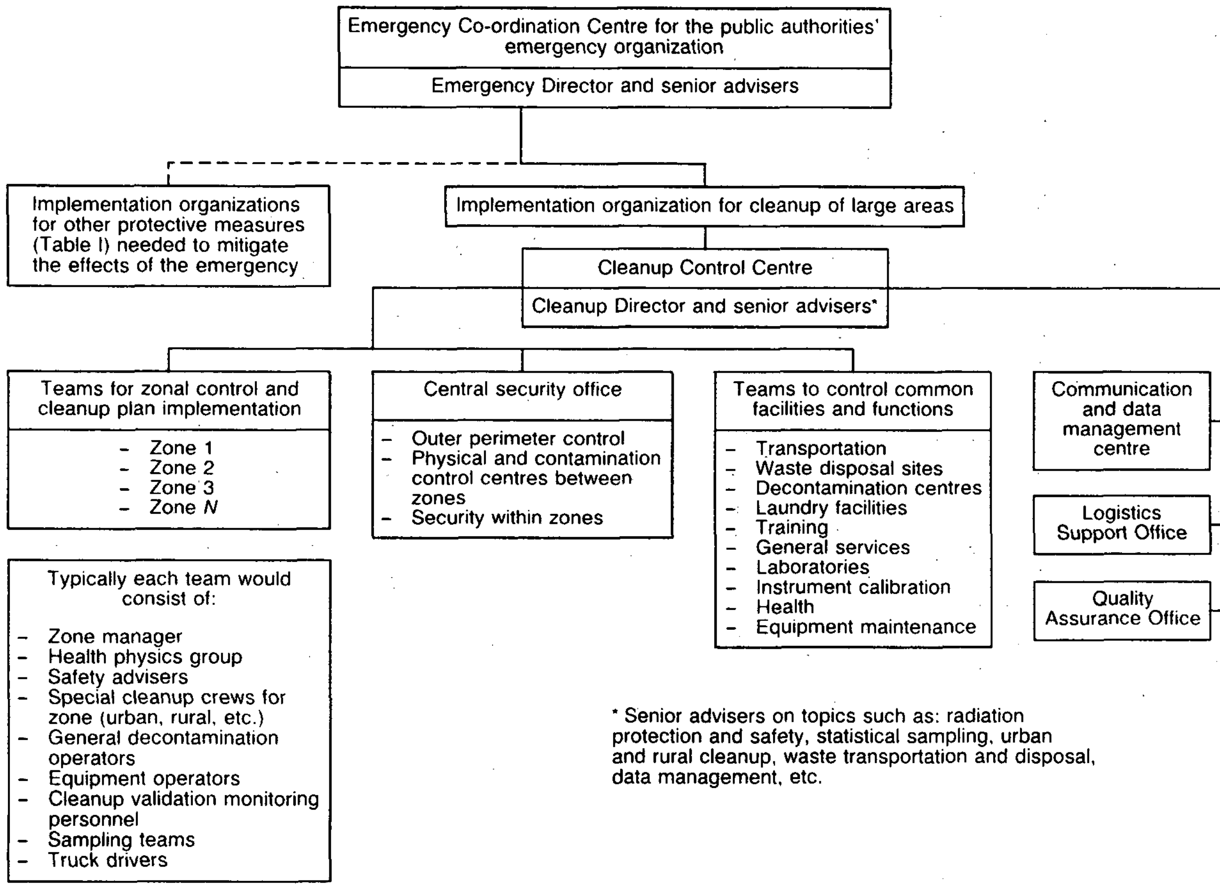


FIG. 2. Management structure for cleanup of contaminated areas.

If the Emergency Director implements large scale cleanup activities, a specific cleanup management team would probably be set up in its own control centre, especially if these activities are likely to continue for long periods. The management team, consisting of the Cleanup Director assisted by suitable advisers (Fig. 2), would plan and implement necessary actions under the general supervision of the Emergency Director.

The Cleanup Control Centre should possess or have access to items such as [7]:

— Information on topics such as the local geology, climate, hydrology, type of land use and agriculture, and type of urban development.
— Information on the kinds of equipment available locally and nationally which could be of use in a cleanup operation.
— Maps or displays showing the current status of the radioactive contamination levels in the defined zones.
— Maps showing information such as control checkpoints, decontamination centres, status of the cleanup, transportation routes and disposal areas.
— A reliable radio and telephone communication system.
— Access to a central data management and computer facility for data acquisition, analysis, plotting and recording. The data management system could be used to calculate, record and assess radiological survey data and occupational doses, the location and status of major equipment, waste transportation data, the location and status of disposal sites, etc. (see Section 6).

If the cleanup continues for many months, the public authorities' emergency organization may revert to its normal stand-by status and some of its responsibilities may be transferred to the cleanup organization. These responsibilities could include: control of the communication network (Fig. 1); public relations; information flow to local and national authorities, the public and the media; enforcement of zonal control; liaison with other organizations such as the police, public health authorities and the facility owner; and assessment of doses to the public. During the first few months of the emergency, central control and co-ordination of these responsibilities would probably be with the Emergency Director to minimize confusion.

To implement and control the cleanup operations, the Cleanup Director would require extensive support services (Fig. 2), each of which would be under the direction of a manager reporting directly to the Cleanup Control Centre. These services would include:

— A logistics support team which supplies the required material, equipment and staff and has control over essential services such as power and water supplies.
— A quality assurance organization which is responsible for all quality assurance and quality control functions (see Section 11).
— Field teams for zonal control and cleanup plan implementation. Each team should consist of a zone manager and enough special personnel and equipment

to clean up the zone in a safe and efficient manner. The make-up of a team could be as shown in Fig. 2. The teams should all include radiation protection staff.

— A central security organization which could be responsible for: security within and at the perimeter of the affected area; controlling the movement of personnel and equipment between zones; and the interaction between zones.
— Teams for the control and operation of common facilities such as waste disposal or storage sites, decontamination centres and medical services, and for the co-ordination of common functions such as transportation.

The above description of a cleanup organization is only for illustrative purposes. The exact organizational structure, the number of field teams and their make-up would vary considerably depending on factors such as site and accident specific conditions, the scale of the accident, availability of trained staff and equipment, local infrastructure and urgency of cleanup.

5.3. CLEANUP STRATEGIES AND TACTICS

As discussed in Section 5.1, the Cleanup Director and advisers, under the supervision of the Emergency Director, would define the strategies and tactics required to implement and successfully complete the cleanup of a contaminated area.

This section briefly outlines some of the important factors which should be considered by the Cleanup Director in defining the overall strategy for cleanup as well as the strategies and tactics related to zones and generic types of areas, e.g. the nuclear facility site, urban areas and forests.

5.3.1. Overall strategy

In defining the overall cleanup strategy and the major tactical decisions required to implement cleanup successfully, the Cleanup Director should consider a wide variety of factors and determine:

(a) Which actions should be taken as soon as the accident is brought under control. These could include:
   — Spraying the area with rapidly polymerizing solutions to fix the dust and minimize the windborne spread of contamination. This was one of the first actions taken at Chernobyl in 1986 after the accident had been brought under control.
   — The diversion of surface water and groundwater streams around the damaged facility.
   — The construction of diversion ditches and dykes to direct badly contaminated water to holding areas to minimize further contamination of water bodies close to the facility.

By defining these possible first actions during preliminary planning, the Cleanup Director reduces the possibility that the actions would be overlooked during the hectic time immediately after the accident. Depending on the accident and site, not all of these actions might be used or it may turn out that other 'first actions' are required.

(b) Which areas are to be cleaned up and which are to be interdicted.

(c) Whether cleanup should be started immediately or delayed to take advantage of decay and natural decontamination effects.

(d) The logical subdivisions into which the contaminated area should be divided for cleanup and control (Section 5.4).

(e) The location and required number of essential facilities such as storage and disposal facilities for solid wastes, storage and treatment areas for liquid wastes, and the Cleanup Control Centre.

Many options are available for the design and siting of facilities for the disposal of large volumes of low level radioactive wastes [7, 10]. Designs include trenches, ring dyke or valley impoundments and large engineered mounds. The disposal or storage facilities could, for example, be located in an area in Zone 2 (Section 5.4) since there would probably be limited access to this zone for many years. The reader is referred to Ref. [10] for further information on these topics.

(f) Which existing facilities should receive first cleanup priority in the whole area, for example essential services such as electrical production and distribution systems, communication networks, water treatment and distribution systems for fire fighting purposes and facilities which could be seriously damaged by unplanned or long term shutdown.

(g) The best method for interfacing between different subzones and cleanup teams and for transferring people and equipment from zone to zone.

(h) Which cleanup criteria should be used.

5.3.2. Strategies and tactics for zones

Within the overall strategy for cleanup defined by the Cleanup Director, each zone manager should determine a specific strategy to carry out the cleanup and control of the zone for which he or she is responsible. Since the development of detailed zonal cleanup strategies is very site specific, the following comments are quite general and may not apply in all cases. The zone manager should decide on items such as:

— The make-up of the cleanup team;
— The general direction of cleanup in the zone;
— The main access roads and transportation corridors, which should be kept reasonably clean and open;

— General categories for priority decontamination within the zone (Table II);
— Cleanup strategies for the land classes or land uses in the zone;
— The duration of cleanup — this would depend on the availability of suitable staff and equipment, the number of people evacuated, the value of the real estate, the level of contamination, etc.;
— The location of the Zone Control Centre;
— The best means of co-ordinating and controlling the personnel, teams, data flow, etc.

In defining the overall strategy, the Cleanup Director could designate the nuclear facility site, urban areas, rural areas, forests or aquatic systems as separate cleanup zones or, alternatively, include them as parts of larger zones. Regardless of which approach is taken, each of these special types of area has unique characteristics which should be taken into account by the zone manager when establishing the cleanup strategy and tactics.

For the nuclear facility site, the first sequence of actions, apart from the general actions listed above and those implemented by the Cleanup Director (Section 5.3.1), includes: bringing the accident under control, sealing off the damaged facility and immobilizing the contamination. Following the cleanup of pieces of nuclear fuel and other highly active material on the site or on buildings by means of remotely operated devices, the more normal cleanup activities could commence. The equipment and methods to carry out these activities are described in Ref. [7].

Before defining an urban cleanup strategy, the planners should have a good understanding of: the physical layout of the area; the location and interaction of sewers, storm sewers, surface drainage and sewage treatment plants; areas of higher elevation; directions of slopes; the location of critical facilities, etc. The general strategy would probably be to have a preliminary cleanup to remove the major fallout and then a longer term, block by block final cleanup. Since urban areas would contain a wide variety of buildings (constructed of many types of materials), equipment, vehicles, road surfaces, etc., many techniques would be required to achieve the desired cleanup levels [7].

The cleanup strategy for rural areas would be dictated by land type and use, type of crop, value of land, etc. For highly productive farmlands, removal of crops, sod and a thin layer of soil may be required in seriously contaminated zones. However, in areas having lower levels of contamination, deep ploughing, addition of a layer of clean soil or application of chemical additives to fix the contamination may be acceptable [7]. Key transportation routes should be flushed down as often as necessary to wash away waste lost from trucks to prevent resuspension.

The major decision for forest cleanup is whether to defoliate the trees by chemical means or to let nature take its course. The danger in the latter case is the widespread dispersion of activity which could occur in the case of a forest fire. This decision would depend on the types of trees, accessibility in the forest, the equipment

TABLE II. EXAMPLES OF GENERAL CATEGORIES FOR PRIORITY DECONTAMINATION AFTER A NUCLEAR ACCIDENT [7]

Category		Cleanup priority		
		High	Medium	Low
I	Residential areas			
	— large developments	×		
	— remote single residence		×	
II	Other structures			
	— hospitals	×		
	— businesses		×	
III	Water sources			
	— primary municipal source	×		
	— secondary water source		×	
	— recreational use			×
IV	Agricultural land			
	— foodstuff products	×		
	— non-food products		×	×
	— gardens	×	×	
	— grazing, etc.	×		
V	Forests			
	— commercial forest		×	
	— non-utilized areas			×
VI	Roads, rights of way			
	— primary	×		
	— secondary		×	
VII	Remote areas			
	— deserts, forests, etc.			×
VIII	Plant site and adjacent buildings	×		

Note: From the results of pathway analyses, the above categories could be weighted on the basis of the resultant dose equivalents and the percentage of total area encompassed in the particular land use.

available, the likelihood of forest fires, etc. Bush areas could be reduced to chips using commercially available machines. The chips, sod or forest floor debris could then be collected and disposed of [10]. If the forest is dense, pathways may have to be cleared if it is decided to collect foliage or underbrush for disposal.

Aquatic systems are very difficult and in many cases impossible to clean up. The best strategy here is to control the amount of contamination being carried from the land to the aquatic systems by precipitation, snow melt runoff, water from wash-down of buildings or roads, etc. Drainage ditches should be built as early as possible in areas having serious loose contamination so that runoff can be directed to holding ponds (rather than rivers) where the contamination can be controlled better. In the case of isolated systems such as ponds, the water could be pumped out and sent for treatment. Mobile treatment facilities for such purposes are being developed under the Uranium Mill Tailings Remedial Action (UMTRA) Project in the United States of America to treat water at a reasonable cost [11].

5.4. ORGANIZATION AND CONTROL OF ZONES

In this section, examples of the means of organizing a zone for cleanup are presented. The organization and control of the zone are very important in ensuring that the cleanup proceeds in a logical and organized manner to minimize recontamination of clean zones, the spread of activity outside the restricted area and occupational exposure to the workers.

5.4.1. Main control zones

An area seriously contaminated as a result of a nuclear accident would probably be divided into several main control zones, which could be delineated according to radiation levels and the requirements for the protection of the workers. For example, the restricted area could be divided for control purposes into three main zones as described below.

Zone 1, the most radioactive zone, would include the nuclear facility site and areas close to the site, where dose rates in many places could, for example, be greater than 100 $mGy \cdot h^{-1}$. Human intervention for extended periods without heavy shielding and airpacks would be virtually impossible. Remotely operated equipment or (possibly in certain areas) heavily shielded equipment would be required for cleanup.

Zone 2 would include areas where the dose rates could, for example, range from 1 to 100 $mGy \cdot h^{-1}$. Depending on the radiation fields, equipment with light to medium shielding could be used along with respiratory equipment or cabs with clean-air supply systems on vehicles.

Zone 3 would include areas where the dose rates could, for example, range from 0.1 to 1 $mGy \cdot h^{-1}$. Ordinary machines could be used in this zone. However, respiratory protection could be required at times. The control measures and radiation protection requirements would be the same as for radiation workers.

The division of the contaminated area into the main control zones would not be finalized until after the accident. The variability of weather, wind direction and rainfall can significantly affect the shape of the zones and the dispersion and distribution of radionuclides.

After the Chernobyl accident, the area within a 30 km radius of the plant was divided into three control zones [6, 7]: a special zone of 4–5 km radius around the plant, where entry of the general population will not be permitted in the near future and where no work besides that required at the installation will be permitted; a zone of 5–10 km radius where partial re-entry and special activities may be allowed after some time; and a zone of 10–30 km radius where the population may eventually be allowed to return and agricultural activities resumed. The last zone will still be subject to a strict programme of radiological surveillance.

Figure 3 shows the gamma field distribution around the damaged Chernobyl plant about one month after the accident. The accident differed from those which are usually considered in radiological assessments of hypothetical accidental releases from nuclear power plants in that the releases were prolonged with major releases occurring over several days. The releases varied in rate and radionuclide composition over time and meteorological conditions were complex. These conditions led to a very complex pattern of radioactive fallout dispersed on the ground.

If the radionuclide releases from the facility had been over a shorter period and if weather conditions had been stable, e.g. wind blowing in a constant direction and no precipitation, then the fallout pattern would have been less complex. Theoretical studies have been done using computerized modelling codes and physical data on actual sites to predict the possible shape of a plume for well defined conditions (e.g. Ref. [9]). Figure 4 gives an example of the results of such calculations done using the physical data on an actual site, fairly uniform wind direction and other meteorological parameters to describe the dispersion of a hypothetical plume. Figure 4 shows the release point, the predicted direction and shape of the plume and dose isopleths. Such studies are useful in evaluating potential release scenarios to predict possible health and economic consequences.

Each of the major zones would have to be divided into subzones, each of which would be assigned to a team manager whose responsibilities would be to complete the cleanup of the subzone by choosing the appropriate tactics and equipment on a case by case basis and to ensure the safety and radiation protection of workers and protection of the environment.

5.4.2. Zonal control

The movement of people, equipment and contaminated material across the outer security perimeter and between zones or subzones should be monitored and

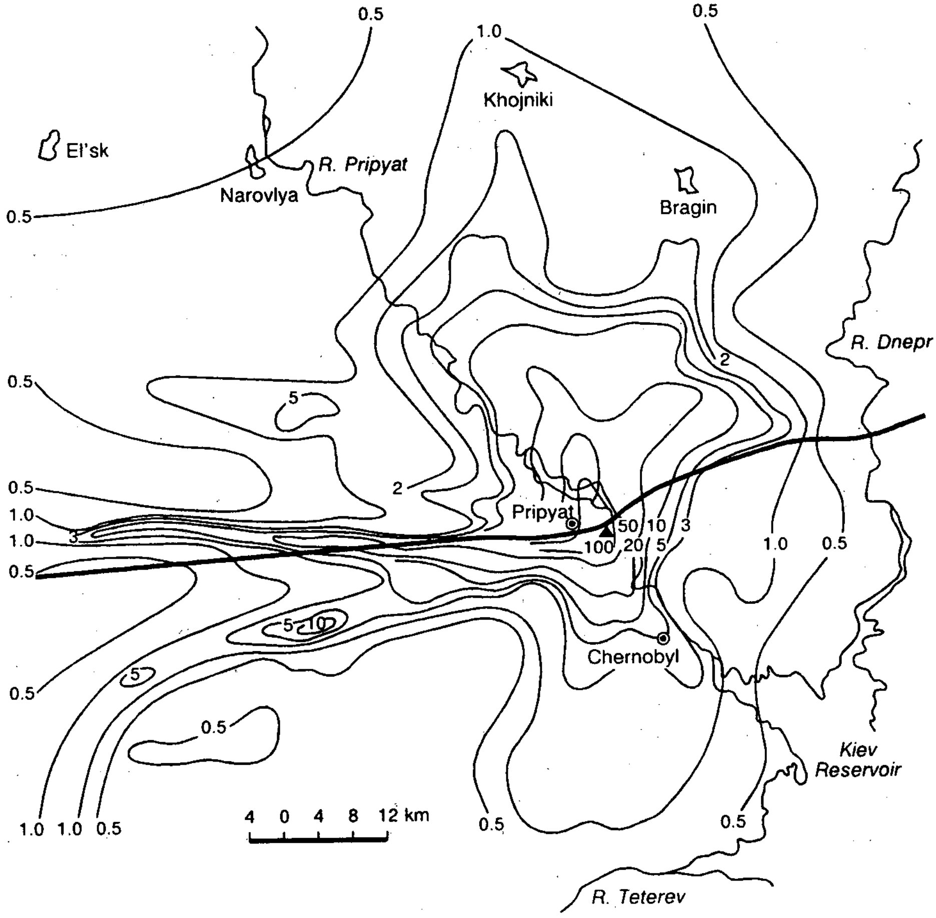


FIG. 3. Gamma field distribution (mR/h) around the Chernobyl nuclear power plant on 29 May 1986. (1 R = 258 μC/kg.)

controlled to minimize the spread of radioactivity to clean zones and provide maximum radiation protection. Security control is also required to prevent looting, to provide protection for deserted buildings, equipment and facilities, and to help inhabitants to remove personal belongings in a controlled manner if this is possible.

This control is organized through a central security office, which reports directly to the Cleanup Director (Fig. 2). The security office, in co-operation with the radiation protection staff:

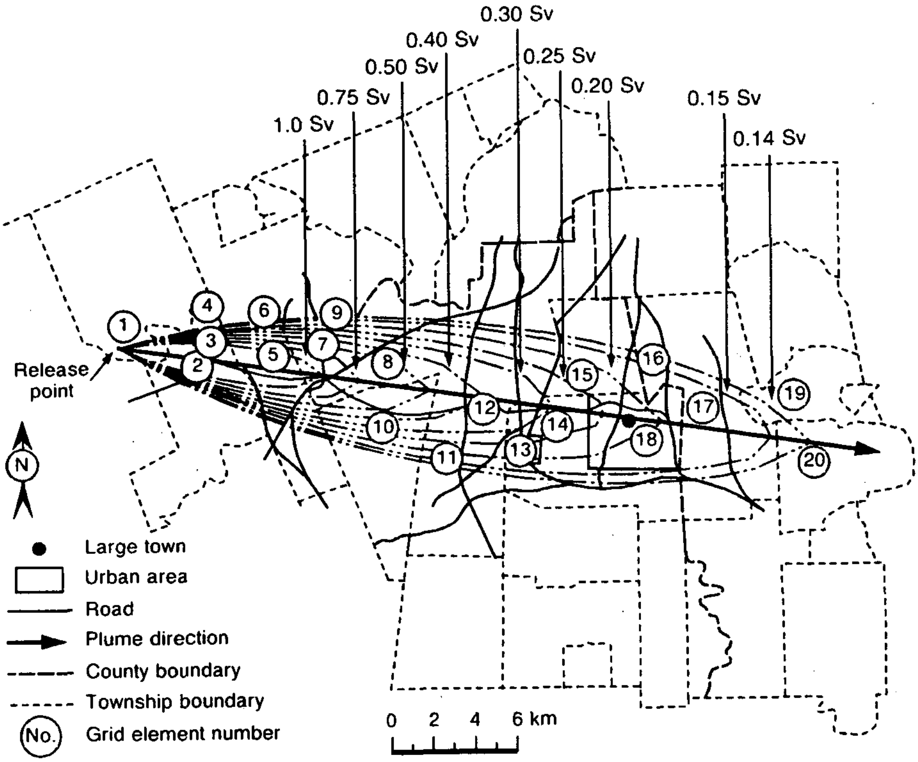


FIG. 4. Dose isopleths calculated for region affected by hypothetical accident (measured as 70 year whole body dose commitment starting 14 days after time of release).

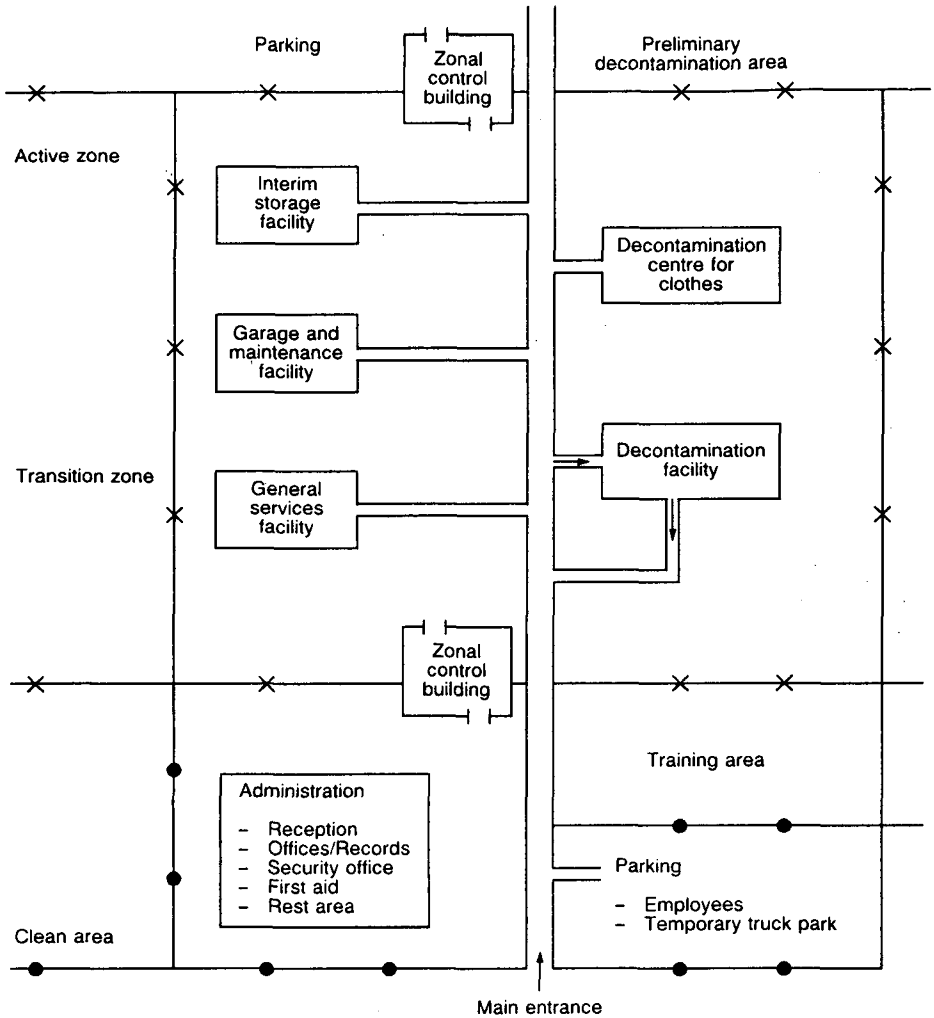
(a) Organizes the construction and maintenance of security fences around different zones,

(b) Enforces zonal control through its security patrols and zonal control offices,

(c) Controls the flow of personnel and traffic between zones to ensure that significant cross-contamination does not occur,

(d) Collects and disseminates information relative to the security of the controlled areas and workers.

Between zones and between major subzones there is a zonal control office which has the dual function of security control and contamination control. At each cleanup front, there should be a transition zone between the contaminated and clean areas with zonal control offices at each boundary. Figure 5 shows a possible arrangement at the transition zone between active and clean areas.



Zonal control building

- Operators' changing/shower rooms
- Portal monitoring: personnel and equipment
- Security control
- Health physics and environmental protection laboratory
- Personnel decontamination

General services facility

- Equipment maintenance and storage
- Laboratories
- Utilities substation (water, power, fire fighting)

Decontamination centre for clothes

- Active laundry
- Respirator cleanup

Decontamination facility

- Decontamination of trucks, equipment, etc.
- Contamination monitoring of equipment

FIG. 5. Example of a control centre between zones.

6. DATA MANAGEMENT

The team managing the cleanup of a large contaminated area will have to assimilate, correlate and evaluate a large amount of diverse, multidisciplinary information in order to monitor progress, make decisions and develop new tactics and strategies for cleanup. If the information is well managed and can be readily accessed and presented in a suitable form, this will help ensure that the cleanup is carried out in a safe, efficient and cost effective manner.

The handling, evaluation and use of this information, especially the mass of data arriving during the cleanup phase, require means to collect, process and store the data and to present them in forms suitable for a variety of users.

The system used for this purpose should be designed and made operational during preliminary emergency planning so as to avoid the extreme pressures inherent in an actual radiological emergency.

This section briefly reviews: the types of data that might be collected before, during and after the accident and their formats; data presentation requirements; and the development of a suitable information management system.

6.1. INPUT DATA

A vast amount of basic data and calculated results will eventually be contained in the information system and used for the management and cleanup of large contaminated areas. Some of these data would be entered during preliminary planning and others after the accident has occurred. Some of these data may also be used as input for emergency planning together with other protective measures during the early stages of response to protect the public.

Examples of the types of information which should be gathered during preliminary planning and during the cleanup are shown in Tables III and IV, respectively [7].

In addition to the types of information indicated in Tables III and IV, some of the information gathered by the Emergency Co-ordination Centre during the early phase [1] of the accident would be useful to the Cleanup Control Centre if cleanup is implemented. For example, the early aerial and ground radiological survey data could be used to estimate the approximate boundaries of the affected area and the significance of the contamination with respect to the status and location of the affected population.

Where possible, it would be preferable to enter the data automatically (from surface or air scanners, or magnetic media provided by the analysis laboratories) to speed operations and prevent errors associated with data entry by hand.

TABLE III. EXAMPLES OF INFORMATION WHICH SHOULD BE GATHERED DURING PRELIMINARY PLANNING FOR A POTENTIALLY AFFECTED AREA [7]

Demographic data
Layout of cities/towns, including areas/facilities requiring special attention or priority cleanup and building and material types
Land classes, land usage, etc.
Geology and hydrogeology of the area: soil types and permeability, groundwater depth and direction, topography, etc.
Data on nuclear facility accident scenarios and possible source terms
Background environmental monitoring database for the area
Type of geographical co-ordinate grid system for the area
Appropriate sampling and monitoring plans for different zones in the area. These could include data on sampling procedures, laboratory facilities, measuring equipment, monitoring teams, quality control programmes, etc.
Locations of critical areas of river/lake systems which could be susceptible to inflow of large volumes of contaminated water from the accident or cleanup
Locations of critical downstream drinking water supplies which could be affected
Actions which may have to be taken shortly after the accident, e.g. immobilization of contaminants by spraying, installation of in-ground hydraulic bypasses to reduce groundwater flow through the contaminated area and construction of diversion ditches or dams to prevent contaminated water from reaching clean water systems
Cleanup criteria for different zones and other relevant regulatory and radiation protection information
Organizational aspects of managing the cleanup plan for different zones
Analyses of preferable cleanup options for each area based on assessment of soil type, land use, equipment available, etc., and the quality control programmes associated with each option
List of equipment and facilities required for cleanup and locations of available items (including potential disposal sites)
Assessment of personnel requirements for various scenarios, including a list, with telephone numbers, of key members and details of the notification system
International contacts on cleanup
Cost–risk analysis data
Overall quality control programme requirements

TABLE IV. EXAMPLES OF INFORMATION WHICH SHOULD BE GATHERED DURING CLEANUP

Post-accident radiological survey data:
— details of comprehensive radiological characterization of affected area; isopleths of radionuclide concentrations or gamma exposure rates
— details of control monitoring for excavation and other remedial actions
— updates on status of cleanup in various zones
— final radiological survey for lands and buildings
— records of doses received by workers
Results of laboratory analyses on soil, air, water, flora and fauna to back up survey data
Status and location of equipment, staff and facilities
Information from support offices, e.g. logistics, quality assurance and security

All data should be entered in, or converted to, a format suitable for use by a modern data management program, such as the Paradox Data Management Program (Borland International, Belmont, California) or a similar program which allows the user to 'learn by example'. These systems allow automatic searching and sorting for specific sets of data (by location, radionuclide concentration, etc.), and 'learn' query patterns to allow flexible and efficient access to data. In this way, data can be quickly accessed for real time use by cleanup managers, and specific patterns of access (e.g. sorting by location, then by concentration) can be 'learned' by the program and quickly repeated throughout cleanup.

In designing and operating the system, the following points should be addressed [12]:

— Qualified staff should be assigned for all aspects of the data management.
— Original data sheets should be recorded, collated and cross-referenced for easy referral; the site location to which the data refer should be clearly and unequivocally defined.
— Data should be assessed as to quality, validity and priority of importance for the response before being entered into the appropriate database. Entries should be edited and verified.
— Individual data points should be unambiguously defined as to location with respect to the geographical co-ordinate grid system.
— Key data should be retrievable in any category desirable. Results will need to be evaluated, summarized and placed in proper perspective quickly and easily on a continuous basis.

— Environmental and cleanup data should be plotted on maps or overlays separately by data type.
— It should be possible to distribute easily, quickly and continuously detailed organized data for assessment purposes and highly summarized data for management.

Suitable quality assurance procedures should be used (Section 11) to ensure that information entered into the database has been assessed as being technically accurate before it is used for decision making.

6.2. DATA PRESENTATION REQUIREMENTS

To be useful, the database management system should be able to present data in a format which is compatible with the needs of the technical assessor, report writer, decision makers and other users. In addition to the normal data presentation methods, e.g. text, bar charts, tables and figures, map overlays are a very useful form of presentation for the type of multiattribute data arising from a serious accident.

Overlay mapping techniques have been used for a long time in both developing and developed countries in a wide variety of planning activities, for example environmental impact assessment [13] and geological mapping. In this method, a transparent sheet is prepared as the base map showing the area of interest, its boundaries and other basic features. Layers of other information relevant to the investigation are prepared as transparent overlays using the same grid system and land area as the base map. The degree of importance of selected features such as radioactivity level can be shown by different colours, shading or isopleths.

With manual overlays, interpretation of up to 10–12 overlays is possible. With a computerized system, composite maps indicating individual impact or a range of impacts can be produced.

Figure 6 shows some examples of the layers of information that should be plotted on the same geographical co-ordinate grid system and could be collected before and after the accident. The information collected before the accident would relate to the whole area which could be seriously affected by the accident, for example a 10–30 km radius around the nuclear plant. After the accident, that part of the area which has actually been seriously contaminated would receive most attention in data collection, assessment and presentation.

Within the restricted area, the basic information should include larger scale geophysical maps, including city and town maps having sufficiently large scales, e.g. 1:50 000 for non-urban areas and 1:20 000 for urban areas.

Outside this area, maps and data on adjacent water systems, downstream drinking water supplies and road and rail connections should be collected up to a radius

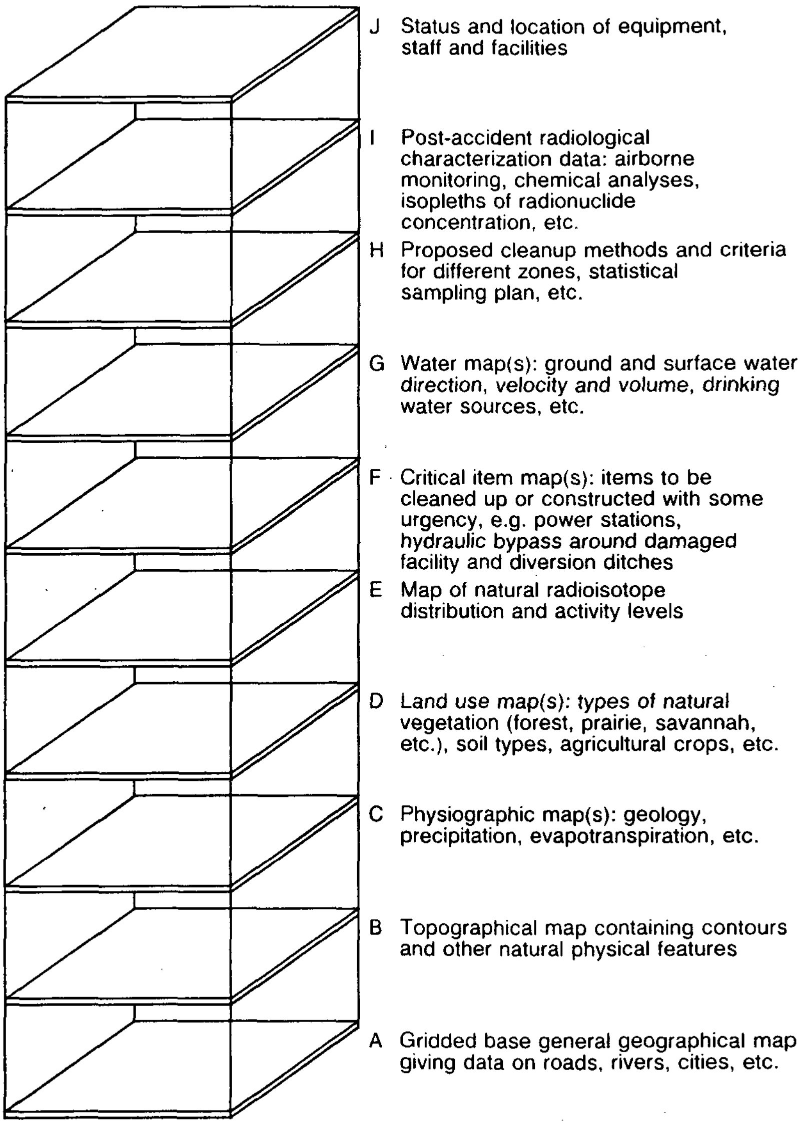


FIG. 6. Some of the layers of information that should be plotted on the same grid for managing the cleanup of large areas.

of several hundreds of kilometres. The amount of detail on maps may be much lower in this outer region.

6.3. DEVELOPMENT OF A DATABASE MANAGEMENT SYSTEM FOR CLEANUP

A conventional file management system could be used to handle the large volumes of information arising from the cleanup of a contaminated area. However, a more efficient means of handling such large amounts of data is through a computerized database management system [14]. The organization of data files into a database achieves three major objectives: data integration, data integrity and data independence. This concept avoids much redundancy of data as occurs in conventional file management systems. Since cleanup is a multidisciplinary activity, the system would have individual databases related to the various disciplines involved. The database management system should also be interfaced with other packages and other programs running in the same computer for direct access and processing of data. Examples of other programs include: codes related to plume migration, pathway analysis, dose prediction, geostatistical analysis and kriging.

Therefore, it would be desirable if the data handling system were automated to assist the Cleanup Director and team in storage of the data in appropriate databases, overall planning, day to day operational and logistic tasks, report preparation, data plotting, etc.

Examples of the kinds of routine tasks that a data management system might have to perform include:

(a) *Establishing data storage and backup archives.* Collecting field data during early stages of cleanup could result in significant radiation exposure to the collecting technicians. Since loss of such data would require resampling and further exposures, routine backup and storage of data in permanent electronic archives should, if possible, be established when setting up the database management system.

(b) *Calculating the accuracy of data collected* and predicting radionuclide distributions and concentrations and potential doses to humans. The doses are based on statistical data from gamma surveys, soil and water analyses, etc., and calculated using predictive models and computer programs. All data should carry information about errors to allow cleanup managers to be constantly aware of data accuracy. In general, knowledge of the error associated with a particular dose estimate (being used, for example, by a manager to direct soil excavation) may be applied to setting cleanup criteria. During excavation to remove contaminated soil, data with known accuracy could be used to set an excavation depth somewhat deeper (or shallower) than the average concentration value would indicate, to ensure at a high confidence level that the limiting radionuclide concentration (dose) is not exceeded.

(c) *Co-ordinating data* from various sources, including: gamma scans, soil sample analyses, quality control results, water sample analyses, soil type, groundwater quality, surface watershed, groundwater depth, soil contamination depth, predicted evolution of soil concentration profile with time, and meteorological data and forecasts. These data should be linked and plotted on the established grid to allow efficient use in directing cleanup.

(d) *Plotting isopleths* of radionuclide concentration or gamma exposure rate data on the official grid layouts (Section 5). Isopleth contour plots (e.g. Figs 3 and 4) are the principal tool used by a cleanup manager to determine areas to be given priority for cleanup.

(e) *Plotting 'hot spots'*, for use in directing heavy duty equipment (scrapers, etc.) to clean specific areas, to isolate areas, etc.

Computer systems have been used in the past in assessing accidents at nuclear facilities and for the implementation of other emergency measures and considerable progress is being made in this field (see, for example, Refs [15–18] and Appendix B). In a particular region, various organizations concerned with the management of nuclear and non-nuclear emergencies may have need for similar databases and data management systems. Where possible and practical, it may be desirable for these organizations to use common or shared databases and data management systems and common terminology to minimize duplication of effort and inconsistency of similar data inputs.

In addition, sophisticated data management systems related to other needs may also be available on a regional or national level. For example, the type of data management system used for mineralogical exploration could be adapted relatively easily to handle the data required to manage the cleanup of a large area (see Appendix B). Such mineralogical data management systems are available in many developed and developing countries [14].

Regardless of whether the data management system for cleanup is dedicated to cleanup or shared with other organizations, it should be compatible with the needs and capabilities of the group assembling the data and doing the assessment as well as other potential users and the custodians [15]. It should be part of a system which is in regular use. This should ensure that the system will be maintained routinely and thus be more reliable and that personnel who routinely operate the system are readily available.

If a country has nuclear facilities at several sites, a standard data management system could be adopted and modified for use at the various sites. In addition, some countries have computerized emergency response and assessment systems which are centralized but are connected with similar systems at each site [17, 18]. This type of arrangement might also work between countries.

To effectively implement a computerized data management system for cleanup, a team of approximately 15–20 persons would be required, including: a systems manager, systems programmer, systems engineer, database manager, secretary, statistician, systems analyst, programmer, digitizer and data entry staff. If a manually operated system is used, a larger number of personnel would be required.

In summary, the availability of a reliable and well organized database and a database management system would allow advance preparation of a geographical database and give virtually instantaneous access to the types of information discussed in Section 6.1 during the critical early stages of an accident. As noted, the same system could then be used to handle and store all information acquired during cleanup, including graphics and other mapped data.

7. GEOGRAPHICAL CO-ORDINATE GRID SYSTEM

In the preliminary planning stage, it is essential that the location of each sampling or data point be precisely and unambiguously known and related to a nationally recognized co-ordinate system covering, as a minimum, the restricted area as well as the surrounding area which could be affected up to distances extending to some hundreds of kilometres.

In many parts of the world, the Universal Transverse Mercator (UTM) grid system is printed on topographic maps [19]. On maps of 1:50 000 scale, this is usually a grid of 1 km by 1 km. The UTM system provides a convenient means of recording sample location. Similar systems include the Lambert and Gauss–Krüger systems. Geographical co-ordinates (latitude and longitude) could also be used; however, they provide a variable, non-square system that would require later conversion to a square grid before computer plotting.

It would be useful to refer territorial information (geology, land use, background radiation, sampling points, etc.) to each element of a grid system defined by choosing an adequate scale within the co-ordinate system adopted. The geographical co-ordinate grid system will hereinafter be called the grid system.

When the grid system is being set up around the nuclear facility during normal emergency preparedness activities, the grid should be accurately located by surveying and tied to permanent benchmarks.

For cleanup purposes, the size of individual grid squares could vary from about 5 to 100 m depending on factors such as: uniformity of radionuclide distribution, type and concentration of radionuclide, land use class (e.g. urban or agricultural), land type, population density and future habitation (unrestricted or restricted use).

Some experience is available in using grid systems to assist in the cleanup of medium sized areas and to help validate that the cleanup meets the set criteria [20]. The required scale of the grid system could vary depending on land use and other factors. For example, in urban areas a location accuracy of 0.5 m may be required while for open land accuracies of 2 m or more could be adequate.

8. RADIOLOGICAL SURVEY PLAN

8.1. INTRODUCTION

A good radiological survey plan is an essential element in planning and implementing the cleanup of contaminated areas. This plan has two basic components (Fig. 7):

(a) During preliminary planning as part of normal emergency preparedness activities the concentrations of natural and man-made radionuclides in the affected area around the nuclear facility should be assessed and mapped.

(b) Post-accident radiological surveys. These are required:
   - (i) To provide a comprehensive radiological characterization of the contamination which has been deposited as a result of the accident and to characterize the different areas after various stages of cleanup;
   - (ii) To determine how and to what extent the deposited radionuclides are moving as a result of runoff, resuspension, migration, plant uptake and so on;
   - (iii) To do control monitoring during cleanup to decide on further actions;
   - (iv) To have a general radiological survey at the end of cleanup operations to verify that the activity and dose rate levels in the affected area are within levels acceptable for the purpose for which the area will be used;
   - (v) To ensure that the dose to the affected population remains within acceptable levels.

Figure 7 shows the various components of the radiological survey plan and indicates the interrelationships of the survey data acquired during such a process. The figure also lists some of the protocols that need to be developed for each component of the plan.

The majority of the data for these purposes would probably be obtained as a result of radiological monitoring surveys using non-destructive scanning and monitoring equipment either mounted in aircraft or ground based vehicles or hand held [7, 21]. Laboratory analysis of selected samples of air, soil, water, vegetation, building materials, etc., would also be required to validate radionuclide ratios if they are likely to change.

Each of these monitoring functions would produce a large amount of data which would provide the essential information required to characterize the radiological consequences of the accident and to plan and implement the cleanup. To

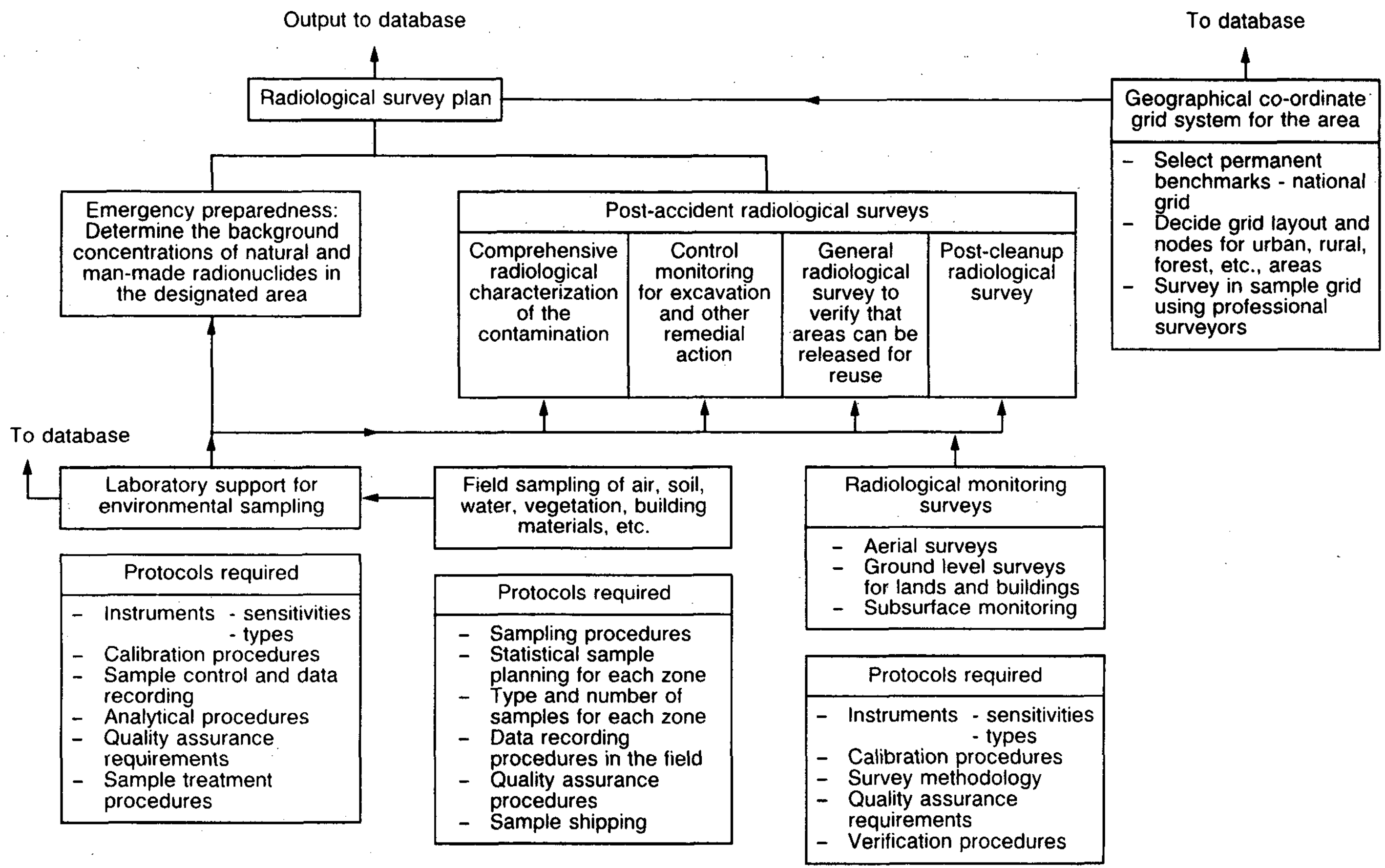


FIG. 7. Example of a radiological survey plan.

ensure that these data are of maximum value and that results are readily available to the cleanup teams, it is important that:

— Protocols be defined, outlining step by step the methods to be used in taking and analysing samples, in taking monitor readings, in presenting data, for validation of analytical methods, comparison of different analytical methods, etc.
— The teams be well trained to follow the protocols and use the instruments. The provision of protocols and training is particularly important since inexperienced people would probably have to be trained and used because of the likely magnitude of the cleanup problem and the limited number of available experts.
— The location of the sample points be unambiguously referred to a standard grid system.
— The number and type of samples taken during the cleanup should not greatly exceed the throughput of laboratories available at the time of the accident (or new analytical facilities established after the accident if deemed necessary by the Emergency Director). During exercises with the preliminary plan, the Cleanup Director should determine how the predicted number of analytical samples for the accident scenarios being used compares with the throughputs of the available laboratories.

If the off-site dispersion of radionuclides from an accident at a nuclear facility occurs while wind speed and direction are uniform and there is no precipitation, plotting the distribution of radionuclides and dose isopleths may be relatively straightforward. On the other hand, if the dispersion occurs while there are localized heavy showers and/or gusty multidirectional wind currents, radioactive hot spots would occur and dispersion patterns would be complex and more difficult to define [22]. If the release is over a longer period, a more complicated dispersion pattern may be expected in any case.

Whatever the deposition, the radiological survey plan should define the distribution and concentration of radionuclides accurately to determine hot spots and assist in setting cleanup priorities.

8.2. PROTOCOL DEVELOPMENT

During the cleanup of large contaminated areas, many people having different abilities would have to be used as surveyors, samplers, laboratory assistants, etc. The level of training of these people would vary considerably. Also, a large number of measurements and samples would have to be taken to validate that the cleanup meets the set radiological criteria. Therefore, detailed protocols outlining step by step procedures for a variety of tasks associated with the cleanup should be prepared in advance to ensure that the tasks being undertaken by different operators are performed in as consistent and reproducible a manner as possible (Fig. 7). In addition, statistical sampling protocols should be established to limit the number of samples to the minimum required to validate that the cleanup meets the established criteria.

Protocols for some of these functions have already been developed and these should be reviewed during preparation of the required protocols for large scale cleanup. For example, detailed survey and sampling protocols and procedures based on quality control and statistical analysis principles have been developed for remedial action and other programmes [20, 23–25]. These procedures are being modified continually to improve efficiency as a result of cleanup actions on relatively large areas ranging from 0.5 to 5 km^2 and the movement of large volumes of contaminated material.

Other good sources of certain protocols and procedures are the manufacturers of the instruments and equipment that would be used during the cleanup.

8.3. SAMPLING AND MEASUREMENT

The overall sampling protocol should be designed with speed and efficiency in mind but it should provide consistent and reproducible results. Sampling procedures should take into account the possibility of field sampling errors. These procedures should be developed as a matter of preparedness in parallel with laboratory analytical procedures.

Where possible, field monitoring techniques should be used rather than physical sampling and laboratory analyses of soil, water, flora and fauna. In fact, field monitoring would probably be the major data acquisition method, with samples only being used for key quality control measurements, definition of radionuclide ratios as required, analysis to determine contamination depth, and some final verification. The use of field monitoring techniques not only saves sample procurement and analysis costs but also reduces delays in getting results back to cleanup crews. Resampling frequency should be based on statistical analysis of the developing database of results for a particular area.

Measurements for calculating the dose commitment to the workers (Section 14) should be integrated into the monitoring programme for the cleanup.

Information on the need for and location of samples to determine contamination depth can be gained if computerized pathway analysis programmes are available. For agricultural areas, with knowledge of the soil type, soil partition coefficients, stratigraphy, hydrogeology, meteorological conditions, etc., calculations can be done to estimate the depth of penetration and the migration rate and direction of radionuclides. For urban areas, understanding the drainage systems and building materials used would assist in determining where sampling should be carried out. For lakes, rivers and reservoirs, samples of the water and sediments should be taken during the cleanup and for long periods after termination of the cleanup, especially in the most seriously contaminated areas. In forested areas, sampling of the forest floor layer as well as leaves should be done periodically to determine whether the uptake of radionuclides by the trees is changing.

8.4. POST-CLEANUP RADIOLOGICAL SURVEYS

In the event of a serious accident there could be regions in the affected area which could be interdicted for continuous human habitation for many years even with extensive decontamination. Also, there could be areas to which the population could return safely because radiation levels are acceptable as a result of cleanup activities. In the latter areas, post-cleanup radiological surveys should be carried out periodically to ensure that activity and dose rate levels are not exceeded and do not increase owing to migration or accumulation of radionuclides. In addition to portable dose rate meters, backpack or vehicle-borne gamma spectrometers can be used in the field [7]. The field spectrometers can cover an area relatively quickly (compared with sample taking and analysis), provide adequate averaging over an area in one measurement and distinguish between natural background and radionuclides due to accidents. Field spectrometer and dose rate measurements should also be backed up with analyses of samples of soil, water, flora and fauna.

9. COMPLIANCE WITH RELEASE CRITERIA

9.1. INTRODUCTION

The decision to implement the cleanup of a contaminated area is made on the basis of the DILs [8] for this protective measure. Once the decision has been made, then cleanup criteria should be available to define the specific radionuclide concentration limit or gamma exposure level which should be achieved by remedial action in a particular area. In addition, re-entry criteria should be established by which it can be decided whether to allow the return of the population and/or reuse of the land for agriculture, etc.

The development of such criteria which relate the dose to humans to contamination levels using pathway analysis is difficult for small sites and extremely difficult for large diverse regions. In practice, different acceptance criteria may be set for different zones or situations in large contaminated areas. Fortunately, by the time large scale cleanup is initiated, only a few longer lived radionuclides would need to be considered in setting criteria. The use of cost-risk procedures and the important parameters in establishing recovery criteria are discussed in Ref. [9].

It is beyond the scope of this report to give detailed guidance on the development of such criteria since it is a specialized task. However, the criteria should be based on risk levels translated into acceptable dose limits. For rural areas, concentration limits for radionuclides in soil, water, air and food or acceptable radiation levels can be derived using suitable pathway analysis and, where possible, realistic site specific parameters. For urban areas, an integrated evaluation of the radiation from various surfaces should be undertaken.

Just as important as the cleanup and release criteria are the validation and quality control protocols required to ensure compliance with these criteria.

9.2. BASIC STEPS

The basic steps in developing and implementing a plan to ensure that areas, buildings, materials and equipment being released for reuse comply with release criteria include [20, 21, 26]:

(a) Selection of release criteria to be used for each application;
(b) A preliminary survey to assist in defining the scope of the cleanup and what instruments are required;
(c) An assessment of the monitoring and sample analysis requirements and preparation of the required protocols for an efficient and comprehensive compliance survey;
(d) Selection and calibration of instruments;
(e) Determination of background radiation levels (done during the preliminary planning);
(f) The final survey to ensure compliance with release criteria;
(g) Documentation (Section 6);
(h) A quality assurance programme which should ensure that the sampling, analysis, monitoring, documentation, interpretation, use of data, etc., would not result in the release of an area having activity levels greater than the designated criteria.

9.3. COSTS AND NUMBER OF MEASUREMENTS

The cost of ensuring that areas, buildings, materials or equipment being released for reuse comply with release criteria can be highly variable and depends on many factors such as the type and size of the component, the release criteria and labour and analytical costs.

For example, in the UMTRA Project in the USA, about 100 measurements per hectare were required during the final verification measurements of cleaned land [27]. Each final measurement might be preceded by 10–20 preliminary measurements such as airborne measurements, hand held monitor scans and soil data analyses.

Depending on factors such as future land use, population density, soil type, uniformity of contamination, type of topography and accessibility, and equipment availability, the number of measurements required for verification may vary to a great extent.

Since the number of samples taken during the cleanup operations may be very large, statistical sampling plans should be developed for various zones to minimize the number of samples required and increase the probability that unacceptable levels of contamination are not missed. This sampling plan should be backed up by an appropriate quality control programme (Section 11). For measurement sets having a large number of samples, the quality control programme, measurement validation function, type of measurement, etc., would be strongly influenced by costs.

Depending on the intended use of a specific type of measurement, differing quality control requirements may be appropriate. For example, less stringent quality control need be applied to initial aerial survey data, since (for various reasons) interpretation of such measurements is difficult, and measurements are in general used either for preliminary direction of cleanup or for final checks of cleanup effectiveness on a broad scale only. On the other hand, quality control for final surveys and for sample and laboratory analyses, including sample preparation, should be stringent, since the instruments are capable of good accuracy and the results could be critical for release of sites.

Selection of quality control criteria should be performed in advance, based on an evaluation of such factors as:

(a) Variation of the parameters being monitored;
(b) The purpose of the particular data set, for example for final dose estimates or preliminary gamma exposure estimates;
(c) The costs of sampling and the funding available.

To control costs and maintain adequate accuracy when quality control for a large number of individual measurements is required, a logical sequence of measurement quality control should be considered in advance. In general, only a small fraction of quality control is performed using expensive laboratory chemical separation analysis. This level of quality control is used only as a final check on the absolute accuracy of well designed field analytical systems, which in turn are used to regularly corroborate inexpensive scan type systems that produce the vast majority of the cleanup measurements.

10. LOGISTIC SUPPORT

A great deal of logistic support would be necessary to supply and maintain: the staff and equipment associated with the Cleanup Control Centre and its associated facilities; the field teams doing the cleanup; the personnel controlling and operating the common facilities such as machine shops and decontamination centres; security offices; etc.

A Logistics Support Office (LSO) should be set up to fulfil these functions and the head of this office should be one of the senior advisers to the Cleanup Director (Fig. 2). The LSO could provide some or all of the following functions:

— Order and supply all necessary materials and equipment for the teams and facilities which are under the direct control of the Cleanup Director, including health physics equipment and supplies;
— Provide food and accommodation for all cleanup personnel;
— Provide auxiliary facilities such as health clinics, mobile showers and personnel decontamination centres, and respirator cleanup areas;
— Keep records of all materials, and equipment supplied to the restricted area as well as data on personnel;
— Provide maintenance and construction assistance;
— Provide warehousing for chemicals and materials, and mixing areas and facilities for chemicals such as the spray solutions used for decontamination or fixation.

11. QUALITY ASSURANCE PLAN

11.1. INTRODUCTION

Any activity which could have an impact on the health and safety of the workers or the public or affect the success of the cleanup should be covered by a suitable quality assurance (QA) programme. For such activities it is necessary to have procedures, documentation, controls, guidance on selective application of QA procedures, and accurate information and techniques to verify compliance with QA procedures. Personnel working in these areas should be well qualified and trained to implement such programmes [27].

Since QA is an essential element of all cleanup activities, the programme should be applicable to all activities that could compromise the successful cleanup of the area. The development and co-ordination of the QA programme should be assigned to a Quality Assurance Office (Fig. 2) which reports directly to the Cleanup Control Centre. This office defines an overall QA plan which describes how the appropriate criteria are to be applied to all cleanup activities. The QA Office would also have each subcontractor provide a detailed QA plan applicable to each phase of the work, e.g. for sampling, monitoring, procurement and transportation. The overall and subelement QA plans could be prepared in a generic manner before the accident and applied as required to a particular accident. The generic plan could be adapted to be applicable to several sites within a country or for several countries.

In developing the plan, it should be recognized that public health and safety are not always affected to the same degree and a graded approach to QA can be developed to ensure an adequate level of quality for factors such as maintenance and operational reliability. Less stringent but still viable quality levels could be utilized for quality related functions not affecting safety whereas the criteria should be applied to the maximum for safety related functions.

The overall QA plan should show the compatibility of QA programmes applied to the cleanup and outline how each QA subplan fits into the overall picture to give total QA coverage.

This section briefly reviews the main elements of a QA programme suitable for the cleanup of large areas. A generic QA programme suitable for such cleanups should be prepared by experts in this area of activity.

11.2. IMPLEMENTATION

QA personnel at each level should have direct access to managers to ensure that they can:

(a) Have ready and free access to records and work areas so that they can identify quality problems,
(b) Initiate and recommend solutions,
(c) Verify that solutions have been implemented independent of costs and schedules.

The Senior Quality Assurance Officer fulfils the overall QA responsibilities with the assistance and advice of technical staff in the QA Office or outside technical assistance contractors. The QA Office staff discharges its responsibilities by: participating in design reviews and QA audits; approving test plans and QA procedures; providing QA surveillance and policy guidance; and reviewing and approving QA subplans prepared by the various groups (Fig. 2) participating in the cleanup.

To implement the cleanup successfully and safely, the QA programme should include the following elements:

(1) *Design controls* define by drawings, criteria, specifications, procedures, etc., how any activity or investigation which could affect quality is to be conducted. Cleanup should be accomplished according to these controls, which should

also include acceptance criteria. Peer reviews should be conducted to verify that the controls fulfil the requirements.

(2) *Document control:* To ensure that QA documents are issued correctly in the first place and are not subsequently changed in an unauthorized manner, the QA Office should have written procedures which define the methods used to control QA related documents. The procedures should cover controls on issuing, distributing and revising such documents to ensure adequate QA coverage. Changes to documents should undergo the same review as the original documents.

(3) *Procurement control:* Written procedures for the procurement or purchase of equipment, services, materials, etc., should include the appropriate QA requirements and also define methods to be used to evaluate suppliers and means for verification that suppliers conform with specifications and for the periodic surveillance of contractors providing a service.

(4) *Identification methods:* To ensure good control, means of identifying equipment, materials, parts and data procured as part of the cleanup programme should be established. The methods of identification and control should be documented by the responsible group and verified by the QA Office.

(5) *Special processes* are those governed by the quality of the process itself and/or the qualification of the operator, e.g. taking radiological measurements. To control these processes, criteria for qualification of operators, procedures for taking readings, procedures for maintenance of qualification records, etc., should be specified by the subplan managers.

(6) *Inspection:* The cleanup of urban, rural and forest areas consists to a large extent of earth moving, decontamination and agricultural remediation. Written inspection procedures for each subprogramme should: require that inspections be performed by qualified inspectors; define qualification requirements; detail methods used for acceptance of data; detail documentation requirements for inspection results.

(7) *Calibration procedures:* In addition to defining how activities are to be conducted (item (1)) and ensuring that suitable equipment is procured (item (3)) and used properly (item (5)), procedures should be available to ensure that laboratory and field equipment is properly calibrated at all times. This is particularly important in view of possible contamination of detectors and dose rate probes. The procedures should include: recommended frequency of calibration, standards to be used and records to be kept.

(8) *Non-conformance procedures* should be developed by subplan managers to cover items which do not conform to specified requirements, such as cleanup criteria, equipment specifications and disposal site criteria.

(9) *QA records* which support the conclusions reached from tests, investigations or remedial action operations should be maintained in a Document Control Centre in the QA Office or other suitable office. Access to the documents

should be controlled and fire and security protection should be provided. Duplicate copies of essential documents should be kept in a separate place. The record management system should meet the requirements of the best systems suitable for such records available in the country.

(10) *Audits of the QA aspects* of the overall and subplan programmes should be carried out on the basis of how they affect the cleanup. The more important or safety related components would be audited more frequently than less critical parts of the programme. A schedule listing all audits for the year should be prepared to ensure that at least the minimum number of audits is carried out. Additional audits can be defined as the need arises.

12. TRAINING AND EXERCISES

Reference [1] states: "There shall be exercises at suitable intervals covering to the extent practicable each aspect of the Overall Emergency Plan, including on some occasions the participation of all the organizations concerned." The objective of such exercises during normal emergency preparedness activities is to reveal any deficiencies in the plan, procedures, equipment or interfacing of personnel and to familiarize personnel with what might be expected in a real accident.

Since the cleanup is part of the overall emergency plan, key personnel associated with the cleanup should also receive thorough initial and refresher training at regular intervals. In particular, the training of personnel involved in shared functions like data management should be well co-ordinated.

Each function associated with the cleanup operations should be practised where possible. Training of small groups should precede integrated training of increasingly larger groups and more complicated functions such as communications, data management and reporting. Practising the interactive functions of subplans with each other and their interaction with the overall cleanup plan should be done. Because of the nature of cleanup operations, it may only be possible to practise the management plan and the operation of key equipment elements (e.g. computers and data management systems) but not of cleanup equipment.

As part of preliminary planning and training, the Cleanup Director and associated management team should develop realistic strategies for several accident scenarios at a particular facility. The implementation of these strategies should be practised during training and in the exercising of the emergency plans from time to time. In assessing the implications of the accident for the affected area, use should be made of computerized aids and programs during training and during the accident itself to perform parametric studies and to correlate the data to understand the progress of the accident and cleanup campaign. Reference [9] gives an example of such an aid. The authors describe procedures for conducting an analysis of an area radiologically contaminated by a nuclear power plant accident to establish recovery criteria for the area. The procedures for conducting the analysis require that the major off-site health risks and costs related to the accident be quantified. The only risks and costs relevant to the analysis are those which vary with the level of cleanup criteria. The major parameters fall into the following categories:

— Health risks and costs,
— Costs of temporary and long term relocation,
— Costs of radiological surveying and monitoring operations,
— Property value losses,
— Costs of decontamination and cleanup,
— Waste disposal costs.

The procedures are illustrated by analysing a hypothetically contaminated site using software developed for determining the effects of major accidents on property and health.

The strategy actually used to carry out the cleanup could vary considerably depending on such factors as the type of accident, weather conditions, population density and distribution, the need for the area that has been contaminated, and the human and material resources available in the country.

13. UPDATING THE PRELIMINARY CLEANUP PLAN

The cleanup plan should be reviewed regularly to ensure that the available data are up to date. The person responsible for maintaining and updating the cleanup plan would call upon experts in various areas or use outside consultants to review the status of the plan, equipment, etc. The revised plan should take into consideration recommendations arising from training exercises or experiences and incidents in the country or elsewhere.

14. RADIATION PROTECTION AND SAFETY OF WORKERS

Planning and implementation for the radiation protection and safety of workers are inherent parts of all nuclear activities and are especially important in activities such as the cleanup of large contaminated areas.

During the last few decades, considerable work has been done on the development of the principles of radiation protection and on techniques and procedures to implement these principles for controlled situations [28–33]. To ensure that the principles are correctly applied, a wide variety of instruments are available for personnel monitoring, air monitoring and the detection and measurement of all types and levels of radioactivity. The application of these principles and techniques is demonstrated daily at nuclear facilities around the world and they have also been applied successfully to small and large cleanup tasks. The cleanup tasks include: regular maintenance procedures in operating facilities; the decommissioning of nuclear facilities for unrestricted use; the rehabilitation of seriously damaged reactors; and the cleanup of large contaminated sites and areas.

As part of standard emergency response planning, a preliminary radiation protection and safety plan should be formulated with the assistance of radiological experts. If a serious accident should occur, this plan should be tailored to meet the specific accident situation.

The radiation protection and safety plan should include a comprehensive radiation monitoring and data management programme [29, 33] which provides for the measurement, evaluation and recording of all exposures incurred by individuals through different pathways. The plan should also cover practical aspects related to the implementation of this programme, including training and classification of personnel, duties and responsibilities of various groups in all aspects of cleanup (e.g. handling, transport and disposal), and the use of protective clothing, respirators [29] and other means of reducing occupational exposures.

The plan should also include a list of equipment, facilities and personnel needed to implement the radiation protection programme and state where and how these resources could be obtained.

A major consideration in planning for radiation protection and safety in any cleanup operation is the radiation dose which the workers would be allowed. The limits should be set by national authorities on the basis of recommendations of the IAEA and ICRP and taking into consideration the accident situation. It is possible that decontamination operations might be dependent upon a small number of key individuals such as health physics personnel, and operations could be placed under severe pressure if such personnel are exposed to high doses early in a cleanup programme, which would thus exclude them from future activities. As a consequence, management of dose and manpower resources would be of crucial importance.

The IAEA and ICRP documents on standards for radiation protection [30, 32] outline a formal system of dose limitation based on justification of a practice, optimization of protection and compliance with specified dose limits. This system is intended to apply whenever the source of radiation exposure is under control. After a major nuclear accident which results in widespread contamination, a temporary loss of control may occur during which time it may not be possible to comply fully with the specified dose limits. However, by the time the cleanup programme starts, the public would have been evacuated from the contaminated area and the authorities would have re-established control. Also, the justification and optimization principles would still apply. During a cleanup operation, the risks taken to clean up the area need to be balanced against those that might prevail if cleanup does not proceed. These considerations and the continually changing situation will place a great burden on the health physics staff and those controlling the cleanup. They should ensure that adequate effort is put into the planning and implementation of each stage of the cleanup to prevent unnecessary exposure of workers and the general public.

During the implementation of the cleanup operations many tasks should be controlled or initiated to ensure that radiation protection and safety are maintained, including [33]:

(a) Safety and radiation protection procedures;
(b) Specification of the type and extent of monitoring to be done;
(c) Selection, testing, calibration, maintenance and issue of suitable dosimeters and other instruments;
(d) Monitoring and sample collection;
(e) Processing and interpretation of individual and area monitoring data;
(f) Maintenance of adequate records and provision of the means to report such records;
(g) Quality assurance;
(h) Provision of trained staff for the above activities;
(i) Provision of materials and supplies to protect workers, including respirators, disposable clothing and airpacks;
(j) Decontamination of workers;
(k) Provision of first aid teams and other medical support;
(l) Control of non-radiological health problems within the cleanup zone, e.g. concerning sanitation and decaying foodstuff or garbage.

In considering the cleanup of areas shortly after the accident, a decision would have to be made whether to implement cleanup actions immediately and thus cause higher occupational doses or wait until short lived isotopes have decayed and/or weathering has reduced the radiation levels. For example, the decision may be to stabilize the contamination using sprays to prevent resuspension followed by a delay before actual cleanup starts. The timing of such actions would be determined by the Emergency Director in consultation with the Cleanup Director at the time of the planning for cleanup and would depend on many factors, including: weather conditions, the area involved, available equipment, and the training and type of workers.

Means of reducing occupational exposures during the performance of all tasks should be clearly outlined in procedures. In general, reductions in occupational exposures during operational tasks can be accomplished by reducing radioactive sources, dose rates or the time workers spend in radiation zones, as well as by using protective clothing, respirators and shielding. During the cleanup of the most highly contaminated areas at Chernobyl, heavily shielded bulldozers and a variety of remotely operated vehicles were used to reduce occupational exposures [7]. The cabs of the operator driven vehicles also had clean-air supply systems.

An important way of reducing occupational exposures is to minimize the time workers remain in radiation fields, especially high level fields. Thus, any technique that allows the cleanup workers to perform duties more efficiently or in a shorter time should reduce exposures. For complicated cleanup or disassembly tasks, such as removing a highly contaminated piece of equipment, training of operators on mock-ups can lead to reduced occupational exposures.

Owing to the large number of workers involved, the large areas to be cleaned up and the long time-scale, the training of key workers to perform radiation protection actions themselves may be required or even desirable.

This section has briefly reviewed the methods which could be used to improve the radiation protection and safety of workers involved in the cleanup. The operational plan would, in addition, have to consider site and accident specific factors.

15. SUMMARY

The cleanup of large areas contaminated as a result of an accident at a nuclear facility could cost hundreds of millions of dollars and cause inconvenience to the public. Such a cleanup programme would be undertaken only if the detriment to health and social life resulting from cleanup activities would be less than that resulting from further exposures. All reasonable means should, however, be used to minimize the costs and detriment to humans of such a cleanup. For such a cleanup to be carried out safely, efficiently and as quickly as possible under adverse conditions requires:

(a) Good preliminary and final planning,
(b) A cleanup team having a well defined management structure and well trained personnel,
(c) Suitable cleanup methods and equipment and cleanup criteria.

However, it is recognized that further development of the technical and managerial information may require some additional activities, such as:

(1) Development of manuals summarizing important aspects related to the cleanup of large areas, e.g.:
  (i) Protocols for sampling and monitoring;
  (ii) QA related to all aspects of such a cleanup;
  (iii) The use of important types of equipment, with more detail than is available in current documents, and identification of how conventional equipment or methods can be modified to improve cleanup operations;

(iv) Assessment of the materials, equipment, costs and personnel required to clean up unit areas of specific types of zones, e.g. urban areas;

(v) Further guidance on the cleanup of urban centres.

(2) Development of an appropriate data management system and database required to handle large cleanups effectively, building on existing systems such as those described in Appendix B.

(3) Review of factors to be taken into account in optimizing cleanup planning and implementation.

Appendix A

BRIEF REVIEW OF CLEANUP METHODOLOGY AND TECHNOLOGY

A great deal of experience is available related to the decontamination of nuclear facilities and to the cleanup of small and medium sized land areas. A variety of techniques and equipment are available for the cleanup of contaminated areas and for the transportation and disposal of wastes arising from such cleanups [7, 10].

Reference [7] is a state of the art report reviewing in an integrated manner:

(a) Means of physically characterizing an area during normal emergency preparedness planning to get the information required to assist in cleaning up the area if it becomes contaminated;
(b) Deposition of contamination on surfaces;
(c) Means of characterizing the contamination after it has been deposited to define the regions which require remedial action to reduce dose rates to acceptable levels;
(d) Means of stabilizing the contamination to reduce its spread to clean areas, reduce resuspension and airborne contamination, etc.;
(e) Methods and equipment available to clean up/decontaminate (Table V):
  - Buildings, equipment and paved surfaces;
  - Large land areas;
  - Forest areas;
  - Aquatic ecosystems.

Guidance is also given on the selection and application of cleanup/decontamination methods, interdiction, and loading, transporting and disposing of large volumes of waste [7, 10].

Reference [7] also briefly reviews the methods and remotely operated equipment used during the cleanup of the area around the Chernobyl nuclear site.

The selection of methods and technical procedures for cleanup after an accident will be governed by criteria such as:

- External dose rates and the mixture of radionuclides present;
- The nature of the location and of items requiring cleanup;
- Mechanical properties of the materials requiring treatment;
- The availability of different methods of cleanup and the technical facilities for applying them;
- The availability of trained staff.

As an example, after the Chernobyl accident, the following procedures were evaluated:

TABLE V. SUMMARY OF METHODS AND EQUIPMENT AVAILABLE TO CLEAN UP/DECONTAMINATE DIFFERENT TYPES OF AREAS

Decontamination of buildings, equipment and paved surfaces

Precipitation runoff, washoff and weathering
Motorized sweeping and vacuum sweeping
Firehosing
High pressure water jetting (hydrolasing)
Steam cleaning
Aqueous methods incorporating chemical additives
Abrasive jet cleaning
Road planing/grinding
Spalling
Gels and foams
Strippable coatings
Cleanup of indoor contamination
Decontamination of equipment

Decontamination/cleanup of land areas

Physical and chemical methods
- physical and chemical separation of radionuclides from the soil
- deep ploughing
- removal of vegetation
- removal of surface soil

Biological decontamination of soil using plants
Restoring land to productive use
Decontamination of soil and vegetation in an urban environment

- Washdown of buildings, trees and roads with water and aqueous chemical solutions;
- Liquid and steam-jet cleaning;
- Shot blasting;
- Vacuum cleaning;
- Removal of the surface layer of soil by mechanical means;
- Removal and subsequent burial of structures, equipment and timber;
- Dismantling and removal of roof coverings;
- Dry decontamination using polymer films;
- Collection of contamination by adhesives;
- Isolation of areas prior to dust suppression;

— Covering with clean material such as concrete or asphalt;
— Binding of radionuclides into insoluble forms or conversion to soluble forms in soil.

Although a great deal is known about such cleanups, further work is required, especially on the decontamination of urban areas.

Appendix B

EXAMPLES OF DATA MANAGEMENT SYSTEMS WHICH COULD BE APPLIED TO THE CLEANUP OF LARGE AREAS

B.1. FEDERAL EMERGENCY MANAGEMENT AGENCY

In the USA, the Federal Emergency Management Agency (FEMA) is developing computerized aids to assist in accident assessment [18]. Its Integrated Emergency Management Information System (IEMIS) uses a digitized resources database as a geographical underlay for the organization of input and the display of output parameters in the form of a digital line graph subsystem. The cartographic database provides a national map system which is arranged for detailed studies of any area. The database includes political boundaries to county level, federal lands, roads and railway networks, hydrographic features such as various water bodies, and populated areas. The system has a suite of simulation models and is supported by advanced communications techniques and colour graphic chart and graph presentation.

The IEMIS is being developed to fulfil the following objectives:

(1) Increase the ability to review analytical options in planning emergency measures;
(2) Evaluate preparedness to commit resources by simulation of complex, interactive events;
(3) Improve exercises by providing realistic simulation of complex, interactive events;
(4) Develop credibility in the use of computerized aids to decision making in actual events;
(5) Allow study of post-event recovery options to optimize use of resources;
(6) Encourage and permit the maximum feasible access to the system from other agencies, states and local governments.

The basic IEMIS network is shown in Fig. 8. It is operational at FEMA headquarters, in the ten FEMA regions, at the National Emergency Training Center and in five states. The computer equipment is divided into three major components: the field workstations, the high resolution workstations and the central minicomputer [18]. Currently a field workstation supports each regional office. In future, each region will become a node with its own minicomputer acting as a hub for state and local use.

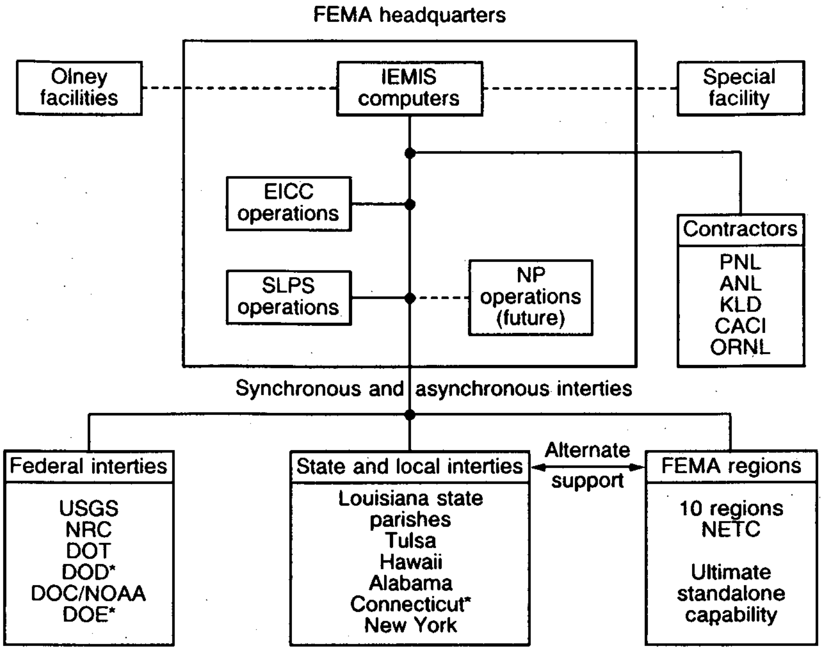


FIG. 8. Basic IEMIS user network. ANL, Argonne National Laboratory; CACI, CACI Inc. (data processing corporation); DOC/NOAA, Department of Commerce/National Oceanographic and Atmospheric Administration; DOD, Department of Defense; DOE, Department of Energy; DOT, Department of Transportation, Transportation Research Laboratory; EICC, Emergency Information Co-ordination Center, FEMA; KLD, KLD & Associates, Inc. (engineering technology corporation); NETC, National Emergency Training Center; NP, National Preparedness Office, FEMA; NRC, Nuclear Regulatory Commission; ORNL, Oak Ridge National Laboratory; PNL, Battelle Pacific Northwest Laboratory; SLPS, State and Local Program Support Office, FEMA; USGS, United States Geological Survey. (pending.)*

B.2. US DEPARTMENT OF ENERGY

A system similar to IEMIS is being prepared to assist the US Department of Energy in providing real time emergency response assistance to Government authorities during a serious radiological accident [17]. The core of the system includes geophysical databases, atmospheric transport and diffusion models, experienced staff and a communication network linking the central computer system and on-site computer systems.

B.3. JOANNEUM RESEARCH ASSOCIATION

The Mineral Resources Research Division of the Joanneum Research Association (JRA), Leoben, Austria, has developed a sophisticated data management system for geochemical exploration programmes and land use planning. Already a great amount of data is on the system, including: a variety of maps (soil, geology, topography, land use), demographic data, forestry data and geographical information for the province of Styria. The JRA is currently looking into the feasibility of using the system to assist in the management of data arising from the cleanup of large contaminated areas. The JRA graphics are so designed that they can run FEMA software.

Systems such as those developed by the JRA are frequently found in the geological industries and can form the core of an accident site data management system [34]. The JRA presently supports not only extensive mapping graphics and a geographical information system but also geostatistical systems designed for kriging and spatial data analysis. Multivariate and univariate statistics for the interpretation of geochemical or geophysical data are implemented by user friendly systems with extensive interactive graphics support.

The computer systems and trained staff could be made available at very short notice (three to five days) at remote sites to form the core of an accident site data management system [35].

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