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IAEA SAFETY GUIDES

On-Site Habitability in the Event of an Accident at a Nuclear Facility

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA. 1989
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FOREWORD

During the history of the development and operation of nuclear power facilities the safety record has in general been excellent because of the high standards observed in siting, design, construction, operation, training and maintenance. However, more recent and more stringent design criteria coupled with experience gained from a few accidents at nuclear power plants, notably the fire at the Browns Ferry nuclear power plant and the accident at the Three Mile Island nuclear power plant, both in the United States, and the accident at the Chernobyl nuclear power plant in the Soviet Union, indicate that improvements in safety are still possible.

Effective control of accidents and recovery from them require that operating and emergency response personnel should have access to certain ‘vital areas’ of the installation and, if necessary, be able to remain in them. These areas include, for example, the control room, key plant control areas, emergency response facilities, laboratory facilities, and access routes to and between these areas. In this report it will be convenient to use the term ‘habitability’ to describe a condition that determines whether or not occupancy of an area is possible on a continuous or transient basis.

Experience has shown that in an accident situation, plant personnel may be at risk from radiation dose rates exceeding any selected and specified governing limits and also from conventional hazards such as missiles, high temperature steam, smoke and toxic gases. The causative factor or event which produces these hazards may occur on or off the site, and it may be something over which the plant operator has no control. This does not mean that nothing can be done to prevent the effects of hazards from having adverse consequences for habitability. Improvements and corrective measures can be designed into new installations or implemented at existing facilities, and it is in relation to existing facilities that this report will almost certainly find its greatest use. The report does not directly discuss radiation protection principles applying to the control of emergency workers under accident conditions at a nuclear facility; guidance on this matter is being developed in another publication.

When assessing matters of habitability, it is essential that an appropriate range of accident scenarios should be examined in order to identify the source of hazards, their effects in terms of location and severity in those locations, and the locations and routes which are or will become the vital areas for control of the potential accident being examined. From that point, it becomes possible to identify and take appropriate corrective measures to ensure that vital areas will either not be affected at all by an accident or will be only marginally affected. Corrective measures might
include, for example, changes at the design stage in plant layout or location of off-site facilities. Later modifications, once the plant is established, might be made in engineered safety features or systems, in construction of vital areas in buildings, in operating procedures or even in the emergency response plans themselves.

The International Atomic Energy Agency was asked by a group of consultants in radiation protection to review the subject of habitability, to provide guidance that would assist regulatory bodies, designers and operators in assessing habitability in existing installations and at the design stage for new plants, and to suggest actions to improve habitability in the event of an accident. This guide is intended to complement the IAEA's existing technical guidance on emergency planning and preparedness. Habitability is but one aspect, although a very important one, of emergency preparedness. It has sometimes been too readily assumed that vital areas, including emergency response facilities, will remain operational and unaffected by an accident. If this assumption is made it should be verified, and this report, forming as it does part of the Agency's guidance for emergency preparedness at nuclear facilities, puts forward a generic methodology for making the necessary assessments and verifications to improve habitability. Similarly, it should not be assumed when using this methodology that an accident, if it occurs, will inevitably follow any one of the predetermined and selected scenarios used in the assessment. While the amount of detail in the assessment of habitability will decrease as the probability of occurrence of a particular accident decreases, the need to use imagination in applying an assessment methodology remains paramount.

The assessment methodology outlined in this report, if properly and thoroughly applied, could assist in revealing potential weak points at which habitability might be endangered. The degree of success achieved in this assessment will be largely dependent on the imagination and original thought applied in the assessment so that the proper corrective measures are implemented. To remove the problem is more effective than merely to solve it; it is easier to do this at the design stage than to make changes after construction (backfitting), and it is better to backfit than to have to rely upon possibly complex and costly equipment to improve habitability after an accident has taken place. It may, in fact, not even be possible to improve habitability substantially once an accident has taken place.

This report was prepared by an Advisory Group and consultants comprised of experts nominated by Member States and international organizations. The Advisory Group members and other representatives who participated in the development of the report are listed at the end of the book. Meetings of the Advisory Group were held in Vienna in 1985 and 1986 under the chairmanship of Erika Appelgren of the Swedish State Power Board. The Agency wishes to express its gratitude to all members of the Advisory Group and the consultants who contributed to the preparation of this report, and particularly to Thomas Peterson of the General Dynamics Corporation (USA) who was a primary consultant to the Advisory Group.
and the Agency in this regard. Consultants meetings associated with the preparation of this report are also listed at the back of the book.

During the consultants meeting held in October 1986, this Safety Series publication was reviewed in the light of material presented in the report dated August 1986 by the USSR State Committee on the Utilization of Atomic Energy: The Accident at the Chernobyl Nuclear Power Plant and its Consequences. The consultants also examined IAEA Safety Series No. 75-INSAG-1 (1986), Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident, for material relevant to the development of the present report. It is interesting to note that, although this guide was essentially drafted before the Chernobyl event, the methodology for assessing on-site habitability (particularly in reference to Chernobyl Units 1 and 2) remains valid and unchanged.

The IAEA believes that the technical guidance in this publication will assist regulatory bodies, designers, constructors and operators of nuclear installations to apply some of the general principles laid down in earlier reports in the Agency’s Safety Series. It suggests a methodology but is not a collection of rules for its application. Moreover, any methodology will need re-examination as time passes and new knowledge or experience is gained. The guidance given here should also assist in achieving not only its immediate aim of protecting plant personnel and maintaining control of the operations but also its wider aim, which is to protect the public and the environment. It is not suggested that protection can be made absolute, but the application of this assessment methodology can assist in improving on-site habitability where habitability may be in doubt.
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1. INTRODUCTION

1.1. PURPOSE

This publication is intended to provide technical guidance and a methodology for regulatory bodies, designers, constructors and operators of nuclear facilities to assist them in assessing the current situation as regards on-site habitability for their specific nuclear facilities. (The term 'habitability', for the purposes of this report, describes a condition that determines whether or not occupancy of an area is possible on a continuous or transient basis.) Any of these groups, after making their assessment, should be able to proceed to determine what practical modifications may be necessary or desirable, from either a technical or a procedural standpoint, to improve on-site habitability.

The assessment procedure can be used not only for potential radiation accidents but also to consider the effects on habitability of those probable non-radiological events which, if not correctly and effectively countered, could lead to the development of potentially unsafe conditions in the facility itself. The object of the assessment remains the assurance of the continued safety of the facility, and thus the protection of operating personnel from radiological and non-radiological hazards and of the population at large from any radiological consequences. Initially, the aim will be to ensure that the 'vital areas' of the facility which are necessary for the safe operation and shutdown of the facility will remain habitable, in some cases continuously and in others transiently, in the event of an accident inside or outside the installation.

The procedure outlined should ideally be used at the design stage for new facilities but, because it is now clear that some existing facilities may not meet the latest standards and practices, its main use is expected to be to review habitability in those facilities where habitability may be in doubt. In certain circumstances, and particularly in slow breaking accidents or those in which habitability will be adversely affected over a long period of time, the methodology may also be found helpful by site emergency response personnel who must decide upon appropriate actions needed to ensure habitability of vital areas. It must be re-emphasized, however, that application of these techniques before an accident is much more desirable and effective than any attempt to apply them once an accident has occurred.

1.2. SCOPE

1.2.1. Types of facilities considered

The guidance given in this report is relevant to all kinds of nuclear facilities: nuclear power plants, research reactors, fuel reprocessing plants, and other facilities where significant quantities of radioactive materials are stored or used in industrial
or other processes. The examples given for illustrative purposes are, however, drawn from situations which could occur in a nuclear power plant.

1.2.2. Types of hazards considered

The hazards which may affect the accessibility and habitability of vital areas within the plant and the accessibility and operability of essential plant control systems may arise on or off the site and may be man induced or natural. Man induced hazards may be accidental (for example, the result of failures in design or material) or created by improper operation of otherwise safe systems or equipment. Apart from releases of radioactivity, they include fires, explosions, releases of toxic gases and corrosive fluids. Natural hazards include earthquakes, floods and even very severe storms.

1.2.3. Types of accidents considered

For the purposes of this report, accidents have been divided into two categories, radiological and non-radiological, according to the nature of their main effects on habitability. Habitability assessments and reviews should not be limited to design basis accidents only, because more complex combinations of events can credibly occur. Particularly is this so where an off-site or natural event may create adverse on-site effects on the control of the facility and the habitability of its vital areas.

1.3. LIMITATIONS

This report does not consider extreme events or combinations of events where the probability of occurrence is very small even though their potential consequences would be very serious. A suitable upper level of probability of occurrence for planning purposes must be selected if realistic assessments are to be made. The consequences of acts of war and major terrorism are not considered here. The consequences of minor acts of sabotage are unlikely to be essentially different from those of ordinary equipment failures or malfunction.

Neither off-site conditions nor the response to them, except in so far as they affect on-site habitability, are considered here. These are addressed in other IAEA Safety Series publications in the area of emergency planning and preparedness.

1.4. RELATIONSHIP TO OTHER IAEA GUIDES

This report, although intended to stand on its own without requiring constant reference to other IAEA publications, should be read in the light of the guidance
contained in the Nuclear Safety Standards (NUSS) guides, Basic Safety Standards for Radiation Protection—1982 Edition, Safety Series No. 9 [1], Basic Safety Principles for Nuclear Power Plants, Safety Series No. 75-INSAG-3, which is a report by the International Nuclear Safety Advisory Group [2], and in other Safety Series publications. IAEA reports dealing with the wider aspects of siting, design, operation and emergency planning and preparedness are also relevant to habitability and accessibility.

2. KEY ELEMENTS OF A HABILITABILITY ASSESSMENT METHODOLOGY

2.1. GENERAL

Before discussing a generic methodology for habitability assessment leading to any necessary improvements, it is useful to examine some key elements which are fundamental to the assessment process. These are:

(a) The accident scenario
(b) The hazard source
(c) The habitability criteria.

The accident scenario and the hazard source are interdependent and together they form the base for the generic methodology. These two key elements also lead to the third, the habitability criteria, which are used in the methodology to judge whether or not the conditions in the area of interest in the facility are acceptable.

These key elements are discussed in this section, while specific guidance on how to develop and evaluate them in accordance with the steps in the methodology is given in Section 3.

2.2. THE ACCIDENT SCENARIO

Postulated accident scenarios are usually developed for two purposes: (1) to verify the design of a nuclear facility (the design basis accidents) in terms of being able to withstand, control and contain the thermal or other effects of accidents and the release of radioactive materials used within the facility; and (2) to help establish an emergency planning basis and a preparedness infrastructure for the facility both on and off the site. Generally, the scenarios postulated for the second purpose are by nature more severe than those for the first.

The quality and thoroughness of the design analysis made for a nuclear facility before it became operational, and the accident scenarios which were analysed with habitability considerations specifically in mind, together determine, in large
measure, the range of scenarios which should or could be used to assess habitability beyond the scenarios in the first category. Generally, for older facilities insufficient attention may have been paid to on-site habitability, and in this case the range of scenarios that can be used to assess habitability may be larger than in the case of newer facilities where the analyses have taken recent accident experience into account. The scenarios can be divided into radiological and non-radiological hazard types.

2.2.1. Radiological accident scenarios

Radiological accident scenarios are based upon successive breaching of the many barriers between the radioactive material's normal place of confinement and areas where it is not intended to be. Habitability of these areas may thus be compromised. The scenarios are also based upon the operation, partial operation or failure of various engineered safety systems used to control the progression of an accident. By nature, they are highly specific to the facility involved. Accident scenarios may also be based upon or further aggravated by operator errors, which have been an important factor in accidents of record [3–5].

2.2.2. Non-radiological accident scenarios

Non-radiological accident scenarios are based upon the presence of chemical or toxic substances and physical agents in the plant, on the site and in some cases off the site as well. The scenarios focus on accidents involving these materials, which in turn may result in a release of the materials, thereby compromising habitability in the nuclear facility [6]. For some scenarios, a secondary effect may be the compromise of habitability and damage to equipment or other vital features, thus leading to a radiological hazard.

2.3. THE HAZARD SOURCE

The hazard source and the accident scenario are interdependent. On one hand, the existence of a hazard source forms the basis for the accident scenario. This is typically the case when dealing with non-radiological hazards, as mentioned in Section 2.2.2. On the other hand, the scenario itself will serve to characterize the source as to both composition and quantity. This relationship is applicable to both radiological and non-radiological hazards.

An evaluation of sources and scenarios should have been conducted when originally designing the plant. Normally, with good facility design which is predicated upon thorough analysis for a wide spectrum of accidents, the majority of these hazards should have been eliminated or at least reduced substantially.
However, design acceptability is often based upon the proper functioning of engineered safety systems. Should any of these systems fail or operator errors occur, some of these hazards could develop to the point at which they would pass outside the ‘design envelope’ of the facility. Moreover, in older facilities which in retrospect may be seen to have insufficient design in some areas, the hazards which can manifest themselves may be unique; there may be more of them, or they may be different in nature from those in more modern facilities. In addition, as time passes, other potential scenarios may evolve owing to changes outside or inside the facility.

2.3.1. Radiological hazards

A radiological hazard source is of course based upon the presence of radioactive material in the nuclear installation. The type and amount of radioactive material is uniquely installation specific. As mentioned in Section 2.2.1, on-site habitability might be compromised owing to the breaking of barriers between the radiological material’s normal place of confinement and other areas in the installation.

For example, if the scenario is a loss of coolant accident inside the containment of a light water reactor, the source will be the radioactivity released to the atmosphere and water within the containment. This radiological source can then be spread throughout the facility by leakage and/or by operating systems connected with the containment or released to the environment owing to containment failure [5]. Another example of a radioactive source is the radioactive material collected in an off-gas treatment system. A scenario involving fire in off-gas filters, for example, will lead to spreading of this source to different areas in the plant.

Thus, the main interest when making an assessment of habitability is not to know the total amount of radioactive material in the plant or in a certain location. It is, rather, to know the amount and type of radioactive materials and the transport mechanisms or paths that can lead to affected areas that need to be habitable or at least of limited accessibility under accident conditions. To obtain this knowledge, the source has to be identified and evaluated (this is further discussed in the description of the methodology in Section 3).

2.3.2. Non-radiological hazards

The observations concerning radiological hazards in Section 2.3.1 are generally valid for non-radiological hazards which may be generated by accidents occurring during operation of the nuclear facility or by accidents occurring in on-site equipment or facilities which are not radiological in nature. For some nuclear facilities, the proximity of off-site hazardous materials, whose release might affect the habitability in the nuclear facility itself, poses additional considerations involving determination of the quantification and characterization of the non-radiological
hazards involved. Accident scenarios postulated for these off-site hazardous materials facilities will lead to this determination. Here again, these scenarios are uniquely site specific.

Non-radiological hazards can be divided into two basic categories: chemical or toxic substances and physical agents. Also included among the non-radiological hazards are natural hazards of off-site origin.

2.3.2.1. Chemical or toxic substances

Various chemical or toxic substances, acids, alkalis, gases and organic compounds are used in or around nuclear facilities which could cause habitability problems should they be released by accident. These may include (but are by no means limited to) chlorine used in some facilities for water treatment, coolants such as metallic sodium, carbon dioxide, nitrogen used in inert atmospheres in the containments of some reactors, and hydrogen and hydrazine which are added to reduce water oxygen levels. Each of these may present its own unique problems relative to habitability and should be examined as a hazard to personnel and to the facility from the point of view of operational safety. Clouds of chemical gases, volatiles and smoke or fumes from accidental releases could enter ventilation system intakes, leading to serious effects on the facility personnel. Corrosive gases and liquids can damage various equipment in safety systems, e.g. insulation of electrical cables. Release of these toxic materials can also potentially result in the control room and other vital areas of a facility becoming inaccessible or uninhabitable if prompt isolation of the release or of the vital areas is not feasible.

2.3.2.2. Physical agents

IAEA Safety Series No. 50-SG-D5, External Man-Induced Events in Relation to Nuclear Power Plant Design [7], provides information on physical agents which could be involved in accidents at a nuclear facility. These include:

(a) Fire

Fires are common to a number of accidents. On the site they may be, for example, fuel fires, electrical fires, flammable gas fires or material fires. All of these could generate smoke, dust, corrosive/toxic gases or vapours and aerosols. The burning of organic materials, such as electrical insulation or plastics, may generate toxic fumes. In the event of a serious fire, smoke, CO or toxic fumes may penetrate some vital areas, not only affecting habitability but also cutting off emergency access and escape routes or pathways to and from the vital areas. Also, vital equipment may be directly or indirectly affected by the fire. The Browns Ferry nuclear power plant fire accident in March 1975 in the United States of America demonstrated some of these
effects upon habitability [6]. Fire fighting equipment and materials used for fighting chemical and electrical fires should also be considered as potential sources of hazardous chemicals (CO$_2$, halogens, etc.) Fire fighting materials such as water may also directly affect the operation or performance of vital on-site equipment and sometimes lead to the generation of additional smoke or fumes as combustion temperatures in the fire are lowered.

(b) Steam release

High temperature steam released from leaking pressurized systems or components may cause some similar problems. There have been incidents in nuclear power plants where high temperature steam and water releases resulted in deaths and injuries. In some designs, control rooms are located relatively near turbine buildings, in which case escaping steam might enter a control room if isolation is not available. Other vital areas located near the turbine building may be affected in the same way.

(c) Missiles

Missiles can be caused by explosion, rupture or failure of equipment with high potential energy such as a pressurized tank or with high kinetic energy such as high speed rotating equipment. The probability of the control room being hit by missiles should normally have been analysed as a part of the design process.

2.3.2.3. Natural hazards

Assuming that the radiological integrity of the installation is unaffected by the impact of phenomena like earthquakes, floods and extreme meteorological events, losses of power, confinement barriers or communications equipment and damage to machinery may still occur, and these could affect habitability. Normally, safety features designed to cope with these effects should operate automatically, but this does not imply that the protective features of vital areas at risk need not be examined in an assessment of habitability. The effects of the phenomena might also directly or indirectly affect vital areas on or off the site (e.g. by loss of access through damage to buildings). Other vital facilities not located on the plant site but belonging to the nuclear power plant operating organization, such as emergency response facilities and laboratories, might also be affected, rendering them uninhabitable or reducing their usefulness.

2.4. HABITABILITY CRITERIA

In order to be able to judge whether habitability is acceptable in the vital areas, some criteria are needed against which existing and predicted conditions can be judged. The methodology for so doing is described in Section 3.
Habitability criteria can be selected or established for all hazards, both radiological and non-radiological. However, the levels of knowledge about these criteria differ not only between these two fields but also between one hazard and another. For instance, limits established for radiation exposure are universally recognized [8] and are based on reducing stochastic effects to an acceptable level and avoiding non-stochastic effects. The limits established leave a wide margin between the specific limit and the point at which a worker is either considered to be overexposed, or temporarily or permanently incapacitated. On the other hand, in the case of chemical or toxic substances and physical agents which may cause harm to workers, a slight exceeding of a limit may cause a temporary incapacity of some exposed individuals which could have relatively immediate severe consequences upon a facility’s operations and maintenance, which is not the case for slightly or moderately exceeding radiation exposure limits. Therefore, not only impairments to health but all the potential consequences of exceeding a prescribed limit should be considered when habitability criteria are established.

The habitability criteria selected or developed are based upon human exposure (as opposed to equipment exposure) and should be developed on the basis of occupational exposure levels for an unprotected individual. A good basis for reference will be the maximum permissible occupational exposure as promulgated in applicable national or international standards. In the case of radiological hazard, one of the parameters of interest will be the dose delivered to, or projected for, the individual. The concept of collective exposure is also of interest, and it will be explained later how these various criteria can be applied in the assessment of habitability. Radiological protection of the public under accident conditions is not discussed in this report and may be found in Refs [9–11] and elsewhere.

### 2.4.1. Radiological hazards

By way of example, when considering an accident scenario involving the release of radioactive materials into vital areas, a habitability criterion (in reality, a limit) for radiation exposure to personnel must be developed. On the basis of radiation protection standards [8], the current occupational limit of 50 mSv (5 rem) for whole body exposure could be recommended for planning purposes for the duration of the early and intermediate phases of the accident [9–11]. This number is then used in conducting the analysis for evaluating whether or not dose rates in various areas are acceptable on the basis of occupancy times expected for those areas.

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1 The IAEA is preparing additional guidance on radiation protection principles applicable to the control of emergency workers under accident conditions at a nuclear facility.
Hazards may also exist as a result of contamination and inhalation but these hazards can in general be mitigated by the use of personnel protective equipment such as special clothing and respiratory protection devices.

2.4.2. Non-radiological hazards

If the accident scenario involving a leak of a toxic substance is considered (such as chlorine), then criteria relative to the maximum concentration of that substance to which individuals could be exposed would have to be considered. If the accident scenario involving a major steam release is considered, then habitability criteria for steam relative to temperatures and oxygen concentration would need to be developed or acquired.

For example, for an accident scenario involving the release of chlorine gas, a habitability criterion for exposure to chlorine must be developed. On the basis of one existing regulation [12], a ceiling limit of 1 ppm (3 mg/m$^3$) is established. This limit of 1 ppm Cl is therefore a habitability criterion for chlorine gas. It is noted that this value, unlike habitability criteria established for radiation exposure rates, is an upper limit that should not be exceeded.

3. A GENERIC METHODOLOGY FOR HABITABILITY ASSESSMENT

3.1. GENERAL

This section describes a generic methodology to assess habitability at a nuclear facility and to aid in developing actions which could be taken to improve habitability in vital areas. These actions are further discussed in Section 4. The method used divides the process into discrete, manageable steps and has been devised to be applicable to the assessment of any type of postulated nuclear facility accident and to any nuclear facility. The methodology is applicable to other types of installations or plants containing large quantities of radioactive materials or hazardous substances.

The method described in this section is illustrated in the flow diagram, Fig. 1, which shows how the discrete steps of the assessment process are interconnected. This section discusses the process in generic terms and, where applicable, section numbers in the text are identified on the flow diagram.

The process as discussed here is considered to be iterative. The initial assessment of habitability is made in a rather general manner, associated with any simple actions which could be taken to improve habitability should it be found deficient.
FIG. 1. Flow diagram illustrating methodology for habitability assessment. Numbers beside the boxes indicate corresponding sections in the text.
Once all the simple actions are exhausted, then the second part or the refined analysis takes place where the level of detail is considerably raised. It is recognized that portions of this process may not be utilized since, in some cases, simple actions could completely solve the problem, while in others no simple solutions may be available and a detailed or refined assessment might therefore be required. More detailed examples of the use of this process are given in Appendices A and B.

3.2. DEVELOPING THE ACCIDENT SCENARIO

The experience gained from the accidents at the Browns Ferry, Three Mile Island and Chernobyl nuclear power plants [3–6] and other less severe accidents has shown that, in choosing a particular accident scenario for the purpose of evaluating on-site habitability, the conditions and effects of the event should reflect those combinations of man induced events, natural phenomena, equipment failures and operator errors which could credibly occur simultaneously and independently [13, 14].

Every conceivable accident scenario cannot, of course, be studied, and the evaluators must decide upon the appropriate level or range of the more credible scenarios and the detail in which they are developed. However, it can be suggested that, for a basic assessment of habitability, the design basis type of accidents for the facility can be used as one starting point for further expansion of the scenarios. It is emphasized that the design basis accidents should only be used as a possible starting point since there can be a broad range of possible events that could cause habitability to deteriorate to such a level as to place operating staff and the safe operation of the facility in jeopardy. It is therefore suggested that accidents should be considered which go beyond the design basis accidents, particularly where significant changes in habitability develop as a result of the ‘extended scenarios’.

In any event, the scenarios chosen should be representative, challenging and credible, taking into account recent accident experience [5, 6], and should be based upon both radiological and non-radiological hazards. They should be directed at challenging the habitability of areas where personnel will require access to restore the facility to a safe configuration and so to mitigate any additional consequences of the accident itself.

3.3. EVALUATING THE HAZARD SOURCE

The next step in the methodology is characterization of the source of the hazardous material since it is this material (e.g. radionuclides, toxic chemicals, etc.) which will ultimately be released, transported, and will possibly reside to some degree in vital areas within the facility, thereby affecting habitability. The fact should
be considered that the quantity of material released may be time dependent and this should be recognized when developing the characterization of the source; for example, concentrations of hazardous materials in vital areas may change with time owing to factors such as release rates, source decay or certain engineered safety systems or cleanup mechanisms. In the nuclear safety and radiation protection sense, this source characterization is traditionally known as the source term\(^2\). For non-radiological events it is merely a determination of the amount of material that could be released and would have to be dealt with during the course of the accident. Consideration should also be given to the detailed composition of the hazard source. As an example, in the case of radioactive accidental release, parameters other than total activity should be considered, if possible, such as nuclide composition, chemical form, particle size, etc.

In some cases, non-radiological events may not directly cause impairment of habitability but may damage the plant and thus, secondarily, may cause a radiological hazard which will make habitability unacceptable. Good examples of these events are earthquakes or fires. Non-radiological hazards must be examined in the same detail as radiological hazards, taking into account the basic principles discussed in Sections 1 and 2. Situations where radiological and non-radiological sources exist in combination also merit similar consideration.

3.4. DETERMINING THE GENERAL AREAS OF INTEREST

Once the accident scenario has been chosen and developed and the hazard sources have been determined, it is necessary either to know or to decide in what general areas of the facility it is desirable to maintain habitability so that the situation can be controlled. Areas such as the control room, technical support centre, emergency power facilities and auxiliary equipment buildings are examples of places to which the hazardous substances may be transported. In the initial assessment, these areas can be defined and examined in general rather than in great detail.

\(^2\) Recently, during the deliberations of an IAEA Advisory Group working on a document on principles and methods for the early monitoring of the release source associated with an accident in a nuclear installation, a distinction was suggested between 'source term' and 'accident release source'. According to this distinction, the source term is defined as the quantity, timing and characteristics of the release of radioactive material to the environment following a postulated severe reactor accident, determined from a combination of fault tree analyses, data on material, system and plant behaviour, and the assumptions used for safety studies, regulatory requirements and probabilistic risk assessments. The term 'accident release source', according to this distinction, is derived from measurements made during an actual release and is specific to that particular accident.
3.5. EVALUATING THE TRANSPORT MECHANISMS TO AREAS OF INTEREST

After the potential amount of hazardous material involved in the accident scenario has been established and the general areas of interest identified, the transport mechanisms or pathways for transporting the material to these areas can be evaluated.

For example, a variety of mechanisms may have to be considered, such as the wind which could carry (and dilute) a toxic gas from a nearby railway accident to the facility and its building penetrations, and ventilation systems which could carry the toxic material to areas within the facility and render areas such as a control room uninhabitable. Other mechanisms, such as piping systems which could carry highly radioactive material to various areas within the facility, making areas uninhabitable owing to high radiation levels, might also have to be considered.

3.6. QUANTIFYING THE LEVEL OF HAZARD IN AFFECTED AREAS

In this step, an estimate is made of the effects of the hazardous material that has been released during the postulated accident scenario and then transported to or throughout the facility. It is here that rough estimates are made of radiation levels or the concentration of chemicals or toxic substances in areas of interest. For example, a release of chlorine from a nearby railway accident could ultimately cause a significant concentration of the chlorine in the control room of a nuclear power station. In another example, highly radioactive post-accident effluent could cause high radiation levels in certain areas in the facility. The initial assessment should be made on a rather conservative basis and in general areas within the facility, followed up by a more specific assessment.

3.7. ESTABLISHING HABITABILITY CRITERIA

Habitability criteria, although not directly in the sequential analysis or assessment part of the flow diagram (Fig. 1), are nevertheless essential to obtaining a result at the first decision point in the assessment. Habitability criteria are an input to this assessment logic, as illustrated in Fig. 1.

Criteria for habitability must be selected or established on the basis of the specific hazards identified in the accident scenario, and should cover radiological and/or non-radiological situations as applicable. Also, in any assessment, more than one criterion may be required depending upon the accident scenario chosen if more than one hazard is involved. A general discussion of habitability criteria is included in Section 2, and specific examples are given in Appendices A and B.
3.8. DETERMINING IF HABITABILITY IS ACCEPTABLE

In this step the first comparison is made between the habitability criteria and the estimates made of the level of hazard within the areas of interest. In the examples cited previously, the concentration of chlorine gas in the control room would be compared with the established habitability criteria for chlorine. In the piping system transport mechanism mentioned above, the resulting radiation exposure in certain areas would be compared with the established habitability criteria for radiation exposure.

3.8.1. Habitability found to be acceptable

If the postulated accident scenario results in a situation where habitability in vital areas is acceptable, then no further analysis or assessment is required.

3.8.2. Habitability found to be unacceptable

Once it has been determined that habitability is unacceptable, the question should be asked: “Are there simple corrective measures that can be taken to reduce the hazard to an acceptable level or eliminate the hazard altogether?” Then follows an evaluation of whether or not simple solutions are possible.

3.9. DETERMINING IF SIMPLE SOLUTIONS ARE AVAILABLE

It is believed that in many cases relatively simple solutions can be found which will reduce the level of hazard presented by the postulated accident scenario to an acceptable value. These simple remedial or corrective measures or solutions should be implemented before a more detailed assessment is performed. Using the toxic gas accident scenario as an example, it might be possible to reroute shipments of toxic chemicals away from the facility in order to eliminate the possibility of the accident, or it might be sufficient to limit the size of the shipments so as to reduce the possible impact of the accident that would affect the facility. The choice between these various solutions will be influenced by several considerations, and can be based in part on a cost–benefit analysis. In the case of a release of radioactive material within the facility, a key solution that might be considered is to limit the consequences of the release by system isolation.

3.9.1. Take simple solutions if they are available

After a cost–benefit analysis has been performed and other considerations taken into account, certain simple solutions that are possible (such as rerouting...
vehicles carrying hazardous materials in the vicinity of a nuclear facility) should be implemented.

It will then be necessary once again to go through the ‘initial assessment’ portion of the methodology (Fig. 1) and make any required adjustment to the accident scenario, hazard source, transport mechanisms and quantification of levels, and finally to determine to what extent habitability has improved.

3.9.2. If simple solutions are not available

If the cost–benefit analysis and other considerations show that simple solutions are not feasible, then further analysis will be required.

3.10. PROCEEDING TO MAKE A REFINED DETAILED ASSESSMENT

After all possible simple solutions have been thoroughly examined and those practicable have been implemented, habitability may still remain unacceptable in some areas. A more refined and detailed assessment must then be made, and more elaborate solutions considered.

3.11. REFINING THE ACCIDENT SCENARIO

In refining the accident scenario, the original accident scenario as discussed in Section 3.2 will be used but it will be modified as a result of any actions taken under Section 3.9. More detailed postulations may be desirable if the original scenario used estimates or approximations, e.g. for time related corrective actions.

3.12. REFINING THE HAZARD SOURCE

Since this refined detailed assessment is examining the postulated event in somewhat more detail, the hazard source should now be scrutinized, particularly with respect to time. In cases where a mix of radionuclides is involved, each decays with its own unique characteristic which will in turn affect such things as ambient radiation levels in the vicinity of post-accident effluents. Similarly, the rate of release of a toxic chemical from a tank will often vary with time and, in cases where it is highly chemically reactive, may also change in chemical composition. These factors will all play a role in the refined analysis and should therefore be examined in detail.
### TABLE I. MATRIX FOR HABITABILITY ANALYSIS

Functional group: ____________________

<table>
<thead>
<tr>
<th>Specific operation</th>
<th>Time after accident</th>
<th>Estimate of man-hours needed</th>
<th>Plant location</th>
<th>Projected dose rate (mSv/h)</th>
<th>Total exposure (man·mSv)</th>
<th>Total number of people exposed</th>
<th>Average exposure per person (mSv)</th>
<th>Habitability criteria</th>
<th>Habitability condition acceptable YES/NO</th>
<th>Action required</th>
<th>Additional remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
<td>(8)</td>
<td>(9)</td>
<td>(10)</td>
<td>(11)</td>
<td>(12)</td>
</tr>
</tbody>
</table>
3.13. DETERMINING SPECIFIC OPERATIONS OR ACTIONS REQUIRED BY PERSONNEL

To bring an accident under control and/or maintain a facility in a safe condition, certain operations or actions will be required of facility personnel. Equipment must be monitored, operated and maintained, and in order to do this, facility personnel must have access to certain areas.

Once the accident scenario has been chosen and developed, a list of those tasks should be developed for each functional group of interest such as operator function and maintenance function actions. An example of a technique for doing and displaying this is shown in Table I. Column (1) of this table should include, for the functional group, discrete specific operations or actions required; column (2) should include the time after the accident the action is taken; column (3) the estimate of the man-hours needed for the specific operation or action and for its total duration (e.g. if 1 man-h/d is required over 30 days, then 30 man-h should be entered in column (3)). Also the total number of people involved in each required action should be noted in column (7).

If the action in question will have to be repeated at intervals throughout the duration of the accident, or until habitability is once more acceptable in the location in question, this fact should be noted in column (2) of Table I and the projected dose rates for each occasion can be adjusted to take account of radioactive decay or reduction in dose rates due to functioning engineered safety systems or cleanup mechanisms.

Note: The refined detailed analysis discussed here is performed through the use of a table (Table I) in which are displayed specific operations or actions of individuals, the areas (vital areas) where these operations or actions must take place, and the duration of these operations or actions. In setting up the table, it must be decided how the determination of acceptability of habitability is going to be established. The example shown is for a time related hazard (e.g. radiation exposure) but the table could be set up to evaluate threshold type habitability criteria (e.g. exposure to a toxic chemical, as shown in Appendix B).

3.14. IDENTIFYING VITAL AREAS

Once the specific operation or actions required by the personnel involved are determined as explained in Section 3.13, the location of areas to carry out those actions should be identified. These areas are classified as vital areas and should be posted in column (4) of Table I. There may well be some other areas in which habitability must be ensured, such as access routes and other areas leading to and from these vital areas. These too should be carefully listed.
3.15. EVALUATING THE TRANSPORT MECHANISM

In the refined analysis portion of the methodology, the transport mechanisms for carrying the hazard source to vital areas are examined in more detail than in Section 3.5. In this case, specific vital areas have now been identified, and considerations of transport times, leak rates, dilution and cleanup mechanisms should all be taken into account when identifying the transport mechanism to each of the vital areas. In support of steps 3.16 and 3.17 of Fig. 1, where the hazard levels must be quantified by locations, it may be useful in evaluating the transport mechanisms to identify the areas in which the systems are located and their positions relative to one another. This is particularly so in the case of radiation hazards.

3.16. QUANTIFYING THE LEVEL OF HAZARD

As the next step, the level of hazard with the potential for affecting habitability must be determined throughout the facility's vital areas. The calculations of hazard levels are based upon the information derived from the earlier evaluations of hazard sources and transport mechanisms. The purpose of these calculations is to help establish whether or not habitability criteria are being exceeded in areas where personnel must go to ensure that the facility is operated in, maintained in, and restored to a safe condition or configuration. The level of hazard should be calculated for different points in time throughout the duration of the accident.

3.17. MAPPING THE PROBABLE EXTENT OF THE HAZARD

To obtain a good overview of the assessment results, it is suggested that the information derived from the calculations of the level of hazard is presented in the form of coloured layout diagrams, where the areas are classified in ranges of hazard levels; each colour representing a different range of hazard. The appropriate ranges should be selected on the basis of the results of the calculations. Examples of coloured layout diagrams of this type are shown in Appendix A; these examples are derived for radiation levels and are discussed in more detail in that appendix. A similar approach could be used for anything affecting habitability, such as high temperature, toxic chemicals, steam, smoke, etc. An example of this is shown in Appendix B.

The results obtained from the calculations of hazard levels can now be used to fill in the information in column (5) of Table I. Column (5) should show the exposure level, which will be expressed in terms of exposure rates or concentrations. For time related hazards, e.g. radiation hazards, dose rate will be entered, as mSv/h; for chemical hazards, concentration in air will be entered; for physical agents the
related quantities will be entered, such as °C for temperature, and so on. The coloured layout diagrams are especially useful when evaluating the hazard level along the access routes to vital areas, which may vary considerably.

3.18. EVALUATING HABITABILITY ACCEPTABILITY

On the basis of detailed knowledge of what specific operations or actions are required, their duration, and in what vital areas the actions have to be taken, combined with the information about the projected hazard levels, habitability can now be evaluated.

Using the entries in Table I, for each action calculate the total (collective) exposure (column (6)). When this value is combined with the total number of people exposed (column (7)), then the average exposure per person (column (8)) can be developed. This average exposure is then compared with the habitability criteria established (column (9)) and a determination of habitability can be noted in column (10).

This evaluation is made using the first point in time after the accident at which the specific operations or actions will have to be undertaken. The intervals at which the action must be repeated can be indicated in column (2) (see Section 3.13). If habitability is determined to be unacceptable at the time of the ‘first entry’ for repetitive operations or actions, an expanded study might be useful on the exposure rates and resulting exposures for the points in time when the operation or action must be repeated. The structure of Table I is still valid for this reiterative process of assessment.

Caution must be used at this point since the determination has been based upon an average exposure. If there are cases where an individual could exceed the criteria established for an individual exposure because, for example, a specific part of an operation required a highly skilled person over a relatively long period of time, then individual exposures would have to be examined in detail and habitability criteria applied on the basis of individual exposure.

3.18.1. Habitability found to be acceptable

If, in the refined analysis just undertaken, habitability is found to be acceptable, then no further action is required for the given area/action.

3.18.2. Habitability found to be unacceptable

If the refined analysis shows that habitability is unacceptable, then further corrective actions will be required as discussed in Section 3.19.
3.19. DEVELOPING AND IMPLEMENTING ACTIONS TO ENSURE HABITABILITY CRITERIA ARE MET

If it has been determined that habitability is unacceptable for given operations and these operations must be performed in order to bring the accident under control or to maintain the facility in a safe condition, then techniques must be devised to allow the operation to be carried out in a manner which is safe for personnel. It is assumed that these techniques will be more complex than the ‘simple actions’ described in Section 3.9. As an example, using a railway accident scenario involving the release of chlorine gas (assuming nothing could be done to reduce the possibility of the accident or its magnitude), the facility control room (which has to be permanently occupied) might have to be equipped with a ventilation system that would remove chlorine or prevent entry of chlorine into the ventilation system. Areas where temporary occupancy was required might have to be reached using self-contained breathing devices. The techniques for coping with habitability restrictions can include changes in operating and maintenance procedures, system changes or backfitting, or improvement of control instrumentation. Various techniques for improvement of habitability for both radiological and non-radiological situations are discussed in Section 4.

3.20. SUMMARY

A generic methodology for assessing and implementing improvement in habitability at a nuclear facility has been described. In this analysis, a scenario is developed, hazards in vital areas determined, and an assessment made concerning habitability which leads to actions either simple or complex which must be developed and implemented. As previously discussed, this process proceeds from a conservative/general analysis and assessment technique through a more refined reiterative level of detail until acceptable levels of habitability are achieved so that the facility might be operated and/or maintained in a safe condition or configuration throughout the course of the accident, or restored as soon as practicable to a safe condition.

Application of this generic methodology to a radiological and non-radiological situation is presented in Appendices A and B respectively.

4. IMPROVEMENT OF HABITABILITY

4.1. GENERAL

If the assessment indicates that actions need be taken to improve habitability and to ensure that habitability criteria are met, these actions should be developed and implemented.
This section discusses the improvements that could be considered for a nuclear facility’s vital areas in order to ensure or improve habitability during an accident, with special consideration of the main control room. The actions that can be taken can be classified as follows:

(a) Changes in design and equipment
(b) Adjustment of operating procedures
(c) Selection of appropriate emergency equipment
(d) Operational readiness/training.

4.2. CHANGES IN DESIGN AND EQUIPMENT

4.2.1. Design

Attention should be given to design modifications that aim to avoid unnecessary spreading of harmful materials throughout various areas of the facility. Considerations may include:

— A thorough design review to determine the non-system pathways of the harmful material being considered into or out of the facility and its vital areas (see analysis in Section 3.15). Once the pathways are determined, then actions can be considered for techniques to isolate these pathways promptly following detection of an accident. As examples, (a) the addition of self-actuating ventilation system dampers and automatic self-closing doors, and (b) rerouting of radioactive effluents back to the containment are possible solutions.

— A review of any system pathways should be made in order to identify leak paths. For example, these pathways could be sealed (in the case of building leakage), additional isolation valves added and better valve and pump seals installed.

Once the escape of the harmful material has been limited so far as practicable, then additional actions or alterations may be necessary to ensure that equipment vital to the safe operation/shutdown of the facility can be maintained. When discussing what alterations may need to be made, it is essential to remember that post-accident movements in the facility should be kept at a minimum level. All operator and maintenance operations or actions should therefore be scrutinized to determine whether or not they are absolutely essential and if they must be performed at specified points in time. As an example, some maintenance actions might be deferred until exposure rates have reached more acceptable levels or until the intervals between the operations or actions might be increased without impairment of safety and operating efficiency. To improve accessibility to areas where indispensable operations or actions may need to be carried out, considerations may include:
— Installation of shielding,
— Installation of remotely controlled equipment,
— Relocation of equipment readout,
— Installation of closed circuit television monitors,
— Use of robots (but accessibility for the selected robot must be ensured),
— Installation of emergency lighting and communications or personnel protective equipment,
— Provision of means for flushing or draining rooms or systems as well as elimination of conditions which could trap and hold harmful materials,
— Provision of adequate ventilation to purge harmful materials from the air.

4.2.2. Equipment and instrumentation

Consideration should be given to the installation of monitoring equipment that can detect the presence of harmful materials present as a result of the accident. This equipment could facilitate assessment of the extent of the accident by following its course over time and monitoring parameters necessary for determining on- and off-site emergency response.

Equipment necessary for operation in the course of an accident and during post-accident recovery should be environmentally qualified for any hostile conditions expected under the postulated accident scenarios. Instrument readouts must be placed in habitable areas.

4.3. ADJUSTING OPERATING PROCEDURES

The operational procedures in the event of an accident are extremely important. Assurance that the operators have correct procedures is vital, for without these it will almost certainly be impossible to avoid any undesirable release of harmful materials from their designed place of confinement. Changes in the operational procedures may be necessary in themselves, or they may supplement the effects of design changes introduced with the same aim in view. For example:

— A review of operational routines may show that there are several ways to operate a system during the accident or post-accident situation. The aim is to reduce to a minimum the effect of the accident upon habitability, and therefore prior consideration must be given to the most appropriate operational mode to achieve this aim.
— A change in routes to, from and between vital areas should be considered when a deterioration of habitability along them could jeopardize free and safe movement.
— In cases where single valve protection is provided for isolation of a system which could contain harmful material, special procedures may be implemented to ensure that the valve is always in the desired position.
— In some cases, the desirability of providing bypass systems for certain other systems may have to be considered. An example would be the bypassing of demineralizer organic ion exchangers during a core damage accident if they might contribute to a habitability problem.

For systems and equipment that will have to be operated over long periods of time, aspects of maintenance and repair must be given attention. Examples are:
— Leakage of components can be minimized by introducing more comprehensive testing and maintenance routines that include all systems of interest in an accident.
— Ensuring possibilities of flushing certain systems with clean water can greatly simplify the work when a component in the system has to be serviced. (This also applies to the discussion in Section 4.2 on design considerations.)

4.4. SELECTING APPROPRIATE EMERGENCY EQUIPMENT

4.4.1. Personnel protective equipment

Personnel protective equipment (PPE) required for use during an emergency will mainly consist of protective clothing and respiratory protection. Its purpose is to enhance the safety of anyone who is called upon to work in a hostile or dangerous environment; it must therefore match the demands of the tasks to be performed as well as the physical characteristics of the wearer. By way of example, in the Chernobyl accident, protective equipment was insufficient to protect fire brigade personnel from beta radiation [3, 4]. Virtually every type of PPE detracts in some way from the wearer's normal standards of performance and abilities by affecting bodily comfort, freedom of movement, sensitivity of touch, clarity of vision and speech, acuteness of hearing, etc. (Some personnel are physically unable to wear PPE and this should be individually determined in advance.) It is therefore essential that personnel who may be required to use PPE should not only be trained in how to use it, but should also, through regular exercises, become accustomed to wearing it in conditions they might expect to encounter during an actual emergency. In this way they will realize both the nature of the limitations imposed by the use of PPE and its benefits in terms of self-confidence and personal safety. It is emphasized that the use of PPE should normally be considered as the last resort and that other design or operational changes should be evaluated first.
4.4.2. Damage control equipment

It is important that the equipment that would be employed to control the extent of the damage and to detect conditions that would affect habitability should be clearly identified (e.g. emergency tools and equipment, emergency lighting, fire extinguishers, ventilation systems, communications, detectors for radiation, fire, smoke, temperature). The quantities and types of equipment must receive careful consideration and the equipment must be accessible.

The choice of types of equipment for damage control is site specific. The equipment must match the type of emergency operation that may need to be carried out, the vital area in which this must be performed, and the potential hazards that may be encountered. It is important that not only should all equipment be readily available, fully serviceable and easily operable, but a resource of backup supplies should also be available (and, if it is brought from off the site, be compatible with on-site equipment) in case the emergency situation is prolonged [6]. Routine checks on the operability of the systems and the equipment should be carried out.

4.4.3. Communications equipment

Effective communications are essential in any emergency. For the purposes of this report, it is necessary only to recall that whatever systems are chosen, they must:

— Be capable of transmitting information between vital areas and between them and the location(s), on and off the site, from which emergency response operations are being controlled and directed;
— Be duplicated, with different kinds of systems (e.g. dedicated telephones backed up by two-way personal radios) dependent upon different power sources if the communication is considered to be vital;
— Remain operational in the foreseeable range of temperatures, humidity, radiation levels, etc.;
— Be operable in all vital areas where continuous or transient occupancy may be necessary;
— Be regularly tested and maintained for serviceability and to ensure that personnel know how to use them;
— Be treated generally as what they are: systems vital at all times, and not only in accident situations.

Equipment such as closed circuit television can also be useful, for example in transmitting information from areas to which personal access may, for whatever reason, be temporarily impracticable.
4.5. OPERATIONAL READINESS/TRAINING

4.5.1. Training and education

As in all aspects of emergency preparedness, training and education are especially important for ensuring that all concerned (particularly, in the context of radiation accidents, the plant operators and emergency operations personnel) will cope with any emergency in the right state of mind and take the right actions. *Training and education are essential elements in achieving the condition of mental preparedness*, i.e. the confidence that comes from knowing what might happen as well as knowing that one knows what to do in such a situation.

Operators should therefore be taught to anticipate unusual situations, to be informed of risks they might run in those situations, and to be aware of the actions they must take and the emergency routine they will be expected to follow until conditions are restored to normal. They should also receive training in the use of the emergency communications systems and the equipment they might have to use in order to enter or remain in vital areas or to monitor the emergency situation itself. This training should be carried out routinely at such intervals as are necessary to maintain the efficiency of the operators. The serviceability of equipment and instrumentation should also be regularly checked to ensure that they are operable in case of need.

Emergency technical support personnel should also be trained to be mentally prepared for an accident. This includes familiarizing these personnel with all aspects of their response so that they can act correctly under accident conditions. Since many of these individuals are not called upon in a daily routine to perform these tasks, training may have to be quite rigorous.

Off-site personnel such as fire brigades and medical personnel who might be involved in giving assistance on the site should also receive general training related to the special conditions in which they would have to carry out their tasks, especially in view of potential radiation or non-radiation hazards they might encounter. They should be acquainted with the layout of the plant and the systems they will have to operate. Equipment and materials they might have to employ (e.g. fire-hoses, fire extinguishers, chemical substances) should be compatible with those used on the installation and suitable in the ambient conditions that could prevail during the emergency.

4.5.2. Exercises

Since an actual emergency involving any particular nuclear facility may be expected to occur very infrequently, if at all, drills and exercises provide the only realistic opportunities to test, maintain and improve the effectiveness of the response. Drills normally involve small groups of persons in a learning process designed to
ensure that essential skills and knowledge are available for the accomplishment of non-routine tasks such as emergency radiation measurements or use of emergency communication procedures. Exercises, whether they involve site personnel only or include off-site teams, provide experience in collaboration among groups who may not normally be required to work together. They can also be used to provide training and experience in working under conditions similar to those that might prevail in the event of an accident. Since the habitability situation inside the plant and on the site may differ considerably from the environments encountered during normal operation, it is essential to bring this aspect into the exercise. This is especially important when accessibility or habitability of a vital area is expected to require the use of PPE.

Exercises offer a good opportunity to deal with a special problem which could affect habitability during an emergency: the presence of too many people on the site and, especially, in the control room. Entry to vital areas must be strictly controlled and must be restricted to essential personnel. Measures should also be taken to control access to the site as a whole and even to the area surrounding it so that incoming and outgoing traffic of people and materials can be regulated and/or restricted and individual exposure to radiological and non-radiological hazardous agents can be limited.

IAEA Safety Series No. 73, Emergency Preparedness Exercises for Nuclear Facilities: Preparation, Conduct and Evaluation [15], provides detailed guidance on exercises.

4.6. CONTROL ROOM HABITABILITY

Owing to the vital nature of the control room, a special discussion on this area follows.

4.6.1. Isolation

In most nuclear power plants, the control room is located in a building separate from others such as the reactor, auxiliary, fuel and turbine buildings. In most plants the control room is a shielded structure providing protection from radiation levels considered during its design. The physical separation of the control room from other areas removes it from close association with the hazard source. The functional isolation is its capability to arrest the propagation of the consequences of accidental events at the boundary of the control room.

Functional isolation refers to the leaktightness of this area. It is a very important parameter, ensuring that the infiltration rate into the control room is minimized if necessary. Various designs of leaktight control rooms are envisaged in many publications [16–21], with a corresponding delay in the rise in concentration of hazardous gas. In particular, from the Browns Ferry nuclear power plant fire
experience [6] is derived the need to avoid open penetrations between the control
room and the electrical cable spreading room. If such open penetrations should exist,
use of highly flammable material such as sealant should be avoided. As the
Chernobyl accident illustrated, the lack of prompt isolation of intake ventilation
caused high levels of contamination in the control rooms of adjacent units as well
as throughout other facilities on the site [3, 4].

During a radiological accident, the control room air intake is normally filtered
to remove radioactive iodine and other particulates and aerosols. The cleanup device
does not usually have the same efficiency in removing other hazardous material
which can contaminate the incoming air. However, on a cost–benefit basis, it may
not be possible to design a specific removal system for a certain hazardous material
if the likelihood of an event involving that material is low. What should be a part
of a normal design is the capability of the ventilation system to isolate the control
room area from outside or from other areas.

The ventilation system must be capable of dealing with fires and smoke of any
expected severity or density. Its components should be chosen bearing in mind the
possible presence of corrosive agents, and it must be checked periodically for
leaktightness. To minimize the risk of drawing contamination into the control room,
dual inlets for the intake of air should be provided in locations which are meteorolo-
logically opposite [16, 17] and are as far as practicable from hazard sources.

4.6.2. Relative location of hazard source and control room

The control room inlets should be located taking into consideration the
potential release points of radioactive material and toxic gases [16, 17]. It is
suggested that the control room ventilation inlets be separated from the major
potential radiation release points. The minimum distances between the radiological
or toxic gas source and the control room depend upon the amount and type of the
gas in question, the volume and concentration of the release, and the available
control room protection provisions. References [20] and [21] give guidance on this
matter.

4.6.3. Control room monitoring system

A prompt and effective ventilation monitoring system should be provided so
that the control room operators know the status of the system at all times.

Detectors for radioactive and toxic substances and smoke should be designed
and located so that they will be effective in any situation that is likely to occur. Their
compatibility with, for instance, the ventilation system should be ensured. Human
detection, especially of odours, should not be relied upon; some gases and vapours
such as CO and CO₂ have no smell. Even if smoke detectors are installed in the air
intake devices and at the ceiling of the control room, detectors for CO and CO₂ are
usually required. Portable detection equipment should also be considered as a complement to fixed detection devices.

4.6.4. Respiratory protection

In case it becomes necessary to shut off ventilation in the control room, adequate respiratory protection with appropriate breathing apparatus should be available not only for the operators but also for other persons who will have to work in the control room if an accident occurs. The difficulties likely to be encountered in operating with such devices, and the need for periodic practice and testing under realistic conditions, have been noted in Section 4.4.1 and in Ref. [6]. All protective clothing and breathing apparatus should be regularly checked and properly maintained.

4.6.5. Missiles

The control room should also be protected from missiles which can be generated from other parts of the plant. Use of barriers, protective shields and, again, physical isolation may be required. Ventilation intakes should be protected from external missiles and from damage from natural hazards.

Additional assessment of missile effects and protection should be made in conformity with national regulations. The IAEA Safety Guide, Protection Against Internally Generated Missiles and their Secondary Effects in Nuclear Power Plants (Safety Series No. 50-SG-D4) is a useful reference [22].

4.6.6. Toxic construction materials

Many of the materials used in the construction of nuclear facilities perform quite satisfactorily under normal conditions. During an accident, however, these materials could be subjected to conditions which would result in deterioration and associated failure to perform as expected. In the event of fire, they might release toxic substances which could cause more difficulty than the fire itself. It would be desirable to eliminate or minimize the use of such materials.

4.7. PROTECTION FROM NATURAL HAZARDS

The IAEA publishes a series of Safety Guides concerned with the siting of nuclear power plants. These Safety Guides (50-SG-S1 to S12) include guidance for measures to counter the effects of earthquakes, floods and extreme meteorological events.
4.8. PROTECTION FROM FIRE

Guidance on protecting on-site accessibility and habitability with respect to fires is provided in the IAEA Safety Guide, Fire Protection in Nuclear Power Plants (Safety Series No. 50-SG-D2) [23].

4.9. PROTECTION FROM TOXIC HAZARDS

Methods of improving on-site habitability following releases of toxic chemicals are included in the IAEA Safety Guide, External Man-Induced Events in Relation to Nuclear Power Plant Siting (Safety Series No. 50-SG-S5) [24] (see Refs [20] and [21] for control room considerations).

5. ASSESSMENT AND IMPROVEMENT OF HABITABILITY AFTER AN ACCIDENT HAS OCCURRED

5.1. GENERAL

A logical question which immediately follows the recommended advance use of the general methodology for assessment of habitability and the attendant techniques for improvement is: To what degree can the methodology and techniques be applied after the accident has already occurred? There can be no simple answer to this question for the accidents discussed in this publication; it is complicated by many factors governing the application such as:

(a) Existing and projected accident consequences,
(b) Requirements for protective measures,
(c) The ability to conduct or apply the assessment methodology, and
(d) The ability to make improvements and the availability of resources.

The question is not too relevant for non-radiological hazards since, in general, their consequences will already have had their effect and will in all likelihood be of a transitory nature. Therefore the discussion in this section is directed primarily towards radiological accidents.

Generally speaking and intuitively, some situations might exist in which a limited ad hoc application could be made of the assessment methodology and techniques for improvement of habitability after an accident. However, the intent is that the methodology and the techniques should be applied before the accident happens and as an integral part of design, operations, radiation protection, nuclear safety and industrial safety programmes for the installation.
An examination of historical records and reports of three serious accidents which created on-site habitability problems reveal events which probably could not have been foreseen in addition to those which might have been foreseen [3–6]. The ability to assess habitability at the outset, before an accident, is governed by the scenarios selected to make the advance assessment, but when an accident actually occurs, it would be rare indeed for a selected scenario to match exactly the actual event. Further, real accidents tend to be comprised of and compounded by a set of subscenarios each of which can contribute to or modify the problems encountered as envisioned in the original assessments. Depending upon the specific situation, it might be possible to improve habitability and access after the fact, subject to the restraints imposed by the factors mentioned above and discussed below.

5.2. EXISTING AND PROJECTED ACCIDENT CONSEQUENCES

The course of the accident in terms of its existing and projected consequences at any given moment will be the dominant factor governing application of assessment methodology and in making improvements following the onset of the accident. The severity of the consequences and/or the projection or estimates of further consequences, coupled with the time-scale involved, will determine what can or cannot be done to improve habitability on an ad hoc basis. If the time period associated with projected or future consequences to areas not yet affected permits, it is possible that some formal assessments and improvements might be made for unaffected areas. Actions to regain habitability in, or access to, areas which have already been affected will more properly fall within recovery and damage control operations.

5.3. REQUIREMENTS FOR PROTECTIVE MEASURES

After an accident has occurred and it is determined that habitability has been affected in areas of concern, protective measures will be needed to protect the operating staff of the installation. These protective measures (which may, for example, be evacuation, control of access, and the implementation of personnel protective methods such as respiratory protection, radioprotective prophylaxis and the use of anti-contamination clothing) are not considered to be habitability improvements. They are measures taken to alleviate or mitigate consequences because habitability has already been compromised. Since protective measures are usually burdensome and can in themselves contribute to increased stress upon those who are affected by them, there will be considerable pressure either to make them unnecessary or to reduce or modify them.
5.4. ABILITY TO CONDUCT OR APPLY THE ASSESSMENT METHODOLOGY

The ability to conduct or apply the methodology falls into the area of mental preparedness wherein personnel called upon to assist in mitigating the consequences of an accident have been trained in the use of the methodology set forth in this report. Such training is particularly important because, in an accident situation, rapid decisions may have to be made to implement the required corrective actions. The training that has been provided should have recognized the fact that the accident conditions may severely limit the analysis and assessment time and the potential options available for habitability improvement.

5.5. ABILITY TO MAKE IMPROVEMENTS; AVAILABILITY OF RESOURCES

The ability and effort as well as the quantity, variety, type and cost of the resources required to accomplish improvements after an accident has occurred are demonstrated by reference to studies of the accidents at the Three Mile Island nuclear power plant in the United States of America and the Chernobyl nuclear power plant in the Soviet Union. These reveal the enormous resources, some of them directly or indirectly required to improve habitability or access to portions of the plant, which were needed to handle the various post-accident problems [3-5].

5.6. APPLICABILITY OF ASSESSMENT METHODOLOGY AND TECHNIQUES FOR IMPROVEMENT

As mentioned in Section 5.2, the application of the formal methodology discussed in Section 3 may be somewhat limited after an accident has occurred. Often, only ‘simple actions’ can be taken to improve habitability after an accident has occurred, owing to the time constraints of emergency response, and thus the longer duration design changes cease to be viable options. The simple actions available will usually be oriented towards the specific existing hazard and will be rather ad hoc and of an emergency or temporary nature. Moreover, they may be only partially effective.

5.7. SUMMARY

The various factors governing the assessment methodology and improvement of habitability may severely limit the application of the guidance presented in this
report after an accident has occurred. Existing and projected accident consequences will be the dominant factors. When coupled with the protective measures that have been implemented, these consequences may provide the impetus for taking a prescriptive approach towards improving habitability and access. In any case, this approach is vastly more complicated and costly than making a full assessment of habitability problems at the design stage and carrying out necessary improvements then. If that is not possible, then assessment and improvement should be made before an accident occurs.
Appendix A

EXAMPLE OF ASSESSING AND IMPROVING HABITABILITY
FOR A RADIOLOGICAL TYPE OF ACCIDENT SCENARIO

A.1. INTRODUCTION

This appendix gives an example of the application of the generic methodology described in Section 3 to a particular accident scenario. Its structure (i.e. the numbering of sections) corresponds to that of Section 3, and it also shows how the guidance in Section 4 on the improvement of habitability may be applied. For each step in the methodology, some general considerations are first presented. These are followed by illustrations of a specific example for that step.

A.2. DEVELOPING THE ACCIDENT SCENARIO

A.2.1. General

The term on-site habitability includes habitability both inside and outside the buildings on the site. In a radiological type of accident, habitability inside buildings may be affected by high radiation levels around systems carrying radioactive effluents or by airborne radioactivity due to system leakage, etc. Depending on how the systems are situated, habitability outside these buildings may also be affected for the same reasons. The habitability of the ground area will, however, be more affected by a large release of radioactivity to the environment, depending of course on the weather conditions and the type and amount of radionuclides released. Some releases to the environment might also affect areas inside the buildings on the site, e.g. owing to deposition of radionuclides on the roofs or through intake via the ventilation systems.

The 'worst possible' consequences for on-site habitability can thus not necessarily be studied by using only one scenario. Instead, the personnel performing the assessment will have to cover both accidents having consequences mainly inside the buildings and accidents that primarily affect habitability on the ground area of the site. It can, however, be recommended that the assessment starts with a scenario that first of all challenges the habitability inside the buildings, since that is where the 'vital areas' are located to which personnel need access in order to control and mitigate the effects of the accident.

In either case it should be clear that when assessing habitability, it is of less importance to study the events leading up to core damage except in so far as they affect the source term. More essential to the habitability analysis is what happens
after the core damage has occurred, i.e. how the radioactivity is subsequently transported from its normal place of confinement.

When selecting and describing a scenario of interest for challenging the on-site habitability, a Probabilistic Safety Analysis, if one has been made, might be helpful. Another possibility is to study a 'general type' scenario, e.g. an accident with a line break inside the containment or an accident where the reactor coolant system remains intact, both including a severely degraded core [25, 26]. An illustration of the use of a ‘general type’ scenario is given in the detailed example below.

A.2.2. Example of the development of an accident scenario

In this example a general type scenario is used, which seeks to answer the question: What is the worst impact on in-plant habitability that could result from an accident with severe core damage, but not core melt?

The initiating event is a loss of coolant accident (LOCA) inside the containment in a pressurized water reactor (PWR). Although this is basically a design basis accident, it is then postulated that the engineered safety systems do not initially perform as designed and that extensive core damage results. The further assumption is made that the safety systems do then act to prevent a complete core melt.

A.3. EVALUATING THE HAZARD SOURCE

A.3.1. General

Evaluation of the source term requires that estimates should be made of the quantity and time release characteristics of the radioactive material which could escape from its designed place of confinement.

A.3.2. Example of evaluating the hazard source

The scenario chosen foresees a release of radioactive materials to the containment atmosphere as well as to the water in the containment. This water, from the reactor cooling system, will be diluted by non-radioactive water in the initial stages of the use of the emergency core cooling system (ECCS).

This example uses the source term delineated in Refs [21] and [26] modified by data from the accident at the Three Mile Island nuclear power plant Unit 2 [27].
The source term\textsuperscript{3}, expressed as a percentage of total inventory in the core, can then be summarized \cite{28} as:

- In containment atmosphere: 100% noble gases
  - 2.5% radioiodines\textsuperscript{4}
- In liquid: 50% radioiodines
  - 50% caesiums
  - 1% other fission products

Further assumptions are made that the entire release from the core takes place instantaneously and that after half an hour the activity is homogeneously distributed in the atmosphere and in the water in the containment. At this time the ECCS will have been switched to the recirculation mode. The source term can be expressed as photons \textsuperscript{-3} cm\textsuperscript{-3} s\textsuperscript{-1} for different energy intervals.

A.4. DETERMINING THE GENERAL AREAS OF INTEREST

A.4.1. General

In the initial assessment, certain key areas or buildings would be identified as areas of interest and the consequences of the accident in terms of its effect on habitability in those locations would then be examined.

In a nuclear power station there are certain areas which will have to be occupied either permanently or temporarily in order to bring the plant to a safe shutdown condition. These general areas of interest may include:

- (a) Main control room: continuous occupancy
- (b) Auxiliary building: temporary occupancy.

A.4.2. Example of determining general areas of interest

After a LOCA in the containment, most of the operations needed to bring the plant to a safe shutdown condition and to maintain it there can be handled from the control room. However, some operations, such as sampling and the operation of certain valves, will have to be performed elsewhere in the plant, and the number of actions will increase as maintenance work becomes necessary during the later stages of the accident. In the accident under review, most but not all of the post-event

\textsuperscript{3} This set of numbers was chosen for illustrative purposes only and does not necessarily reflect a specific situation.

\textsuperscript{4} This number for radioiodines in containment atmosphere was chosen purely for illustrative purposes.
actions outside the control room will be taken in the auxiliary building where the systems of interest are located. For the purpose of this example, attention will be concentrated upon the auxiliary building, although in reality other vital areas would also have to be analysed.

A.5. EVALUATING THE TRANSPORT MECHANISMS TO AREAS OF INTEREST

A.5.1. General

Radioactive materials can escape into the facility either through the systems which transport them from their original place of confinement or through leakage. The results may be either radiation fields around pipes and components of the system(s) in question, or direct air and surface contamination, and both of these can affect habitability.

A.5.2. Example of evaluating transport mechanisms

In this scenario it is assumed that the major habitability problem stems from the radiation fields around the systems transporting highly radioactive effluent. Some systems that could be expected to transport this highly radioactive material are:

- Safety injection system
- Residual heat removal system
- Containment spray system
- Parts of the chemical and volume control system
- Sampling system
- Vent and drain system
- Waste processing system (liquid and gaseous)
- Containment sump system.

A.6. QUANTIFYING THE LEVEL OF HAZARD IN AFFECTED AREAS

A.6.1. General

The initial assessment loop in Fig. 1 should be completed in order to show the approximate magnitude of radiation levels that would be encountered and whether or not they would present a habitability problem. It will be sufficient for this purpose to make a rough estimate of the dose rates from a small section of the affected systems.

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A.6.2. Examples of quantifying the level of hazard in affected areas

The pipe dimensions in the systems carrying radioactive effluent vary. The largest pipes are encountered in the emergency core cooling systems. In a rough estimate, a diameter of 250 mm can be used as representative dimension of pipes in the ECCS. As an example, the dose rate from a one-metre section of these pipes, given the source term in Section A.2, can be calculated as about 60 Sv/h at the distance of one metre from the surface of the pipe.

A.7–8. 5 ESTABLISHING HABITABILITY CRITERIA; DETERMINING IF HABITABILITY IS ACCEPTABLE

A.7.1–8.1. General

For illustrative purposes, the dose limit of 50 mSv individual whole body dose for the duration of the accident can be used as a basis for establishing dose rates which could be allowed in the various affected areas, taking into account the projected occupancy times (Section 2.4). Here it is important to differentiate between areas requiring permanent and only temporary occupancy. For areas that have to be constantly occupied and habitable, such as the control room, a dose rate habitability criterion could be fixed at 0.15 mSv/h (15 mrem/h) for the duration of a 30 day accident (this assumes approximately a 10 hour per day individual presence in the control room [29]).

In areas where occupancy is needed for only short periods of time it is not possible to directly specify the dose rates which can be considered acceptable. The judgement should be based upon a combination of factors weighed against each other, such as the maximum individual doses and the average exposures to the personnel performing each action, the relative importance of that particular action, and the number of personnel required and available. The experience gained by health physicists from making similar judgements during normal operation, shutdown and maintenance should be valuable and help in making the evaluation.

At this early stage of evaluation of the chosen scenario, it is not possible to foresee precisely the duration of occupancy times in places where only transient occupancy is necessary. Because of these uncertainties, and before having made a detailed analysis which includes estimates of occupancy times, only a rough evaluation of habitability is initially practicable, and calculations should err on the conservative side.

5 The numbering corresponds to that of Section 3 of the report.
A.7.2-8.2. Example of establishing habitability criteria and judging acceptability

From the calculation in Section A.6.2, a dose rate of 60 Sv/h at one metre distance from a small section of a water filled pipe in the ECCS has been estimated. This implies serious effects upon the possibility of occupancy of any area through which radioactive effluent passes. A more detailed analysis will therefore be required to estimate the degree of severity of the problem.

A.9. DETERMINING IF SIMPLE SOLUTIONS ARE AVAILABLE

A.9.1. General

At this step in the analysis, an evaluation will be made as to whether simple solutions could minimize any habitability problems which may have been created.

A.9.2. Example of simple solution

Since it has been established that habitability has been seriously affected by systems carrying the highly radioactive post-accident effluent, the systems should be examined to see if any simple solutions could eliminate the use of any of them during a postulated accident. On examining the systems listed in Section A.5.2, it is determined that it is not necessary to activate the containment sump system which, if activated, would transfer highly radioactive water into the auxiliary building. By means of this relatively simple solution, substantial improvements in habitability could be realized within the auxiliary building.

Many of the other systems listed are required during the postulated accident in order to maintain the plant in a safe shutdown condition. From the calculation of dose rates surrounding pipes carrying post-accident effluent, it is evident that habitability (even though partially improved by the action taken) will continue to be unacceptable in certain areas within the auxiliary building and therefore a detailed analysis of these areas will be required.

A.10-11. PROCEEDING TO MAKE A REFINED DETAILED ASSESSMENT; REFINING THE ACCIDENT SCENARIO

A.10.1-11.1. General

If the effects of any simple solutions are not sufficient to restore acceptable conditions in all vital areas, or if no simple solutions are available, then a more
detailed analysis must be made. In refining the scenario, it is usually not necessary to introduce many new extraneous factors or details for the sake of realism. The object is to estimate the worst impact the accident could have upon the areas of interest.

A.10.2-11.2. Example of refining the accident scenario

For the assessment of habitability following a LOCA with core damage it is not necessary to know the sequence of events leading to the accident. It is only essential to know the effects upon habitability when radioactive effluents have been transported into vital areas, and this will depend upon the systems which were in operation at the time of the accident, or which will have to be brought into operation during its progression. To establish a ‘worst case’, it will have to be assumed that all these systems except the containment sump system (as discussed in Section A.9.2) will be in operation simultaneously and from the moment of the accident. Although this is unrealistic, developments based on a more probable time-scale would complicate the analysis unnecessarily, and no change is therefore made to the assumption in the original analysis.

A.12. REFINING THE HAZARD SOURCE

A.12.1. General

If the scenario has been described in greater relevant detail it will become possible to refine the evaluation of the hazard source. However, if a ‘worst case’ is assumed in the initial assessment, it is unlikely that further refinement will actually be needed. As the source term is time dependent, it will have to be calculated for different points in time throughout the period during which habitability is assumed to be in question.

A.12.2. Example of refining the hazard source

The source term developed in step A.3 is sufficient for the ‘worst case’ approach. It is now necessary to calculate it at intervals, adjusting for radioactive decay and giving particular attention to the early phase of the accident [11]. Suitable intervals are taken to be 1 hour, 2 hours, 8 hours, 1 day, 1 week, 1 month, 6 months and 1 year after the accident.
A.13. DETERMINING SPECIFIC OPERATIONS OR ACTIONS REQUIRED BY PERSONNEL

A.13.1. General

The initial analysis determined only the general areas of interest, and these can be refined only after deciding upon the actions which would have to be taken by plant staff to deal with the postulated accident. The plant staff will be concerned with the following:

— To shut down the reactor;
— To keep the reactor core in the shutdown state;
— To remove the residual heat;
— To ensure that radioactive substances are confined and retained to the extent required;
— To detect when fixed limits governing protection of personnel and operation of plant systems are reached and to indicate desired protective actions;
— To supply the necessary information on the state of the plant (e.g. process parameters) required during and after the accident;
— To determine as accurately as possible the emissions of radioactive substances.

The particular operations or actions required can be classified as (a) operational and (b) maintenance, with a third category (c) including medical assistance, fire control and evacuation, which are of interest only when they are needed in the circumstances postulated in the scenario.

A.13.1.1. Operator actions

A review of safety assessment documentation, emergency response procedures and plant operating procedures can be made. It is most unlikely that routines will have previously been laid down for post-accident situations after the plant has been brought to a safe condition, and the selection of post-accident activities will therefore have to be based largely on normal operational routine modified accordingly. Many of these operations will, of course, be unnecessary after certain types of accident. On the other hand, some new operations or actions relating to the use of the safety systems might have to be introduced. Identification of post-accident operations or actions therefore requires a considerable degree of imagination and original thinking.

The actions so identified should be analysed with regard to the time after the accident when they would have to be performed, duration of action (expressed in man-hours) and number of people involved. These actions may include valve operations, system operations and system sampling. To facilitate the structuring of this analysis and assessment, the use of a table similar to Table I (described in Section 3.13) is recommended.
A.13.1.2. Maintenance actions

When accident conditions persist over an extended period of time, maintenance and repair of equipment important to safety will have to be undertaken. Under the prevailing circumstances, a certain amount of leakage will probably have to be accepted, even though it would have been corrected during normal operation.

Here also an imaginative approach will be necessary for the identification of operator actions. The listing of expected maintenance and repair actions can, however, be based on normal procedures and experience, modified as necessary in the light of the identification of vital equipment and systems which will be used in the performance of the operational actions.

A.13.2. Example of specific operations or actions required by personnel

As a large number of actions have to be taken, only a single example is given here for each of the two functional groups, together with an illustration of the use of the matrix (Table I) discussed in Section 3.13.

A.13.2.1. Operator actions

The action chosen for discussion is concerned with the residual heat removal system which is assumed to be in operation for the long term cooling. In the hypothetical nuclear power plant, the residual heat removal (RHR) system has two independent loops, each capable of keeping the temperature within acceptable levels. In order to prolong the life of the pumps it is assumed that they will be operated alternately on a weekly basis. It takes approximately 15 minutes (5 minutes for pump check plus 10 minutes for valve operation) for a trained operator to make the switch-over. This example is illustrated in Table II, where columns (1), (2), (3) and (7) have now been completed.

A.13.2.2. Maintenance actions

Since the residual heat removal pumps are in operation over a long period of time they will eventually have to be serviced; for example, oil will have to be changed or replenished. This servicing is assumed to take place one month after the accident and to take one person about half an hour to complete the work on one of the pumps. The other pump is serviced by another person. This information is entered in columns (1), (2), (3) and (7) in Table III.

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TABLE II. EXAMPLE OF MATRIX FOR HABITABILITY ANALYSIS: OPERATIONS

<table>
<thead>
<tr>
<th>Functional group: OPERATOR ACTIONS</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Specific operation</th>
<th>Time after accident</th>
<th>Estimate of man-hours needed</th>
<th>Plant location</th>
<th>Projected dose rate (mSv/h)</th>
<th>Total exposure (man·mSv)</th>
<th>Total number of people exposed</th>
<th>Average exposure per person (mSv)</th>
<th>Habitability criteria</th>
<th>Habitability condition acceptable YES/NO</th>
<th>Action required</th>
<th>Additional remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shifting RHR pumps</td>
<td>1 week (and repeated weekly)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checking pumps before and after startup</td>
<td>5 min</td>
<td>RHR pump rooms elevation 03</td>
<td></td>
<td>4300</td>
<td>-360</td>
<td>1</td>
<td>360</td>
<td>&lt;50 *</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valve operation</td>
<td>10 min</td>
<td>Valve handling area elevation 02</td>
<td></td>
<td>4</td>
<td>-0.7</td>
<td>1</td>
<td>0.7</td>
<td>&lt;50 *</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* See discussion in Section A.7.
### TABLE III. EXAMPLE OF MATRIX FOR HABITABILITY ANALYSIS: MAINTENANCE

**Functional group: MAINTENANCE ACTIONS**

<table>
<thead>
<tr>
<th>Specific operation</th>
<th>Time after accident</th>
<th>Estimate of man-hours needed</th>
<th>Plant location</th>
<th>Projected dose rate (mSv/h)</th>
<th>Total exposure (man·mSv)</th>
<th>Total number of people exposed</th>
<th>Average exposure per person (mSv)</th>
<th>Habitability criteria</th>
<th>Habitability condition acceptable</th>
<th>Action required</th>
<th>Additional remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servicing RHR pumps</td>
<td>1 month (and repeated monthly)</td>
<td>0.5 (30 min for each pump)</td>
<td>RHR pump rooms elevation 03</td>
<td>2000</td>
<td>2000 (2 × 1000)</td>
<td>2</td>
<td>1000</td>
<td>&lt;50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>No</td>
<td>High dose rates in containment spray pump rooms along access routes</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> See discussion in Section A.7.
A.14. IDENTIFYING VITAL AREAS

A.14.1. General

The locations in which these vital actions will be carried out can now be identified. They are by definition the vital areas, and their designations can be entered in the matrix (Table I, Section 3).

The vital areas can be divided into two main groups, depending on whether permanent or transient habitability is required. The first group will include:

- Main control room
- Main security duty room
- Operation support centre
- Technical support centre
- Emergency control centre.

Other areas may need only temporary or transient habitability, e.g.:

- Sampling room
- Containment isolation rest area (annulus)
- Diesel generator rooms
- Waste disposal panel room, etc.

The routes to and from these vital areas should also be taken into consideration since there is a possibility that the radiation levels in adjacent areas will cause trouble along the access route even if the vital area itself is habitable. This can also be indicated in the matrix.

A.14.2. Example of identifying vital areas

The example of operator actions given in Section A.13.2 (alternating the RHR pumps) includes two basic steps, one of which is checking pumps before and after startup and the other the operation of valves to make the change. The first step takes place in the pump rooms and the second step one floor above in a valve handling area. The rooms are listed in Table II, column (4), and the access routes to/from these locations are given in column (12).

For the maintenance actions example cited, servicing is performed in the pump rooms and the access route is the same as discussed for the operator action. Columns (4) and (12) in Table III can be filled in.
A.15. EVALUATING THE TRANSPORT MECHANISM

A.15.1. General

In this step a refined analysis of the transport mechanisms is made. In the initial assessment two basic ways were mentioned for the escape of radioactive material into the facility: by installed piping carrying radioactive effluent or by leakage.

Although the installed systems may be designed in such a way that some radioactive material in them will not significantly affect habitability, under severe accident conditions even small quantities of post-accident effluents escaping into them can render adjacent areas uninhabitable or severely limit habitability. Each system which could be exposed to post-accident effluents, even in very small quantities, must therefore be carefully analysed.

Equipment inside the containment is assumed to leak at the Technical Specification limits for the equipment. Equipment outside the containment is also assumed to leak at the Technical Specification limits or at levels that could be anticipated considering the event postulated. Particular attention should be paid to boundary valves and to valve and pump seal leakage, as these have been demonstrated to be major contributors to leakage following an accident. Systems which are normally non-radioactive could also become contaminated.

A system by system review should now be carried out on pipe drawings and by thorough system walkdowns at the plant in order to identify the areas in which the systems are situated, their positions relative to one another, where radioactive material is likely to concentrate, and the points at which dose rate calculations will need to be made. A detailed list can be made for each system, where it can be followed from location to location, supplemented by a cross-reference list for each room, showing the systems that pass through each room. The lengths and diameters of the pipes in each section of a system should also be noted.

A.15.2. Example of evaluating the transport mechanism

The systems which will be or could be in operation according to the scenario selected have been listed in step A.5 above.

Although it is very difficult to predict exactly which systems will be utilized once a more or less steady state has been reached after an accident, and since the need for any given system naturally depends on the circumstances surrounding the accident, it is necessary to consider as many operational conditions as possible. The systems listed in step A.5 are those which probably will be utilized, although not necessarily at the same time.

The lists of systems, their locations and measurements are then given in the manner explained in Section A.15.1.
FIG. 2. Auxiliary building, elevation 03. Example of dose rate map.
FIG. 3. *Auxiliary building, elevation 02. Example of dose rate map.*
TABLE IV. CALCULATED DOSE RATES (mSv/h)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Calculation point\textsuperscript{b}</th>
<th>Time after accident</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 h</td>
</tr>
<tr>
<td>Elevation 03</td>
<td></td>
</tr>
<tr>
<td>03.1: RHR pump</td>
<td>$87 \times 10^3$</td>
</tr>
<tr>
<td>03.2: Containment spray pumps</td>
<td>$81 \times 10^3$</td>
</tr>
<tr>
<td>03.3: Stairway</td>
<td>9.4</td>
</tr>
<tr>
<td>Elevation 02</td>
<td></td>
</tr>
<tr>
<td>02.1: Corridor</td>
<td>330</td>
</tr>
<tr>
<td>02.2: Corridor</td>
<td>47</td>
</tr>
</tbody>
</table>

\textsuperscript{a} 1 mSv/h = 100 mrem/h.

\textsuperscript{b} Calculation points are marked in Figs 2 and 3.
A.16. QUANTIFYING THE LEVEL OF HAZARD

A.16.1. General

At this point in the assessment process, sufficient information is available about the source term and how the radioactive material is transported throughout the facility to enable dose rate calculations to be performed. The calculations should be done by computer, since the system configurations in the vital areas can be very complex and a large amount of calculation is required.

Dose rate calculations can be performed for all areas of interest which were determined in step A.4. This will give the best overview of the habitability situation. Another possibility is to concentrate on calculating the dose rates in the areas identified as vital in step A.14, but in this case the dose rates along relevant access routes must also be calculated.

A.16.2. Example of quantifying the level of hazard

The dose rate calculations are now performed, for each specified point in time, using the source terms from step A.12 and the descriptive lists of systems discussed in A.15. The dose points at which the dose rates are calculated are chosen in order to study the radiation levels in the rooms or areas containing the radioactive systems and also some strategic dose points in adjacent areas, like corridors, etc. The dose points are normally placed one metre above the corresponding floor level just inside the entrance of the room or (on the basis of the information from steps A.13 and A.14), if the room is a vital area, the dose points can also be placed at the probable position of a person carrying out his/her duties in the room or area of interest.

Figure 2 shows the layout of the hypothetical PWR unit, elevation 03, where the RHR pumps are situated. The layout for elevation 02 is shown in Fig. 3. The chosen dose points for calculations are marked with numbers. The results of the calculations can be shown in tabular form (Table IV).

A.17. MAPPING THE PROBABLE EXTENT OF THE HAZARD

A.17.1. General

A good overview can be obtained of the dose rate levels calculated in step A.16 if the information is presented in the form of coloured graphic layouts. This will facilitate the study and assessment of habitability in certain areas and the dose rate levels encountered along the routes leading to and between them.

The radiation levels can be divided into four or five ranges, where the appropriate ranges have to be selected on the basis of the results in A.16. The colours...
should be chosen so that they cannot be confused with any colour coding used in the
plant for normal operation. The maps and dose rate corrections can be made as a
function of time by developing either a series of maps for different time intervals
or a correction curve of dose rate versus time for time dependent correction of the
t = 1 h map.

The results from steps A.16 and A.17 can then be entered in the matrix in
column (5), which lists the dose rate in each location.

A.17.2. Example of mapping the probable extent of the hazard

In the example, the chosen ranges and colours are:

<table>
<thead>
<tr>
<th></th>
<th>mSv/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>&gt; 1000</td>
</tr>
<tr>
<td>Purple</td>
<td>100–1000</td>
</tr>
<tr>
<td>Blue</td>
<td>10–100</td>
</tr>
<tr>
<td>Green</td>
<td>1–10</td>
</tr>
</tbody>
</table>

The results from the dose rate calculations shown in Table IV can now be illustrated
as in Figs 2 and 3. Sufficient information is now available to fill in the dose rates
in column (5) in Tables II and III.

A.18. HABITABILITY ACCEPTABILITY

A.18.1. General

Habitability can now be evaluated. The vital areas are known, as are the
operations that have to be performed in them and the dose rates in those areas. Using
the entries made in the matrix for each action, total (collective) exposure can be
calculated (column (6)). Combining this value with the total number of people
exposed (column (7)), the average exposure per person (column (8)) can be
developed.

Care must also be taken that the exposure to an individual is considered in the
cases where, for example, a specific part of an operation requires a highly skilled
individual over a relatively long period of time.

A discussion about habitability criteria and judgement whether habitability is
in fact acceptable appears in Section A.7-8. Similar judgements now have to be
made. If, in the detailed analysis just undertaken, habitability is found to be
acceptable, then no further action is required for the given area/action. If, instead,
the refined analysis shows that habitability is unacceptable, then further corrective
actions will be required as will be discussed in step A.19.
A. 18.2. Example of determining if habitability is acceptable

In the example scenario there are locations that have to be continuously occupied, such as the control room. However, the two examples given of operator and maintenance operations or actions deal with situations where temporary occupancy only is required. The evaluation of habitability is made for the first point in time for which the operations or actions need to be performed.

**Operator action:** The change-over of the RHR pumps is divided into two steps. In column (6) in Table II, the total exposure in man·mSv can now be calculated. In the example only one person is involved in the action and therefore the collective dose in column (6) will also be the average exposure per person in column (8). It can now be seen that the 10 min operation of the valves necessary to switch over the pumps gives the operator 0.7 mSv only, while his/her 5 min check on the pumps before and after startup gives him/her 360 mSv. A quick evaluation indicates that the valve handling element of the operation under the prevailing circumstances has to be accepted, but the checkup on the pumps is to be avoided. From the layout diagram in Fig. 3 it can be seen that the dose rates along the access routes to the location for the valve operation can be said to be acceptable. However, the access routes to the RHR pump rooms go through the pump rooms of the containment spray system which has also been in operation, and there the rates are as high as they are in the RHR pump rooms.

**Maintenance action:** To service both RHR pumps one month after the accident would mean a collective exposure of 2000 man·mSv (column (6) in Table III), giving an average exposure of 1000 mSv per person. It can therefore be said that it is not possible to perform this maintenance action in these circumstances. Dose rate levels along the access routes to the pump rooms must also be taken into account.

A. 19. DEVELOPING AND IMPLEMENTING ACTIONS TO ENSURE HABITABILITY CRITERIA ARE MET

A. 19.1. General

If it has been determined that habitability is unacceptable for a given operation, techniques must be devised to allow the operation to be carried out in a manner that is safe for personnel under the postulated scenario situation. This problem can be approached in two ways. The first is to improve the habitability in the vital area to an acceptable status, and the second is to eliminate
the need for access to that specific area. Examples of both these approaches are given in Section 4 in the main body of this report, where means to improve habitability are discussed.

A.19.2. Example of developing and implementing actions

Continuing to use only the same two examples of operator and maintenance operations or actions, this discussion indicates what might possibly be done (before an accident) to improve the situation. In this example, it is assumed that nothing can be done about postponing operations or actions at the first point in time at which they must be carried out. However, for these specific actions, even a delay or postponement of a month or more would have little impact on the dose rate levels since the high dose rates in these vital areas are due to pipes and components filled with highly radioactive water, which contains a large quantity of long lived radioactive material.

*Operator action:* A simple partial solution to this problem could be to eliminate the checkup of the pumps from the routine when alternating the pumps. If supervision and control of the pump is considered necessary, then perhaps closed circuit television monitors might be installed or certain equipment readouts about the condition of the pump be relocated to habitable areas such as the floor above the pump rooms. The most radical corrective measure might involve installation of additional cooling capabilities as backup for the RHR system. Depending on how the reactor coolant system is constructed in the plant being analysed, it might also be possible to include a directive in the emergency operation procedures to make the greatest use of the option of cooling via the steam generators in the long term scenario.

*Maintenance action:* Apart from what was said in the discussion about the operator action and about the more radical corrective measures, other possibilities regarding maintenance may also be considered, for example:

- To arrange refilling and exchange of oil in the pumps from another location where dose rates are lower,
- To implement preventive maintenance by more frequent changes of oil,
- To flush the system with fresh water in order to lower the dose rates (this action might also permit more extensive repair or maintenance if needed).

It should be noted that the possibilities for shielding in the pump rooms are minimal because of the complexity of the system.

The above suggestions must then be carefully evaluated from both a technical and an economic point of view, whereupon one or more should be implemented in order to make it possible to perform the required actions under the accident situation postulated.

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A.20. SUMMARY

In the example discussed in this appendix, a scenario was postulated which involved severe reactor core damage. Habitability in areas within the facility was examined by first performing a rather rough initial assessment of radiation levels around piping systems carrying post-accident effluents. From this analysis it was evident that habitability would be seriously affected in areas outside the containment. Some relatively simple action was possible which would improve habitability in some areas within the auxiliary building, but further, more detailed, analysis was required since habitability still remained unacceptable.

In the detailed analysis the RHR system was examined as to examples of operator and maintenance actions required and habitability conditions in those areas where the actions had to be taken. Corrective measures were then suggested to make these areas habitable.

The purpose of this example was to demonstrate how the methodology described in Section 3 could be applied.
Appendix B

EXAMPLE OF ASSESSING AND IMPROVING HABITABILITY
FOR A NON-RADIOLOGICAL TYPE OF ACCIDENT SCENARIO

B.1. INTRODUCTION

An example is given in this appendix of assessment and improvement of habitability which illustrates in more detail how to apply the generic methodology given in Section 3 of this report to a specific non-radiological accident scenario. The structure of this appendix (i.e. the numbering of sections) corresponds to the structure of the generic methodology for habitability assessment developed in Section 3. This appendix also gives an example of the application of the guidance regarding improvement of habitability given in Section 4.

The different steps in the methodology are discussed in two ways. For each step some general considerations are first set out, and the methodology is then further illustrated by means of a specific example for that step.

B.2. DEVELOPING THE ACCIDENT SCENARIO

B.2.1. General

For the purpose of this illustrative exercise, a hypothetical transport accident involving a toxic gas (chlorine) release will be postulated and analysed. In developing the scenario, various items must be taken into consideration:

(a) Specification of the quantity of toxic gas transported and released in the scenario,
(b) Examination of the potential hazard of the toxic gas to persons involved in the event,
(c) Identification of any other toxic materials that might become involved in the scenario,
(d) Specification of the initiating event and the sequence of events including:
   — Probability of fire,
   — Number of containers involved and their contents,
   — Slow leakage or catastrophic failure of containers involved.

The need to establish whether or not there is a reasonable probability that an event will occur is an integral part of examining a credible event. In this case, one must establish the frequency of transport of the toxic material in the area, the frequency and proximity of accidents to the facility, and the resultant severity of the

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accidents. It is also necessary to be aware of the possibility of one event initiating another, for example a toxic gas problem causing a secondary event.

B.2.2. Example of the development of an accident scenario

A transport accident involving a release of about 200 kg of chlorine gas from a partially empty gas cylinder of one tonne capacity being carried by a truck occurs at about one kilometre from a nuclear power station. No other toxic materials are involved in the release. There is a fire, but no other flammable materials are involved in the accident other than the gasoline from the truck. The fire engulfs both the truck and the cylinder of chlorine strapped to it. For the purposes of a local manufacturing firm, these cylinders are known to be transported by truck essentially ‘empty’ but have been found occasionally to be partially full.

Because of local government restrictions on the transport of chlorine, the chlorine must arrive directly only by rail to the local manufacturing firm, but ‘empty’ cylinders may be transported by truck back to the railhead in a distant town. This return transport route is a road which passes within one kilometre of the nuclear power station.

B.3. EVALUATING THE HAZARD SOURCE

B.3.1. General

During the initial assessment of a toxic materials release as a hazard source, it may be convenient to take a ‘worst case’ analysis rather than assuming a smaller release of the toxic materials. In this way a relatively rapid analysis can be made to determine whether any actions, either simple or more complex, will have to be taken in order to improve habitability at the nuclear facility. Since, in this hypothetical example, ‘empty’ cylinders of chlorine as much as one fifth full (200 kg) have at times been found by local government transport inspectors and police on this road near the nuclear power station, this has been selected as a ‘worst case’ scenario. Rarely has the truck driver or his employer been legally cited or fined for this violation.

B.3.2. Example of evaluating the hazard source

For the purpose of the initial assessment of the hazard source used in this example, it is assumed that 200 kg of chlorine is dispersed over a 15 min period.
B.4. DETERMINING THE GENERAL AREAS OF INTEREST

B.4.1. General

In the initial assessment certain key areas in buildings would be taken as areas of interest and the consequences of the accident in terms of its effect on habitability in those locations would then be examined.

B.4.2. Example of determining general areas of interest

In the nuclear power station, which is located approximately one kilometre from the accident site, there are certain areas which will have to be occupied either permanently or temporarily in order to keep the plant in operation or to bring it to a safe shutdown condition. These areas may include:

(a) Main control room: continuous occupancy
(b) Auxiliary building: temporary occupancy
(c) Turbine building: temporary occupancy
(d) Radioactive waste building: continuous occupancy
(e) Computer room: continuous occupancy.

B.5. EVALUATING THE TRANSPORT MECHANISMS TO AREAS OF INTEREST

B.5.1. General

In evaluating the transport mechanisms involved in getting the toxic material to the area of interest, the following points should be considered:

(a) The release condition (either instantaneous or continuous over some finite period);
(b) Meteorological conditions assumed to be present, including wind velocity, direction and atmospheric stability class (Pasquill category);
(c) Mechanisms within the facility by which the toxic material will be transported, whether they are open doorways or ventilation systems.

B.5.2. Example of evaluating transport mechanisms

In examining the transport mechanisms for the chlorine transport accident, the following factors are determined:

(a) The release is at ground level over a 15 min time span;

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On the basis of a review of meteorological conditions at the plant, a 5% dispersion Pasquill category F has been assumed;

Pathways into the buildings, based upon a general facility review reveal that:

(i) The main control room, radioactive waste building and computer rooms will intake outside air at the normal ventilation rate for approximately 10 s until installed dampers are closed automatically by chlorine detectors and then gas can leak in at the normal infiltration rate thereafter;

(ii) For the auxiliary building and turbine building, the ventilation will run for 100 s until it can be shut down manually with normal infiltration taking place thereafter.

B.6. QUANTIFYING THE LEVEL OF HAZARD IN AFFECTED AREAS

B.6.1. General

For each area selected, the concentration of the toxic material must be calculated so that it can be compared with the habitability criteria established in Section B.7. In order to do this the following factors must be taken into consideration:

(a) Ventilation flow rates in both normal and abnormal modes;
(b) Infiltration outside air rates into inside areas, particularly if pressure differentials and building leakage are present which could cause some infiltration after isolation;
(c) Time required to isolate areas once the toxic material is detected;
(d) Volumes of the areas concerned;
(e) Any significant cleanup mechanisms if existing.

B.6.2. Example of quantifying the level of hazard in affected areas

Because the main control room, the radioactive waste building and the computer room are equipped with chlorine monitoring devices which trigger ventilation system isolation, these areas will intake the chlorine from the cloud for only 10 s, then normal infiltration takes over for the remaining 15 min of release. Calculations show the maximum gas concentrations to be as follows in these areas:

<table>
<thead>
<tr>
<th>Area</th>
<th>Concentration at isolation</th>
<th>Concentration after 15 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main control room</td>
<td>6.5 mg/m³</td>
<td>9 mg/m³</td>
</tr>
<tr>
<td>Radioactive waste building</td>
<td>0.7 mg/m³</td>
<td>3.6 mg/m³</td>
</tr>
<tr>
<td>Computer room</td>
<td>6.5 mg/m³</td>
<td>9 mg/m³</td>
</tr>
</tbody>
</table>
The remaining areas, i.e. the turbine building and the auxiliary building, must have the ventilation manually closed, and it is estimated to take approximately 100 s to do this. Calculations show the maximum concentration in these areas to be:

<table>
<thead>
<tr>
<th></th>
<th>Concn at isolation</th>
<th>Concn after 15 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine building</td>
<td>6 mg/m$^3$</td>
<td>57 mg/m$^3$</td>
</tr>
<tr>
<td>Auxiliary building</td>
<td>6 mg/m$^3$</td>
<td>12 mg/m$^3$</td>
</tr>
</tbody>
</table>

The next step will be to establish a habitability criterion for chlorine with which these levels can be compared.

### B.7. ESTABLISHING HABITABILITY CRITERIA

#### B.7.1. General

Habitability criteria can usually be obtained or calculated from applicable government standards or references. Since some of these criteria are time dependent and some are threshold values, it is important to recognize which of them are going to be applied. Often, it may be necessary to use both.

### TABLE V. HABITABILITY CRITERION FOR CHLORINE

<table>
<thead>
<tr>
<th>Effects</th>
<th>Concentration (ppm by vol.)</th>
<th>Concentration (mg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection by smell</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Coughing</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>Dangerous to life (30 min)</td>
<td>$\sim 50$</td>
<td>$\sim 150$</td>
</tr>
<tr>
<td>Lethal: 1 h exposure</td>
<td>$\sim 150$</td>
<td>$\sim 450$</td>
</tr>
<tr>
<td>Lethal: brief exposure</td>
<td>1000</td>
<td>3000</td>
</tr>
<tr>
<td>Maximum concentration for 1 h (workers)$^a$</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>

B.7.2. Example of establishing habitability criteria

In developing a habitability criterion for chlorine, Ref. [30] was used. Table V shows the values used. A habitability criterion for chlorine of <3 mg/m$^3$ is selected for the purposes of this example.

B.8. DETERMINING IF HABITABILITY IS ACCEPTABLE

B.8.1. General

It is at this point in the initial assessment that a determination can be made concerning the acceptability of habitability. The habitability criteria must be compared with the calculated hazard condition in each area of interest.

B.8.2. Example of determining if habitability is acceptable

From the calculation made of the hazard in Section B.6 and the habitability criterion selected, the acceptability of habitability can be determined in each area of interest. Table VI assists in making this determination. The table shows conclusively that habitability is acceptable in none of these areas, so the next step is to determine what simple actions might be possible to improve habitability conditions.

### TABLE VI. DETERMINATION OF ACCEPTABILITY OF HABITABILITY

<table>
<thead>
<tr>
<th>Area</th>
<th>Calculated concentration (mg/m$^3$)</th>
<th>Applicable limit (habitability criterion) (mg/m$^3$)</th>
<th>Habitability acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main control room</td>
<td>9</td>
<td>&lt;3</td>
<td>No</td>
</tr>
<tr>
<td>Rad. waste bldg</td>
<td>3.6</td>
<td>&lt;3</td>
<td>No</td>
</tr>
<tr>
<td>Computer room</td>
<td>9</td>
<td>&lt;3</td>
<td>No</td>
</tr>
<tr>
<td>Auxiliary bldg</td>
<td>12</td>
<td>&lt;3</td>
<td>No</td>
</tr>
<tr>
<td>Turbine bldg</td>
<td>57</td>
<td>&lt;3</td>
<td>No</td>
</tr>
</tbody>
</table>
B.9. DETERMINING IF SIMPLE SOLUTIONS ARE AVAILABLE; SELECTING A SIMPLE SOLUTION

B.9.1. General

The purpose of this question is to ascertain if some relatively inexpensive solution can be found to solve the problem. Such solutions often take the form of operational changes such as a procedure change, resetting an alarm point, or more rigorous testing of a system. On the other hand, the solution may be to reduce the risk of the accident happening in the first place.

B.9.2. Example of simple solutions

In this scenario, various simple solutions can be envisioned, some of which may be possible and some not. Some of these are discussed below:

<table>
<thead>
<tr>
<th>Simple solution</th>
<th>Analysis/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enforce violations of local government regulations regarding transport of cylinders if found other than ‘empty’.</td>
<td>Possible, but enforcement would be sporadic at best. Thorough enforcement expensive.</td>
</tr>
<tr>
<td>Change mode of transport of returning ‘empty’ cylinders from road to rail.</td>
<td>Possible, but economically burdensome since it would require local user of chlorine to maintain a higher inventory of cylinders for return of cylinders in sufficient quantity to justify rail freight costs on empty cylinders. Truck transport of empty cylinders is less expensive.</td>
</tr>
<tr>
<td>Provide chlorine respiratory protection for all workers at the nuclear power plant.</td>
<td>Not preferred owing to large and varying numbers of workers and length of time required to get into specialized respiratory equipment to protect against chlorine.</td>
</tr>
<tr>
<td>Isolate ventilation systems more promptly.</td>
<td>Possible, particularly where building infiltration rates are so low that limit for chlorine concentration will not be exceeded.</td>
</tr>
</tbody>
</table>
B.9.3. Selecting a simple solution

Where possible, the simple solutions should be implemented to help improve habitability. Although they may not completely solve the problem they may offer some improvement.

B.9.4. Example of selecting a simple solution

Section B.9.2 shows that more rapid isolation of ventilation systems might have the effect of keeping the chlorine concentration below the applicable limits. One possible solution is to place a chlorine detector (or detectors) between the plant and the road which could give sufficient warning of a release. The time so gained might allow isolation of ventilation systems before the chlorine cloud reached the plant. Then, the conditions as calculated for early warning of chlorine near the road will be present, as shown in Table VII.

From Table VII it is seen that habitability has been made acceptable in the continuous occupancy areas through advance warning one kilometre from the plant by using remotely placed chlorine detectors and prompt isolation. In the auxiliary building and the turbine building the habitability criterion is still exceeded, so a more detailed analysis will be required in those areas. It is noted that the main control room, the radioactive waste building and the computer room all had automatic ventilation dampers installed while the auxiliary building and the turbine building had manually operated ventilation dampers.

<table>
<thead>
<tr>
<th>TABLE VII. CONDITIONS FOR EARLY WARNING OF CHLORINE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concn after 15 min (mg/m³)</strong></td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>Main control room</td>
</tr>
<tr>
<td>Rad. waste bldg</td>
</tr>
<tr>
<td>Computer room</td>
</tr>
<tr>
<td>Auxiliary bldg</td>
</tr>
<tr>
<td>Turbine bldg</td>
</tr>
</tbody>
</table>
B.10. PROCEEDING TO MAKE A REFINED DETAILED ASSESSMENT

B.10.1. General

Once it is determined that simple actions are not possible or are insufficient to completely eliminate a habitability problem, then a more refined analysis will be required, with a higher probability of more complex and sometimes expensive solutions being found and implemented.

B.10.2. Example of proceeding to make a refined analysis

As seen in Section B.9, only a portion of the habitability problem was resolved in this scenario so the refined analysis will focus on those areas where habitability is found to be unacceptable. For the purposes of this example, only the auxiliary building will be examined even though the turbine building has similar habitability problems and will need to be assessed.

B.11. REFINING THE ACCIDENT SCENARIO

B.11.1. General

On the basis of solutions assumed during the initial assessment it may be necessary to modify the accident scenario or to become more specific about certain release parameters.

B.11.2. Example of refining the accident scenario

If it had been possible to modify the transport considerations of this accident scenario, e.g. by ensuring that only empty cylinders are transported by road or only return of the cylinders by rail is permitted, then changes would be required in the scenario. Since it was not possible in practice to make any changes concerning the shipment or the initiating event, the scenario remains unchanged. If the simple solutions (1) and (2) in Section B.9.2 were economically and realistically feasible, the scenario could be refined or eliminated.

B.12. REFINING THE HAZARD SOURCE

Since the hazard source was discussed in detail in the initial assessment, no further effort is required to refine it.
B.13. DETERMINING SPECIFIC OPERATIONS OR ACTIONS REQUIRED BY PERSONNEL

B.13.1. General

In this step detailed actions by plant personnel are identified along with the location (vital area) and the duration of the activity. The total number of people involved can also be noted but this in general will be immaterial since the chlorine limits apply individually and have little practical meaning on a collective basis (e.g. man-concentration basis).

B.13.2. Example of determining specific operations or actions required by personnel

Since it has been determined that the levels of chlorine in the auxiliary building are relatively close to the limit, it might be possible to take a variety of corrective actions to ensure habitability, particularly where temporary occupancy is required. Examples of detailed specifications required by personnel are included in Table VIII, which is a modified version of Table I originally discussed in Section 3.13. This table has been modified to suit the situation when dealing with a non-radiological hazard. Columns (1), (2) and (3) are completed.

B.14. IDENTIFYING VITAL AREAS

The areas where the specific operations identified are accomplished should be noted in column (4) of Table VIII. In these vital areas the hazard will be calculated and examined for habitability, as can be seen in Fig. 4.

B.15. EVALUATING THE TRANSPORT MECHANISM

B.15.1. General

In the refined analysis, the transport mechanisms are examined in detail, including any dilution that may take place, transport times, various systems and subsystems, and possible compartmental isolation.

B.15.2. Example of evaluating the transport mechanisms

When the transport mechanisms are evaluated for the auxiliary building, a two-compartment model can be used. It is calculated that the hallways experience flow
### TABLE VIII. MATRIX FOR HABITABILITY ANALYSIS

*(Duration of accident 15 min; functional group: operators; habitability criterion < 3 mg/m³ Cl)*

<table>
<thead>
<tr>
<th>Specific operation</th>
<th>Time after accident (min)</th>
<th>Duration of action (h)</th>
<th>Plant location</th>
<th>Detailed exposure (mg/m³)</th>
<th>Habitability condition acceptable YES/NO</th>
<th>Action required</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Primary coolant sampling</td>
<td>15</td>
<td>1</td>
<td>Sampling room</td>
<td>&lt; 3</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>(2) Control of CVCS(^a) operation</td>
<td>15</td>
<td>0.5</td>
<td>CVCS control panel</td>
<td>&lt; 3</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>(3) ECCS(^b) pump operability control</td>
<td>15</td>
<td>1</td>
<td>ECCS control panel</td>
<td>&lt; 3</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>(4) Valve status control</td>
<td>15</td>
<td>1</td>
<td>Valve room</td>
<td>&lt; 3</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>(5) Access to above areas</td>
<td>15</td>
<td>1.5</td>
<td>Auxiliary bldg corridors</td>
<td>12</td>
<td>No</td>
<td>Perform engineering analysis options</td>
</tr>
</tbody>
</table>

\(^a\) Chemical and volume control system.

\(^b\) Emergency core cooling system.
FIG. 4. Zone map of chlorine concentration in auxiliary building.

CS: containment spray; ECCS: emergency core cooling system; EFWS: emergency feedwater system; RHR: residual heat remover; HVAC: heating, ventilation and air conditioning; CVCS: chemical and volume control system.
and infiltration characteristics different from those in the equipment cubicles which remain somewhat isolated from hallways. From this model the hazard levels can be calculated.

B.16–17. QUANTIFYING THE LEVEL OF HAZARD; MAPPING THE PROBABLE EXTENT OF THE HAZARD

Using the information obtained on building ventilation characteristics, calculations can be made of chlorine concentration throughout the auxiliary building. Since the building is a two-compartment model, there are two basic zones of chlorine concentration. It is then useful to plot these zones on a building map as shown in Fig. 4. From this map, column (5) of Table VIII is filled in.

B.18. HABITABILITY ACCEPTABILITY

B.18.1. General

As in Section B.9, the same habitability criterion (from B.7) is used and is then compared with the existing exposure condition in each area. From this, column (6) of Table VIII can be completed.

B.18.2. Example of determining if habitability is acceptable

In the example used, it can be seen from Table VIII that all work areas meet the habitability criteria established. The only areas that do not are the access routes, where some corrective action must be taken.

B.19. DEVELOPING AND IMPLEMENTING ACTIONS TO ENSURE HABITABILITY CRITERIA ARE MET

B.19.1. General

As in Section B.9, there may be various possible solutions to improve the habitability in an area. Each of these possible solutions should be examined in sufficient detail to make a decision on the most cost effective approach.

---

6 The numbering corresponds to that of Section 3 of the report.
B.19.2. Example of developing and implementing a solution to improve habitability

Several possible alternatives to resolving the habitability problem which exists in the auxiliary building hallways are suggested. No effort has been made to develop the best cost effective solution, but any one of these or a combination of solutions could assist in improving habitability in the hallways. These possible solutions are as follows:

(a) Provide for two widely dispersed air intakes so placed that it is unlikely that both would be involved with the chlorine cloud;
(b) Provide for an emergency mode of operation for the ventilation system at a reduced flow;
(c) Install at the ventilation intakes a chlorine removal system to be used in emergencies;
(d) Install fast acting automatic dampers on the ventilation intakes and on the automatic closing of access doors;
(e) Improve building airtightness infiltration and periodically test it;
(f) Provide emergency breathing apparatus for personnel;
(g) Press the local government for better enforcement of its transport regulations;
(h) Press the manufacturer using the chlorine to return all ‘empty’ cylinders by rail away from the plant, thus eliminating the scenario.

Once the cost–benefit analysis of these alternatives has been made, as well as any others that might be thought of, it must be considered whether or not the habitability question has been solved and if any further iterations of the methodology are required. The cost–benefit analysis would seem to favour solution (h) from the nuclear power plant manager’s point of view but not from that of the local manufacturer using the chlorine. Solution (g) represents a compromise which if effectively carried out should reduce the risks from a probability standpoint.

B.20. SUMMARY

In this example the methodology outlined in Section 3 of this report has been demonstrated by postulating a toxic gas accident which has caused habitability to become unacceptable in a nearby nuclear plant. Using the prescribed methodology, an initial assessment was made and certain relatively simple solutions were chosen which improved habitability at the nuclear plant. However, it was apparent that some areas still remained uninhabitable within the facility, and therefore a more refined analysis was required to analyse these areas.
The methodology was used to accomplish the refined analysis, and it was determined that only certain vital areas requiring temporary access were uninhabitable at the plant. Once these areas were specifically identified, various options were set out to resolve the habitability problems they contained.
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<thead>
<tr>
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<tr>
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</table>

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24–28 June 1985

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<td></td>
<td></td>
</tr>
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