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Research Article

# Severe Accident Management At Nuclear Power Plants – Emergency preparedness and response actions

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## ABSTRACT

Worldwide, large number of nuclear reactors are in operation and also are under construction and commissioning stage for power production which also saves significant amount of carbon. In India, the number of reactor units in operation are 22 with the capacity of 7680MWe, there are 9 units under construction and commissioning with capacity of 6700MWe. Safety measures in these reactors are strengthened over the period in all the stages of nuclear power plants to ensure safety of people and environment. The concept of defense in depth is used to achieve the safety objectives during the operation of the reactor with emergency management as the 5th level of defense that can be used in case of severe accidents. Two major nuclear accidents (i) Fukushima (Japan-March 11, 2011) and (ii) Chernobyl (Former USSR – April 26, 1986) has emphasized the need for strengthening 4th and 5th level of defense to meet the safety objectives in case of severe nuclear accident. To address low probability events at nuclear power plant, emergency management plans are established for the protection of people and environment. Prior to the issuance of a license for the operation of NPPs, it is ensured by regulatory body that the site specific emergency management plans are in place and tested.

This paper presents the current developments in the nuclear emergency management to achieve safety objective. The elements of nuclear emergency management system includes legal and regulatory frame work, emergency preparedness and response plans, hazard assessment of the nuclear facilities considering the hypothetical severe accidents for deciding the preparedness category and sizes of emergency planning zones and distances, defining the goals for preparedness and response actions, criteria for classification & notification of emergency, consideration of health consequences and socioeconomic impact for deciding the implementation of protective

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actions in the affected area, generic criteria and operational criteria for taking the protective actions, radioactivity release phases and consideration for protective action, use of reference levels for setting the targets for protection strategy and termination of protective actions, criteria for changeover from emergency to existing exposure situation, dose criteria for the protection of emergency workers, response organization and their coordination, development of operation criteria (emergency action levels (EALs), operational intervention levels(OILs) and observables) from the generic criteria and use of operational criteria for emergency management, implementation of emergency operating procedures (EOPs), implementation of severe accident management guidelines (SAMGs) and emergency response plans and procedures(EPR), careful harmonization and integration of EOPs, SAMGs and EPR to meet emergency management objectives. This article identifies the important elements of emergency management that influence the decision making and implementation of protective action and protection strategy. The study identifies requirement to carry out research work to study the various factors affecting effectiveness of each important elements of emergency management to meet the goals of emergency response.

***Keywords:*** emergency management, generic criteria, emergency action levels, reference levels, emergency planning zones and distances.

## 1. INTRODUCTION

It is recognized that there is an ever-increasing demand for power for industrial and domestic application. Nuclear reactor power as a clean energy source contributes to power generation. Worldwide number of nuclear reactors in operation are about 450 and reactors that are under construction and commissioning stage for power production are about 50. In India, the number of reactor units in operation are 22 with the capacity of 7680MWe, the units under construction and commissioning are 9 reactors with capacity of 6700MWe. Safety measures in these reactors are strengthened over the period in all the stages of nuclear power plants to ensure safety of people and environment. The concept of defense in depth is used to achieve the safety objectives during the operation of the reactor. Emergency management acts as the 5$^{th}$ level of defense to manage severe accidents. Two major nuclear accidents (i) Fukushima (Japan-March 11, 2011) and (ii) Chernobyl (Former USSR – April 26, 1986) has emphasized the need for strengthening the 4$^{th}$ and 5$^{th}$ level of defenses to meet the safety objectives in case of severe nuclear accident. To address low probability events, emergency management plans are established for the protection of people and environment. Prior to the issuance of a license for the operation of NPPs, it is ensured by regulatory bodies that the site specific emergency management plans are in place and tested.

In India, Atomic Energy Regulatory Board (AERB) has developed and formulated safety codes and guides (AERB, 2014; AERB, 2020) giving the requirements and guidance for the preparation of emergency management plans. These plans are tested prior to the start of reactor operation. Internationally, International Atomic Energy Agency (IAEA) has published the requirements (IAEA, 2014; IAEA, 2015) and guidance documents on emergency preparedness and response. International Commission on Radiological Protection has published recommendations and guidance on EPR (ICRP, 2007; ICRP, 2009; ICRP, 2011).

Operating organization of the nuclear reactor and other response organizations such as DDMA, CMG-DAE has established emergency preparedness and response plans based on the regulatory documents for the protection of people an environment in case of accidents at nuclear facility. This paper describes the various elements of nuclear emergency management system identified by undertaking the study. Paper also identifies the important elements of emergency management that influence the decision making and implementation of protective action and protection strategy. It is recommended that further research work is necessary to study the various factors affecting effectiveness of each important elements of emergency management to meet the goals of emergency response.

## 2. EMERGENCY MANAGEMENT: EMERGENCY PREPAREDNESS AND RESPONSE

Emergency plans including preparedness and response arrangements are established at each nuclear power plant for management of emergency that may arise due to nuclear accident. The extent of emergency preparedness required depends on precise information on source term functions (release quantity, radio-nuclides and their physico-chemical forms) in absolute and relative terms as well as release location, source height and released energy. Following subsections describes the current level of emergency preparedness and also improvements in the emergency management programme based on the study under taken.

### 2.1 Hazard Assessment of Nuclear Facility and Emergency Preparedness Category

Hazard assessment of each nuclear facility (such as NPP, research reactor) at the site is performed considering safety analysis to establish emergency planning zones and distances and graded approach for implementing the protective actions. For the purposes of emergency preparedness and response, emergency preparedness at facilities is classified in to five categories i.e. Categories I to V (IAEA, 2015) commensurate with the hazards identified, these categories form the basis for graded approach. The emergency preparedness of category-1 is necessary for nuclear power plants, hence all hypothetical accident scenarios including severe accidents and also multiple facilities at the site affecting simultaneously are postulated. Hazard analysis identifies the scenarios that can result into severe deterministic effects in the public domain requiring the precautionary urgent protective actions (PUPA), urgent protective actions (UPA) or early protective actions (EPA) and medical management to achieve the goals of emergency management.

### 2.2 Goals of Emergency Management

The goals of emergency management during the nuclear emergency are;

(i) To regain the control of emergency situation
(ii) To avoid severe deterministic effects or tissue reactions due to radiation exposure
(iii) To reduce the risk of stochastic effects due to radiation exposure
(iv) To provide reliable information to the public for appropriate response
(v) Medical management of exposed people
(vi) Manage non-radiological consequences
(vii) To bring back normal social and economic activity in the affected area

### 2.3 Emergency Planning Zones and Distances

For effective management of nuclear emergency, planning and preparedness for protective actions is one of the important element. Based on the hazard analysis and radiological impact assessment, the area around the nuclear facility is divided into precautionary action zone (PAZ), urgent protective action planning zone (UPZ), extended planning distance (EPD) and ingestion and commodities planning distance (ICPD) for implementing the graded approach in the protective actions. For planning purpose at Indian NPPs, the size of planning zones is established as 16 km radius around NPPs and size of planning distances as 30 km radius. In precautionary action zone (PAZ), arrangements for taking protective actions in public domain are made to reduce the risk of severe deterministic effects even before release of radioactivity based on the EALs. In UPZ, protective actions are taken based on appropriate use radiological conditions (OILs) monitored in the public domain and plant parameters (EALs). In extended planning distance (EPD) and ingestion and commodities planning distance (ICPD), arrangements are made for monitoring the radiological conditions for assessment of radiological impact after the declaration of the offsite emergency. These radiological conditions decide the protective actions required to limit the stochastic effect in public domain and also to manage non radiological impact. During actual emergency conditions, the size of zones will vary depending upon core inventory, type of accident and atmospheric parameters. The process of implementation of protective actions should result into the residual doses below the reference level.

## 2.4 Identification and Classification of Emergencies

Identification, classification and notification of emergency class promptly to the response organisations is one of the important function of emergency response. Emergencies are classified into Off-site Emergency, site emergency, plant emergency and alert based on the severity of the accident from high to low in that order. The type of emergency is classified considering the extent and severity of the incident monitored by plant parameters and comparing with emergency action levels (EAL).

## 2.5 Protective Actions and Response Actions

Protective actions and response actions are implanted onsite and offsite after the declaration and notification of offsite emergency. Protective actions are implemented considering the generic criteria (projected dose) and using the operational criteria (EALs, OILs and Observables). The medical management is implemented based on the dose received by the population and using the triage. The dose during an accident condition at various distances from the accident zone is projected using atmospheric dispersion models, meteorological data and accident source terms. Decision Support Systems such as Online Nuclear Emergency Response System (ONERS) (Raja Shekhar et al., 2019) incorporating various environmental models and site specific database such as population, administrative boundaries, real-time field monitoring data, are used to geographically project the radiation dose in all possible pathways and to evaluate suitable protective actions at different temporal and spatial scales. The protective actions that are required to be taken urgently are (precautionary urgent protective actions and urgent protective actions) based on the EALs and OILs. As the accident progresses, more information is available. Early protective actions are taken which may involve the wider geographical area and large population. Urgent protective actions include iodine thyroid blocking, sheltering, evacuation and restriction of contaminated food. Protective actions which are implanted to protect the public from the exposure pathways from ground deposition and contaminated food items are early protective actions. These protective actions include restrictions on consumption of contaminated food item and drinking water, relocation of affected population, controls on agriculture produce and trade. The system of protective actions is based on the biological effects of the radiation exposure and possible health consequences which may include severe deterministic effect and increase of stochastic effect.

a) Severe deterministic effects as possible health consequence of radiation exposures**:**

To protect the people from severe deterministic effects, generic criteria is established from the projected dose. This projected dose level which is approaching the threshold dose for severe deterministic effects. The basis for implementation of precautionary urgent protective actions such as administration of stable iodine, sheltering and evacuation is primarily to prevent severe deterministic effects. Based on the dose received, the response actions involved are management of cases of severe deterministic effect and treatment of exposed people.

b) Increase of stochastic effects as possible health consequence of radiation exposures**:**

To protect the people from increase of stochastic effect, generic criteria is established at a projected dose level to limit the risk of stochastic effect, the protective actions include temporary relocation and control of contaminated food intake. Based on the dose received by people and to limit the stochastic effect, medical management include screening of people from affected area based on their exposure to whole body or specific organ for early detection and registration for medical follow-up and psychological counselling.

## 2.6 Emergency Management Based on Radioactivity Release Phases

After the accident, the radioactivity can get released in the environment depending upon the failure of the barriers to radioactivity release. depending on the progression of the accident, on the time scale and release of radioactivity, three phases are identified as (a) pre Release Phase (b) release Phase (c) post release phase. These three phases are illustrated in Figure-1. The exposure pathways in these three phases are distinctly different. The time scale of each phase and availability of time for implementing the protective actions are different. The release phases plays important role in the implementation of the protective action in public domain.

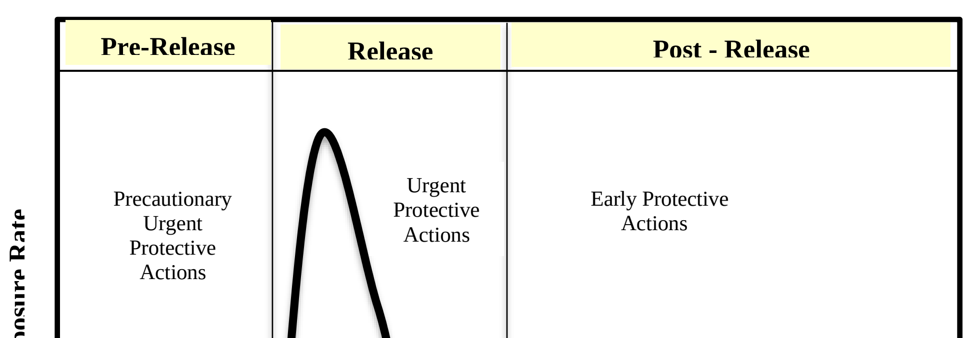

**Fig.-1. Protective actions based on radioactivity release phase**

At the pre-release phase, there is no actual release but based on the EALs, the potential of high exposure is recognized and precautionary urgent protective actions are implemented to avoid the acute radiation syndromes. The time available in this phase is very less, typically hours. In the release phase, radioactivity is released in the environment resulting into exposure of public mainly from the radioactivity in the plume. The time available in this phase is typically in hours to few days. In the post release phase, the release is stopped, radionuclides are dispersed and deposited on the ground and may transfer into the food items and drinking water. The radiation exposure rate is relatively small but can give exposure for long period. The exposure situation is well characterized, sufficiently long time period is available for implanting the optimized protective actions in public domain. The release phases, exposure pathways, radiation exposure rate and time scale available are very important for the decision on the type of protective actions, geographical area affected and population groups where needs urgent attention. Hence these elements need in depth study to develop the optimized protection strategy.

At the onset of the accident, depending on the operational criteria monitored by the response groups e.g. plant conditions (EALs) or radiological parameters (OILs) are important tools for decision on protective action. At the preparedness stage, EALs and OILs needs to be established considering the hypothetical accidents, potential radionuclide release and geographical area affected. As the accident progresses, management decisions are based on complete information on radiological impact and non-radiological impacts that may be due to both nuclear accident and implementation of protective actions such as evacuation of people from the affected area. The residual doses estimated in the affected population group is important parameter for decision making.

## 2.7 Reference Levels

Reference levels are related with residual effective dose, estimated from all radiation exposure pathways. These reference levels are used to decide termination of the protective action / protection strategy or changing from one protective action to another protective action with objective to achieve more good than harm. Reference levels are used to implement the graded approach in the protection. For high exposure potential group, reference values are initially set at 100mSv, the protective actions are aimed to keep he exposure of such group below 100mSv. In a similar way, reference levels / values are set for other population groups between 20 mSv and 100 mSv to implement the protective action in graded approach for optimization of resources and maximization of public protection. The protection strategy is aimed to reduce the radiation exposure below the reference level. After the termination of emergency, the reference levels in the range 1 and 20 mSv per year are used to implement the protection strategy in the existing exposure situation with aim of achieving the exposures below 1mSv/year (ICRP, 2003; ICRP, 2009; ICRP, 2011).

### 2.8 Guidance Dose Values for Emergency Worker

Emergency workers are assigned the responsibility to carry out the mitigatory functions at site and response action onsite and offsite to protect the people and environment. The radiation exposure of the emergency workers is controlled by response organizations by using the guidance dose values. For emergency worker the guidance dose value is ≤ 500 mSv (AERB, 2014). However, the protection strategy should be such that dose of 100 mSv is not exceeded. The dose (acute or annual) of emergency workers should be justified and optimized. Guidance values for emergency workers are provided for three different actions (i) for life saving actions (ii) protective actions to avoid biological effects of the radiation exposure (prevent deterministic effects and limit stochastic effect) of the people in the affected area (iii) protective actions to avoid exposure of large population.

### 2.9 Emergency Response Organizations

Responsibilities of operating organization, response organizations and regulatory body are established at the preparedness stage for effective emergency management (EM). The EM plans clearly identifies responsible officials of response organizations to address all components of the emergency response system and have standard operating procedures. Operating organizations has established EPR plans for management of plant emergency based on the regulatory requirements and guidance. Similarly, for the management of site emergency that may originate from either one facility or multiple nuclear facilities within the site, site emergency response organization has established site EPR plans. For the management of offsite emergency, site response organization in coordination with District Disaster Management Authorities (DDMA) has established offsite EPR plans to protect the public in the affected area. The site response organization and Crisis Management Group of Department of Atomic Energy (CMG, DAE) are responsible for providing the technical assistance to DDMA in carrying out urgent and early protective action in public domain to achieve the goals of the emergency response. CMG-DAE coordinates with the National Crisis Management committee (NCMC) and national executive committee (NEC) for national level emergency response. DM Act (2005) is established for management of all disaster including the nuclear emergency and radiological emergency. NDMA as the apex body formulated policies, plans and guidelines for Disaster Management including nuclear and radiological emergency.

## 3. GENERIC CRITERIA AND OPERATIONAL CRITERIA FOR EMERGENCY MANAGEMENT

Generic criteria and operational criteria are established for planning the emergency management arrangements, preparedness of operating organization and response organization for classification of emergencies and implementing the protective action in a response to nuclear emergency. Generic criteria in term of projected dose is used for establishing the operational criteria. Operational criteria which includes EALs, OILs and Observables is used for implementing urgent protective actions and early protective actions (e.g. evacuation, sheltering, control of food and administration of stable iodine). The basis for generic criteria is consideration of biological effects of radiation exposure, severe deterministic effect (tissue reactions) and stochastic effect.

Generic criteria which is established considering the projected dose for implementing the protective actions and dose received is used for medical management of the exposed population. Operational criteria are developed from generic criteria that include (i) Emergency Action Levels (EALs) (ii) Operational Intervention Levels (OILs) and (iii) Observables (by operators or first responders) (AERB, 2014). The EALs are used for taking decision on emergency classification and implementing urgent protective actions and OILs are used for taking decision on implementation of urgent and early protective actions. EALs are plant parameters monitored at control center. OILs are radiological quantities derived from the generic criteria.

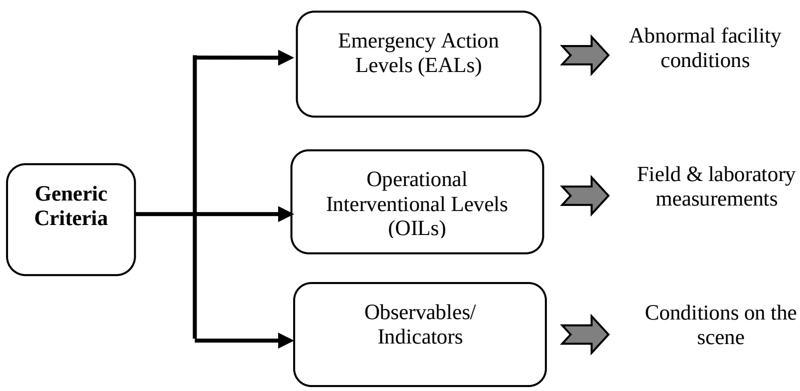


**Fig.-2. Operational criteria for emergency management**

The OILs are used to compare monitored/ calculated radiological parameters such as dose rate, radioactivity release parameters, radioactivity concentration levels in air, radioactivity levels in environment, in food, water and milk to take the protective action. OILs are grouped into OIL1, OIL2, OIL3, OIL4, OIL5, OIL6, OIL7 and OIL8 based on the radiation field and radioactivity levels corresponding to the projected dose. The scheme of operational criteria derived from the generic criteria for emergency management is illustrated in Fig. 2.

### 3.1 Emergency Action Levels (EALs)

The emergency action levels (EALs) (NEI, 2012) are instrument readings of the plant system parameters that can be monitored by the operator from control room panels identified for each nuclear power plant based on the hazard analysis of the hypothetical accident scenario. These EALs are identified for each class of emergency and included in the emergency preparedness and

response plans. Operator during the accident identifies the emergency class based on the EAL parameters observed and also recommends for various urgent protective actions that are required to be taken in public domain.
The generic EALs for PHWR (AERB, 2014) are developed and provided as regulatory guidance for use by each NPP organization. The typical examples of EALs included in the EPR plans are reactor primary coolant pressure, containment pressure, radiation monitor readings, radioactivity release rates that are higher or lower than the threshold values used for decision making. The other observables / indications such as power failure, fire in plant affecting safety systems, earthquake, flood etc are also used as EALs.

The EALs for NPPs (PHWR & LWR) are developed for four emergency categories i.e. alert, plant, site and offsite emergency) based on the following plant parameters and conditions:

(a) Impairment of safety functions (e.g. failure to stop reaction, insufficient cooling of reactor core)
(b) Confirmed core damage and loss of barriers to radionuclide
(c) Higher radiation levels in reactor building and at onsite area
(d) Effluent release rates exceeding specified limits
(e) Fire, release of toxic gas, events related with security and other events (Major natural disaster such as: Earthquake, Flood)
(f) Events with spent fuel damage

## 4. TERMINATION OF AN OFF-SITE EMERGENCY

After the termination of an off-site emergency, the emergency exposure situation is changed to existing exposure situation or planned exposure situation (IAEA, 2014; IAEA, 2015).

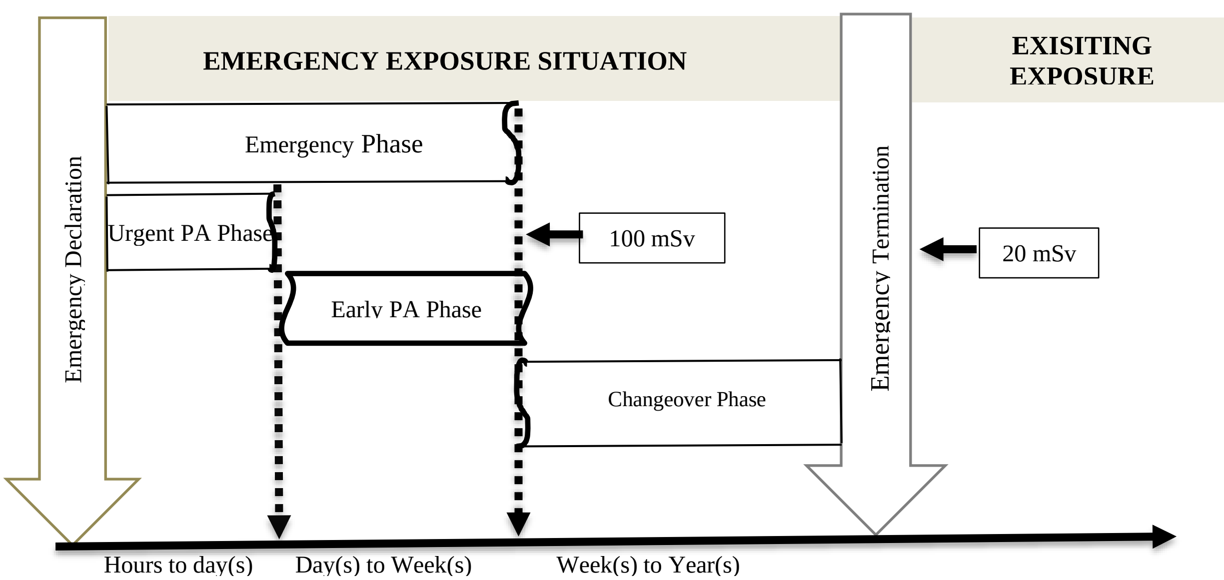


**Fig.-3. Different phases for protective actions in nuclear emergency management**

Prior to the termination of emergency, arrangements for termination of emergency and managing the existing exposure situation needs to be in-place. Termination of emergency exposure situation and changing into an existing exposure situation is decided after ensuring that (a) justified protective actions are taken to achieve the residual dose below 20 mSv per annum (IAEA, 2015) (b) radiological exposure to the members of public is characterized (c) the exposure situations are stable and understood fully (d) limited restrictions in affected area (e) the plant is under control (f) the activity releases from the plant are within the prescribed limit. In an emergency exposure situation, there is emergency phase and changeover phase [see Fig. 3]. The "Changeover phase" is phase in the process of emergency management after the end of urgent protection actions phase and early protective action phase at which the termination of an emergency can be made.

## 5. SEVERE ACCIDENT MANAGEMENT: IMPLEMENTATION OF EOP, SAMG AND EMERGENCY PREPAREDNESS AND RESPONSE PLANS

The national legislative requirement for Nuclear Emergency Management is governed by Atomic Energy Act 1962 (AERB, 2014) and Disaster Management Act 2005. The requirement for radiation emergency preparedness (AERB, 2014) is prescribed in Radiation Protection Rules 2004 (AERB, 2014) framed under the Atomic Energy Act. "Disaster Management Act, 2005" enacted by the Government of India provides requirement of national disaster management plans and national guidelines for establishing the national framework for nuclear emergency management under all disasters approach. At each NPP, the emergency management plans for plant emergency, site emergency and offsite emergency are prepared considering the legal requirement and regulatory requirement. The specific requirements and guidance (Codes and Guides) Nuclear and Radiological Emergency Management are formulated by AERB. Each nuclear power plant has established emergency management plan, severe accident management guidelines and emergency operating procedures for effective and efficient management of nuclear and radiation emergency.

In the event of emergency at nuclear power plant due to the accident, emergency operating procedures (EOP) (AERB, 2020), severe accident management guidelines (SAMG) (AERB, 2020) and emergency preparedness and response (EPR) plans are implemented depending upon the accident scenario and its progression. The protection for operational transients, design basis accidents and severe accidents is provided by using defense in depth concept in wide spectrum of nuclear power plant operation to emergency management. The system of defense in depth involving five levels of protection are as follows:

(a) Level 1: Prevention of operational transients;
(b) Level 2: Prevention of design basis accidents
(c) Level 3: Prevention of severe accidents;
(d) Level 4: Management of severe accidents;
(e) Level 5: Emergency Management : Emergency planning, preparedness and response

As a defense-in-depth requirement, the safety systems and engineered safety systems are incorporated for fulfillment of safety functions which include (i) reactivity control in the core (ii) removal of heat from reactor core (iii) Contain the radioactivity in the core. In order to provide fourth level of defense, SAMG is implemented in severe nuclear accident to minimize early release of radioactivity and large release radioactivity. The important function of this level is confinement the radioactivity inside reactor building. Implementation of EM plan is fifth level of defense.

The emergency management plans are implemented to minimize radiological consequences of the radioactivity release from the nuclear accident. EM plans are prepared and exercised which takes into account accident analysis and arrangements required for its implementation. The transition between the EOPs and SAMGs are clearly defined. The transition from emergency operating procedures to emergency management guidelines is initiated when there is possibility of core damage. Careful harmonisation and integration of EOPs, SAMGs and EPR plans is established for proper implementation.

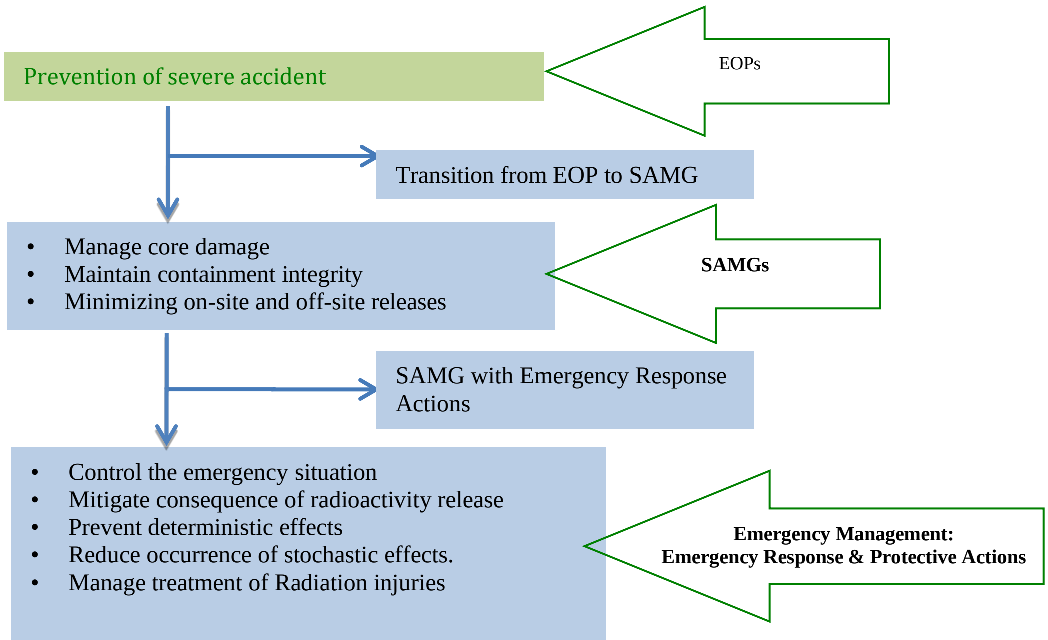


**Fig.-4. Implementation and Transition of EOP, SAMG and EPR plan**

The severe accidents with containment failure or bypass indicates that Defence in Depth layers Level 1 to Level 4 have failed already, in such cases SAMGs can be part of Level 5, which provides actions to limit large releases of radioactive material into the environment and therefore support emergency management and offsite emergency response. The EOPs and SAMGs support to the emergency planning and response in case of beyond design base accident scenarios with potential consequences to population and environment. The harmonisation and integration of EOP, SAMG and EPR plans used for implementation is illustrated in Fig.4. The objectives of management of nuclear accident are (a) prevent the damage of nuclear fuel and reactor core (b) Terminate the core damage progression (c) Maintain containment integrity to prevent the radioactivity release (d) Minimizing onsite and offsite release of radioactivity (e) Achieving stable state at onsite and offsite (f) Maintaining public exposure below the reference levels.

## 6. CONCLUSION

The nuclear emergency management system of nuclear power plants was studied. The study included various elements of the management system and identification of important elements which influence the emergency response. It was identified that decisions making and implementation of protection strategy in public domain are important elements which needs further research to study the contributing factors of these elements.

The regulatory framework has established the requirements and guidance for preparation of emergency management plans for nuclear accidents giving details of emergency planning, emergency preparedness and emergency response. These regulatory documents on EPR takes into account IAEA safety standards on EPR, ICRP publications and international practice. The emergency management plans incorporating the regulatory requirements are established and tested periodically at each nuclear power plant site. Generic criteria in terms of projected dose and operational criteria in terms of plant parameters and radiological parameters are provided for prompt implementation of various protective actions in the public domain. The EALs for NPPs (PHWR & LWR) are developed and provided as regulatory guidance for classification of emergency and initiating the response action. The provision of EOP, SAMG and EPR plan provide adequate defence in protection of public and environment. The harmonisation and integration of EOPs, SAMGs and EPR plans has strengthened effective implementation and provide adequate defence in depth.

## REFERENCES

1. ATOMIC ENERGY REGULATORY BOARD, Safety Guidelines AERB/SG/EP-5(Rev.1) "Criteria For Planning, Preparedness and Response for Nuclear or Radiological Emergency", AERB, Mumbai, India ((2014).
2. INTERNATIONAL ATOMIC ENERGY AGENCY, General Safety Requirements Part 7 (GSR Part 7): Preparedness and Response for a Nuclear or Radiological Emergency, IAEA, Vienna (2015).
3. EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, General Safety Requirements Part 3 (GSR Part 3): Radiation Protection and Safety of Radiation Sources : International Basic Safety Standards, IAEA, Vienna (2014).
4. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Ann. ICRP 37 2–4 (2007).
5. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Application of the commission's recommendations for protection of people in emergency exposure situations, ICRP Publication 109, (2009).
6. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Application of the commission's recommendations for protection of people Living in Long-term contaminated areas after a nuclear accident or Radiation emergency, ICRP Publication 111, (2011).
7. Raja Shekhar, S.S., Venkata Srinivas, C.V., Rakesh, P.T., Deepu, R., Prasada Rao, P.V.V., Baskaran, R., Venkatraman, B. 2019, Online Nuclear Emergency Response System (ONERS)

for consequence assessment and decision support in the early phase of nuclear accidents - Simulations for postulated events and methodology validation. Progress in Nuclear Energy. https://doi.org/10.1016/j.pnucene.2019.103177.

8. ATOMIC ENERGY REGULATORY BOARD, 2020. Accident Management Programme for Water Cooled Reactor Based Nuclear Power Plants. Safety Guide: AERB/NPP-WCR/SG/D-26, AERB.
9. Nuclear Energy Institute, 2012. Development of Emergency Action Levels for Non-Passive Reactors. NEI 99-01 [Revision 6].