5. Accident Management on Site

The essence of nuclear safety is to prevent a loss of control of the nuclear chain reaction and to prevent the possibility for the formation of a critical mass during operation, reloading, transportation and storing of nuclear fuel, provision of heat-transfer and reliable cooling as well as confining the radioactive materials in prescribed boundaries. Nuclear safety at the plant is ensured by maintaining normal operation and by involving technical and organizational measure. The NPP design foresees a system for the inspection of failure detection in all barriers to radioactive release. The mentioned system is intended to assure safe operation.

The essence of radiological safety is to prevent radiation exposure of plant personnel, environment and the general public in excess of authorized limits.

5.1 Handling of Deviations, Incidents and Accidents

Nuclear power plant states may be classified into operational states and abnormal events. The operational states include both normal operation and deviation from normal operation or anticipated operational occurrences. The normal operation is an operation of a nuclear power plant within specific operational limits and conditions including shutdown, power operation, shutting down, starting, maintenance, testing and refueling. Deviations are all operational processes departing from normal operation which are expected to occur once or several times during the operating life of the plant and which do not cause any significant damage to items important to safety nor lead to abnormal events.

Abnormal events refer to all fault conditions which lead to unplanned shutdown. Abnormal events relevant to safety may be classified into incidents and accidents. Incident is an abnormal event, when the reactor safety systems are activated but allowing more or less immediate return to normal operation. Accident is a state defined under accident conditions or severe accident. Accident conditions are departure from operational states in which the releases of radioactive materials are kept to acceptable limits by appropriate design features. These departures do not include severe accidents. Definition of severe accident was given in Chapter 2.

Those departures of process parameters which can lead to an abnormal event during operation are considered as limits of safe operation. Table 5.1 presents the values of the RBMK-1500 reactor parameters which, if reached during operation on load, are considered as exceeding the operational safety of the plant.

Table 5.1 Limits of safe operation of Ignalina RBMK-1500 plant [14]

Parameter	Variation limit
Reactivity margin in the effective manual control rods, pcs	below 30
Reactor power, MW	over 4800
Fuel channel power, MW	over 4.25
Fuel linear rating, W/cm	over 485
Critical heat flux margin coefficient in the fuel channel	less than 1
Maximum linear fuel rating coefficient	less than 1
Graphite temperature margin coefficient	less than 1
Design graphite stack temperature, ^{o}C	over 760
Excess pressure in the steam separator, MPa	over 7.95
Water flow in control rod cooling circuit, m^3/s	less than 0.256
Water flow in the CPS channel with inserted rod, m^3/s	less than $0.83 \cdot 10^{-3}$
Heat-up rate of the reactor and MCC, ^{o}C/h	exceeding 30
Cool down rate of the reactor and MCC, ^{o}C/h	exceeding 30
I-131 activity level in MCC water for maximum allowable number of failed rods in accordance with the "Regulations for Nuclear Safety of the Nuclear Power Plant Reactors" PBYa RU AC-89, Bq/kg	over $3.7 \cdot 10^5$

Deviations are controlled by the reactor main operating and control systems. Necessary organizational measures are also established to prevent exceeding of the limit and violation of the requirements for safe operation of the plant. Automatic reactor protection devices against unallowable change of the parameters and failures of the power unit equipment are activated on signals and setpoints. When indications of deviation from process parameters occur, the necessary actions including reactor shutdown and power drop to a safe level are taken.

In emergencies, the staff is generally guided by special plant procedures [11-13], which describe actions to be taken for elimination and management of the accident and/or mitigation the accident consequences. Established procedures provide a basis for a suitable operator response to abnormal event. Operators are trained to take advantage of time requiring no immediate operator action to recognize and identify causes of the abnormal plant response. These procedures cover design basis accidents. The main task of the operating personnel in case of an incident or accident is to prevent the development of a design basic accident into a severe accident. For this purpose, any available main or safety systems must be used. By the use of these resources, the following three main safety functions should be performed:

- provision of reactor subcriticality and shutdown;
- provision of heat transfer from the reactor and reliable core cooling;
- confining of the radioactive materials into prescribed boundaries, ensuring integrity of fuel channels, MCC, feedwater and steam pipes as well as the integrity of ACS compartments.

The main tasks of the operators for elimination of accidents are as following:

- identifying the cause of the accident by activating reactor scram systems, safety interlocks, alarm systems, indications, changes of process parameters and reports of operating personnel;
- detecting the accident location and evaluation of the scale of the accident;
- preventing accident development, isolation of damaged equipment;
- ensuring nuclear, radiation and fire safety;
- ensuring safety of the on-site personnel;
- preventing accident progression and eliminating the effects;
- preventing violation of the requirements for safe operation of the equipment not enveloped by the accident;
- minimizing size and effects of the radioactive contamination of compartments, unit, site and environment;
- surveying conditions of isolated equipment and possibilities to return it to service;
- ensuring the reliable core cooling.

The main safety systems described in Chapter 3 should always be ready to perform their functions during operation on load. According to [11-13], all actions that are necessary for elimination of accident conditions and switching should be performed by two persons with obligatory mutual confirmation of actions to minimize the probability of errors [13].

5.2 Alarm Criteria

Values of the main reference parameters that are used for accident diagnosis and decisionmaking on whether or not the emergency should be declared and the emergency response plan [15], implemented are given in Table 5.2. The parameters given in this table are the high importance reference parameters which are monitored continuously. Decision about implementation of the emergency plan can also be taken on technical criteria if the current level of radiation is below the limits given in Table 5.2, but the prediction of accident development tells that these limits may be exceeded. Such decision is taken by either the Director General or Technical Director, or in case of their absence, by the Plant Shift Supervisor.

5.3 Alarming and Notification

A block diagram of the emergency notification and communications system is represented in Figure 5.1. The emergency notification system at Ignalina NPP includes:

- notification of plant personnel;
- notification of Visaginas residents and administration authorities of the nearby regions;
- direct phone connections with the Department of Civil Defence in Vilnius and Dispatcher of the Lithuanian Power System;
- INMARSAT satellite communications system to notify Swedish authorities: Radiation Protection Institute, Swedish Nuclear Power Inspectorate and Swedish Meteorological Institute.

Personnel notification system includes:

- one-way loudspeaking communications network, consisting of 23 loudspeakers installed in reactor buildings and around the site;
- wire transmission network consisting of radio center and office radio receivers;
- conference hall cabinet where telephones of the plant administration are linked;
- 17 emergency warning sirens installed inside the power plant units and on site.

Table 5.2 Main indicators of radiological accident for decisionmaking about emergency notification and implementation of the on-site emergency plan [15]

Description	Units	Notification of emergency	Emergency plan implementation
1. Fast increase of volumetric activity of fission products in coolant:			
Total activity	Bq/kg	$7.4 \cdot 10^{7}$	$7.4 \cdot 10^{8}$
Noble gases	Bq/kg	$1.2 \cdot 10^{5}$	$1.2 \cdot 10^{6}$
Iodine	Bq/kg	$3.7 \cdot 10^{7}$	$3.7 \cdot 10^{8}$
2. Fast increase of volumetric activity of fission products in turbine ejectons:			
Noble gases	Bq/day	$8.3 \cdot 10^{14}$	$8.3 \cdot 10^{15}$
Iodine	Bq/day	$3.7 \cdot 10^{11}$	$3.7 \cdot 10^{12}$
3. Increase of volumetric activity of radionuclides released to the atmosphere			
Noble gases	Bq/day	$1.4 \cdot 10^{14}$	$1.5 \cdot 10^{12}$
Iodine	Bq/day	$2.8 \cdot 10^{9}$	$2.2 \cdot 10^{10}$
Long-lived aerosols	Bq/day	$4.5 \cdot 10^{9}$	$1.1 \cdot 10^{10}$
4. Increase of volumetric activity of radionuclides in discharges to the lake	Bq/l	11.1	$1.11 \cdot 10^{8}$
5. Increase of dose equivalent rate:			
On-site	Sv/h	$1.2 \cdot 10^{-3}$	$2.4 \cdot 10^{-3}$
Within protection zone	Sv/h	$3 \cdot 10^{-4}$	$6 \cdot 10^{-4}$
6. Increase of coolant discharge flow from MCC	m^3/s	$2.8 \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$
7. Increase of radionuclides specific activity in water of observant chinks	-	$3 \cdot 10^{-11}$	$3 \cdot 10^{-10}$

Notification of Visaginas administration authority is effected remotely via the Ignalina NPP-Visaginas cable line. The officials of the Ignalina and Zarasai regions are notified by telephone. Direct cable telephone lines between Ignalina NPP and Vilnius are provided for communications with the Department of Civil Defence and the Lithuanian Power System. A satellite communications system INMARSAT MCS.9120 is installed in VATESI office in the plant administrative building for notification of Swedish authorities. The system includes a panel for automatic transmission of emergency messages, phone and fax channels.

5.4 Principles for Recovering of Safety

The safety priority is to prevent any accident by sound design, quality of manufacture and safe operation, and especially to prevent severe accidents. Nuclear power plants are designed so that the public is protected from a wide range of malfunctions. Nevertheless, the possibility that prevention might fail and a severe accident happen, cannot be ignored and such accidents have always been taken into account in considering safety. The first part of the safety approach is accident management, to stop accidents developing and the second is to contain any radioactive materials. The last is emergency planning if there is a risk of a significant release of radioactivity to the environment. Accident management is a constituent of normal operation. Accident management starts functioning in the course of an accident as specified in emergency procedures. The main tasks are as follows:

- assessment of the accident;
- provision for setting the on-site accident management into effect, implementation of all relevant actions as applied to accident control and management, putting the plant back to safe status and activation of emergency organization;
- notification of state and local authorities;
- emergency notification of the plant personnel and community.

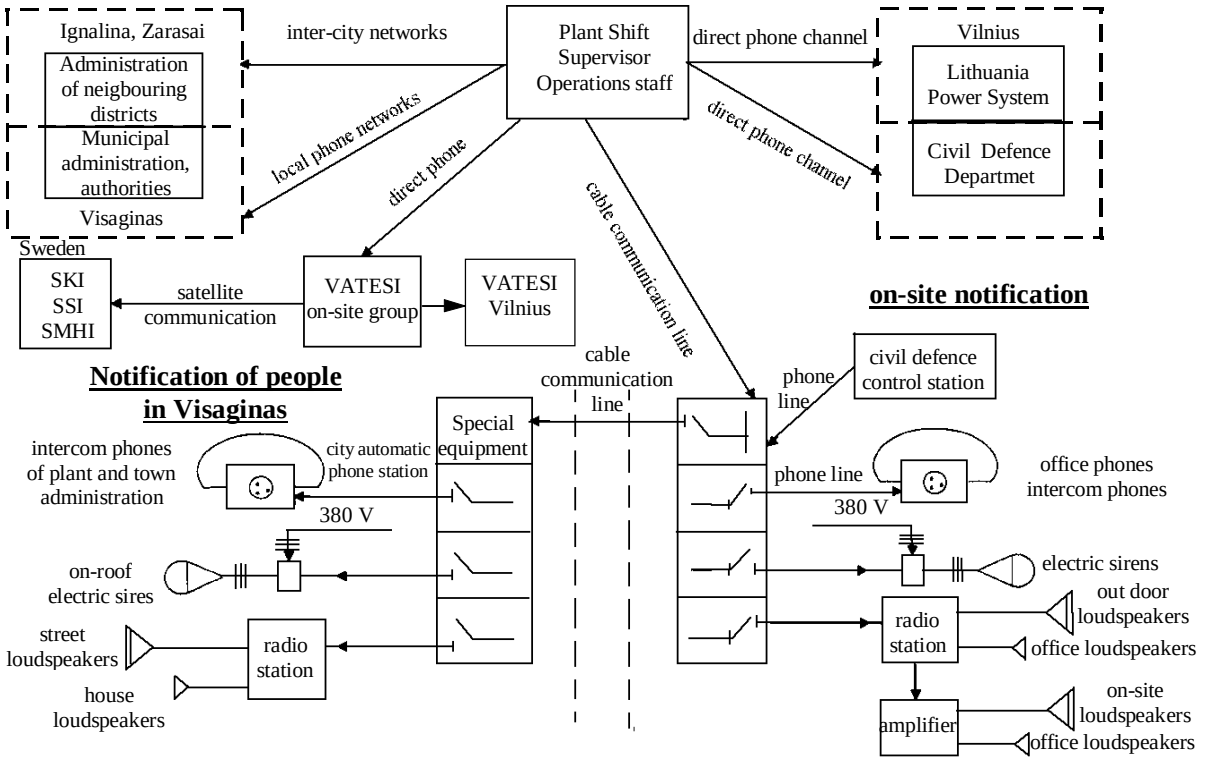

Fig. 5.1 Block diagram of Ignalina NPP notification system for personnel and population [15]

The main objectives of accident mitigation are protection of the population and plant personnel as well as protection of the plant equipment and premises. The emergency response plan [15] is designed for protection of the personnel as well as confinement and mitigation of the radiation accident at the Ignalina NPP. This is a basic document for taking organizational engineering, medical, evacuative and other actions. This plan is valid for all on-site personnel, the fire protection staff, the security guards and the attached persons. The actions required by the plant shall be taken on-site and within the exclusion zone (3 kilometer in radius). The existing plan based on old regulations will be revised during 1997.

5.4.1 Types of Radiation Accidents

A radiation accident at the Ignalina NPP is defined as an infringement of the normal operation in which release of radioactive materials and ionizing radiation goes beyond the specified limits and which requires to stop the operation of the facility/equipment containing ionizing radiation sources. Accidents are classified according to the spread of involved radiation materials or ionizing radiation into three types: on-site or local, off-site or area and general accidents [15]. To enable an early start-up of the emergency organisation, on-site as well as off-site, technical criteria are under development which will identify the level of radiation accident at an early stage.

Local accident is an infringement of plant operation in which on-site release of radioactive materials and ionizing radiation goes beyond the normal operation limits specified for equipment, process systems, facilities and buildings. Certain actions have to be taken to protect the plant personnel.

Area accident is an infringement of plant operation in which off-site release of radioactive materials and ionizing radiation within the exclusion zone exceeds the specified normal operation limits. Radiation exposure of personnel and contamination of plant facilities, buildings and territory may occur and go beyond the permissible limits. Actions have to be taken to protect the plant personnel.

General accident is an infringement of plant operation in which off-site release of radioactive materials and ionizing radiation outside the exclusion zone exceeds the specified normal operation limits. Radiation exposure of plant personnel and population may exceed the specified limits. Actions have to be taken to protect the plant personnel and population.

5.4.2 Technical Priorities for Recovering Reactor Safety

Reactor design and accident safety measures allow for design basis accidents. Severe accidents, however, cannot be ruled out. Accident management implementation procedures deal primarily with bringing these beyond design basis accidents under control. Severe accidents will at some point involve a mismatch between heat production and removal, that is, either an excess of power or inadequate cooling. Consequently, the two key safety functions are important here. The first is the reactivity control system which regulates the power rate and is needed to stop the chain reaction. The second is the cooling system and its power supply, with special attention to the residual heat removal system, which is needed after the reactor has been shutdown.

In the event of severe accident the fuel pellets, cladding of fuel rods, pressure tubes and pipelines of primary circuit could be damaged already during the initial stage of the accident. Only accident confinement system could prevent release of radioactive material to the environment. In this case, radiological consequences of accident would depend on the capability of this system to withstand elevated temperatures and pressure for the duration of the accident. It is therefore very important to have technical means for the reduction of pressure and release filtering. For the RBMK-1500 reactors to perform these functions and to recover reactor safety the following engineered safety systems should be ready to perform their functions:

- control and protection system,
- emergency core cooling system,
- accident confinement system,
- pressure relief system,
- reactor cavity overpressure protection system,
- venting systems,
- emergency power supply system.

5.4.3 Measures to Protect Vital Equipment and Buildings

The emergency response plan identifies the plant capabilities and planned actions to protect the equipment important to safety. This includes the capability to detect and fight fires, the support from external emergency response organizations, interface with the main control room emergency operating procedure, and the capability to repair damaged equipment and systems.

Fire safety assurance is one of the key aspects of accident prevention and mitigation of accidents as well as protection of the general public and plant equipment. The design requirements for existing fire protection system are quite stringent, but functioning should be improved. Automatic fire protection system is designed for detection, preventing and coping with fires at Ignalina NPP. This system includes automatic fire alarm system, automatic fire detection and fighting systems, fire confinement and smoke removal systems as well as the ventilation system. The automatic fire alarm system is installed in areas housing electrical equipment, repair shops and store rooms. Special attention is given to rooms housing electrical equipment of safety systems. Automatic fire detection and fighting system includes foam and water fire-fighting subsystems. The foam fire-fighting subsystem is designed to protect oil system equipment inside the reactor and turbine generator buildings. The water fire-fighting subsystem is designed to protect cable rooms, cable ducts and unit transformers. Both subsystems consist of two independent pump stations interconnected by pipelines. Fire confinement system is designed for automatic closure of air inflow/extract dampers in the area where the fire started. The fire is confined to one room. The smoke removal system is designed to remove smoke from the cable vault in which the fire was initiated. The general concept of ventilation of areas with potential formation of explosive materials consists in diluting these materials to non-explosive concent-rations and discharging them into the atmosphere.

On-site emergency response unit is set up based on the production principle. When an indication of the accident becomes evident, the plant shift supervisor takes a decision on emergency shutdown of the unit, takes actions to limit the size of the accident in accordance with operating procedures for process equipment, and coordinates actions of the department's shift managers. Special units are meant for emergency repair and performing specific activity when coping with accidents at the plant (restoration of reactor, turbine and electric equipment, instrumentation and automatic devices, decontamination of plant personnel, etc.). Special Units comprise personnel of the appropriate workshops (Figure 5.2). As well as the operating staff, special departmental units, the fire brigade and the town hospital are involved in mitigation of accident consequences. If necessary, other national fire brigades and medical institutions are called for. Based on the situation the Governmental Commission for Emergency Situations can draw in additional civil defence resources and other national institutes.

5.4.4 Measures to Protect Plant Personnel

The major action to protect the personnel is to timely diagnose the accident. The following main provisions are aimed at protecting the personnel in case of an accident:

- notification about the accident,
- availability of management structure and emergency response units,

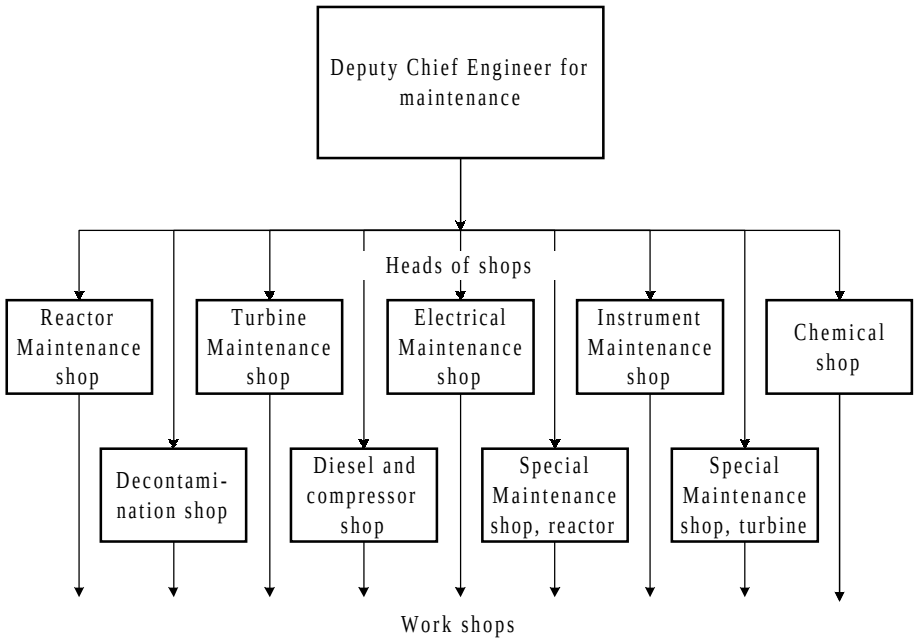

Fig. 5.2 Plant special branch unit organization

- engineering, medical aid and fire protection,
- physical security of the plant,
- logistics and evacuation.

The Director General has authority for implementation of the emergency response plan through the Emergency Operating Center and services. The time for the managers to assemble is 20 minutes on working hours and 2 hours outside working hours. The maximum time for the emergency response staff to get ready is 1 hour on working hours, and 6 hours outside working hours. Progress actions reports shall be submitted to the Emergency Operating Center every 30 minutes and, if the situation changes considerably, then immediately. By order of the Plant Shift Supervisor the on-site plant personnel (about 3000 people) have to evacuate to the shelter, which can accommodate 800 people, to the underground plant rooms having the minimum radiation level or other gathering places for evacuation. The shelter work in three operating modes: mere ventilation, ventilation with filters and air regeneration. The shelter is capable of reducing radiation by a factor of 1000 and sustaining overpressure up to 0.2 MPa. It is equipped with emergency power supply, a first aid point and water reserves. If an accident is declared, the personnel in the accident zone have to act as follows: put on personal protective equipment, take stable iodine tablets available at workplaces, undergo sanitary treatment and change clothes if contacted some contaminated process liquid, follow the reports of the radiation protection department shift supervisor on radiation situation and the orders of the direct managers, the radiation protection shift supervisor and the Emergency Operating Center.

Evacuation of the on-site personnel to Visaginas is planned in the optional manner: during office hours and during non-office hours. Estimated evacuation time for 2500 people is 72 minutes. There are about 230 people working at the plant during non-office hours. These people will be evacuated by shift transport within 60 minutes.

The emergency response system is currently under revision. The emergency response organization will be based on the plant responsibility, while the task of civil defence forces will be to cope with protection of the public outside the plant.

5.5 On-site Emergency Response Organization

The emergency response system at Ignalina NPP is meant to protect plant personnel, the general public and the plant in case of an accident [15]. This system is established with objectives to organize and implement rescue and other urgent activities as a part of coping with consequences of an accident, to take part in developing and implementing measures to enhance plant safety in emergencies, as well as to provide emergency training to emergency response authorities and forces. This also includes sheltered on-site emergency center, computerized radiation monitoring system and local notification system.

The proposed new organizational structure at Ignalina NPP for emergency response is shown in Figure 5.3. The Director General is the head of the on-site emergency response. He has overall responsibility for coordination and management of the on-site

organization and is directly supported by the Emergency Operating Center staff and services. Emergency Operating Center is responsible for organization of all emergency response activities and control of emergency response services on site. Emergency response services take care of all emergency engineering, technical, medical, radiation protection and other activities. On-site Emergency response services are set up on the basis of plant departments and deal with notification and communication, radiation and chemical protection, emergency technical support, shelters and covers, power supply and other special activities. The evacuation committee is responsible for evacuation from the site.

The training program for the emergency organization is planned annually. The aim is to acquire personal experience and interaction skills in diverse accident mitigation. Emergency training for all members of the staff is planned according to established schedule. Overall plant emergency exercises are hold every third year with all plant departments and services involved.

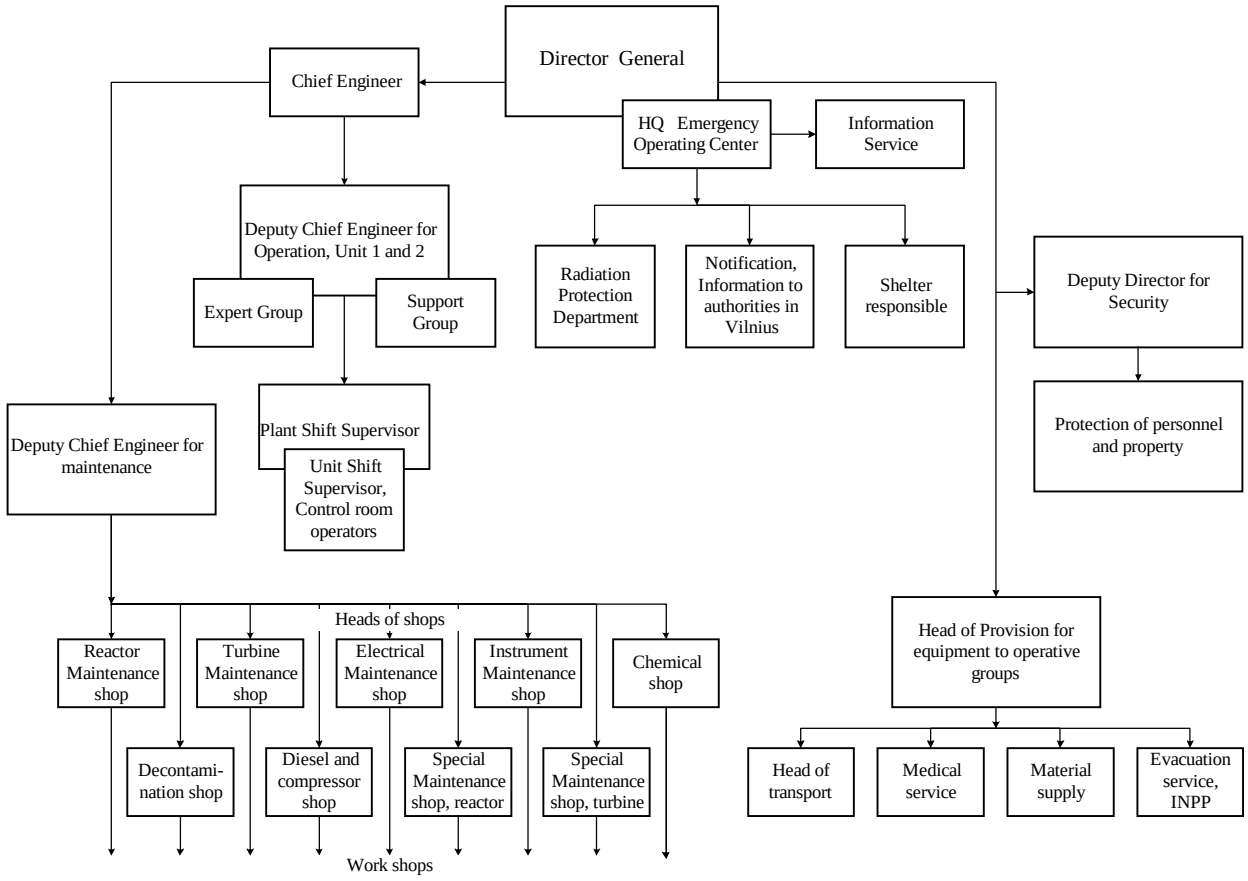

Fig. 5.3 Emergency response organization at Ignalina NPP (proposed new organization)