Federal State Unitary Enterprise VO «Safety»

Beyond Design Basis Severe Accident Management as an Element of DiD Concept Strengthening

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Regulatory requirements (1)

OPB-88/97 General provisions...

***it. 1.2.3*. Level 4 DiD (BDBAs Management) identifying BDBAM tasks as:**
-accident propagation prevention and consequences mitigation
- defense of hermetic enclosure from damages and keeping its functionality
- to return the unit in a control state when chain fission reaction is terminated, permanent nuclear fuel is cooling and radioactive substances in established boundaries are keeping

Definition No 62 of SEVERE BEYOND DESIGN BASIS ACCIDENT, as beyond design basis accident with fuel elements damage more than maximal design limit.

⇨ ***Severe Accidents (SA) – are a subset of all BDBAs set***

***it. 1.2.16*. Analysis of BDBAs consequences including accidents with core melting is a basis for Emergency planning of personnel and population protection, as well for BDBAMG development**

***it. 1.2.14*. If BDBAs could not be exclude on the basis of the reactor inherent safety features and RI design principles, the BDBAMG should be developed.**

Regulatory requirements (2)

NP-082-07. Rules of NPPs RI Nuclear Safety

it. 2.1.8., … accidents with severe core damage should considered among BDBAs

NP-006-98. Requirements to SAR content and structure

it. 15.6. BDBAs Analysis ➡ Development of BDBA Management Measures

NP-032-01. Nuclear plant sitting. Basic safety criteria and requirements

it. 4.1.6. for the site located on sea coast or water body, it is necessary to determine probability of tsunami (seiche) initiation and maximal height of tsunami wave considering seism tectonic conditions and a shore configuration (relevant for Fukusima accident)

The availability of BDBAMG approved by the Regulatory Body is an obligatory condition to get the license for NPP unit operation

The BDBAMG , as a part of operation documentation should be in the correspondence with the actual state of the unit, and thus with DiD realized in it design

BDBAMG development – as “stress test” for unit design

BDBAMG development is launched when design development is finished (or mainly finished).

The revision of design basis of some elements composing DiD Levels, should be carried out during BDBAMG development, to identify the “weak” points of DiD.

This procedure is named “stress test” now. The revision of DiD and “stress test” were carried out after SA on NPP “Fukushima”.

The re-evaluation results may be the basis for unit modernization,

i.e.

BDBAMG development may also influence on the design, thus strengthening DiD realized in the design.

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Preparation for development (connection with Levels 1 and 2)

The effectiveness of personnel activity per Guidance is forming during the phase of preparation for it directs development.

Preparation contains two main components:

(1) evaluation of exist safety substantiation calculations, including PSA;

(2) investigation and consideration of Unit capabilities and the NPP site features.

Evaluation of safety substantiation calculations presented in SAR and PSA (1)

a) Re-evaluation of representative BDBA scenarios selection

Level 1
- assessment and selection of a site,
- establishing safe area around the NPP, where protective emergency measures shall be planned;
- developing the design on the basis of a ***conservative*** approach

- The analysis of selected BDBA scenarios and their consequences should be presented in SAR. These scenarios forms a basis for AM measures definition as well for development of plans arrangements for personnel and population protection.

- The substantiation of representative BDBA scenarios selection is attained by postulating of NPP unit "*levels of severity state*" = *"state of protective barriers".*

- All possible combinations of protective barriers states are generated with the help of combinatorial analysis and then screened by analysis of physical realizability of each barrier damage rate with revealing a mechanism of such damage, as well as reasons which may cause it (e.g. extreme IE).

Evaluation of safety substantiation calculations presented in SAR and PSA (2)

- Those scenarios should be selected as representative ones, which provide coverage of all physically possible severe states of a unit and meet combination of following representativeness criteria:
  - maximal dose rate for personnel and /or population
  - maximal intensity of radionuclide's release
  - maximal integral radionuclide's release
  - maximal scale of systems and components damage on the plant
  - maximal input in cumulative core damage frequency for given group
  - more quick progression of accident events (minimal time in personnel disposal to undertake accident management measures)
  - the worst conditions for personnel and equipment performance.

- Application of PSA results should be evaluated for vulnerability places identification through minimal cross sections of event/failure tree, as it is necessary for identification of BDBA initiation reasons, it progression and transition to severe phase.

- The PSA results should be obtained for the complete list of initiating events which are personnel errors or causing NPP components failures, e.g. on site EI - fires and flooding, external impacts of nature and anthropogenic character.

All EIs should be considered, if they are physically not excluded at the place of unit location

Evaluation of safety substantiation calculations presented in SAR and PSA (3)

b) Representative scenarios calculations for strategies and instructions substantiation

Level 1
- assessment and selection of a site,
- establishing safe area around the NPP, where protective emergency measures shall be planned;
- developing the design on the basis of a **conservative approach**

Level 2
- Identification of deviations from normal operation;
- management of operation with deviations.

➢ Realistic (best estimate) method. 3-D codes application.

- BDBAs calculation analysis for substantiation of BDBAMG strategies and instructions should be performed using “best estimate” approach, which provides AM on the basis of realistic “symptoms” of unit state and consider resources of existing unit’s equipment availability and efficiency as well as personnel capabilities for control of equipment.
- Based on calculations results design basis “safety margins” (e.g. departure from the nucleate boiling ratio criterion) in the frame of which *operation with deviations* is still possible, are checked.
- 3-D codes application is necessary when local effects are significant and processes in the core are asymmetrical.

Evaluation of safety substantiation calculations presented in SAR and PSA (4)

- Consideration of uncertainties

Calculation analysis results should be accompanied by demonstration of uncertainties analysis. Consideration should be given to uncertainties of calculation methods, equipment characteristics, instrumentation sensitivity and other uncertainties, taken into account in the evaluation of the result

- Results of calculations and analyses usage

On the basis of calculations and analyses the following is identified, then to be used:

- specific symptoms of *levels of severity*
- criteria of transition to severe phase
- timing of accident scenario progression
- parameters for identification of success/not success of personnel actions
- radiation consequences in compartments and on the site.

- Elaboration of auxiliary calculation means

Results of calculations and analyses, if necessary, may be used for elaboration on their basis auxiliary calculation means, which may be used for indirect parameters assessment, in case of unavailability of technical means of measurements, and also for checking the authenticity of obtained information.

Investigation of Unit capabilities and the NPP site features (1)

a) Means and methods of information acquisition for AM

Level 1

- developing the design on the basis of a **conservative** approach
- maintaining in operable state of systems (elements) important to safety by means of timely detection of deficiencies, undertaking preventive measures, replacement of equipment which reached the end of its service life

To be checked and assessed:

- design control and instrumentation devices with respect to their applicability for acquisition of information required for accident management,
- possibilities to compensate failures of design measurements channels,
- methods for indirect assessment of missing parameters by carrying out operational calculations
- methods of identification and screening of false information coming from measurement channels

Investigation of Unit capabilities and the NPP site features (2)

b) Technological equipment of the unit (including equipment of SS):

Level 1

- assessment and selection of a site,
- developing the design on the basis of a conservative approach,
- maintaining in operable state of systems (elements) important to safety by means of timely detection of deficiencies, undertaking preventive measures, replacement of equipment which reached the end of its service life

To be checked and assessed:

- equipment, which can be used beyond the scope of its design dedication and/or qualification limits, i.e. operability in these conditions and how long, its performance;
- if adverse conditions of environment and external and internal impacts (including mechanical) of severe BDBA will influence the equipment operability;
- effect of auxiliary and supporting systems failures;
- alternative equipment needed for realization of defined strategy, as well time required for putting it in operation;
- necessity and possibility of main and alternative equipment to operate jointly.

Note. The assessment is performed by additional calculations, on results of which it should be defined whether it is necessary to continue recovery of main equipment operability and for what time.

Investigation of Unit capabilities and the NPP site features (3)

c) Ensuring of electricity supply

Level 1

- assessment and selection of a site,
- developing the design on the basis of a **conservative** approach,
- maintaining in operable state of systems (elements) important to safety by means of timely detection of deficiencies, undertaking preventive measures, replacement of equipment which reached the end of its service life

To investigate and identify:

- the reasons of complete electricity supply failure (station “black-out”, i.e. diesel generators are not operable) and root cause of all sources of alternating-current loss;
- the relevant measures of electricity supply restoration including such means of restoration as delivery of portable generators, increasing of battery energy storage capacity, installation of alternative alternating-current sources, connecting up to external nets, should be studied.

Note. Electricity supply provision is a top-priority task of accident management since without electricity supply any actions are impossible.

Investigation of Unit capabilities and the NPP site features (4)

d) Containment

Level 1

- assessment and selection of a site,
- developing the design on the basis of a conservative approach,
- maintaining in operable state of systems (elements) important to safety

To check and to consider:

- the strength of containment in BDBA conditions and real non-tightness of hermetic enclosure. Penetrations, hatches, doors, locks and their embedded fittings as well insulating devices to be considered in BDBAMG;
- the systems for containment depressurization and algorithms of their actuation (in particular of sprinkler system in presence of hydrogen in containment atmosphere).
  Note Containments of VVER reactors are equipped with passive H_2 recombiners. Their sufficiency and places of location in design of unit should be assessed.
- as a part of long term accident management, the means for water feeding in containment with pressure equal maximum permissible containment pressure and with capacity sufficient for residual heat removal;
- the necessity and admissibility of direct discharge of radioactive substances from containment through special *filtered venting* for severe accidents

Investigation of Unit capabilities and the NPP site features (5)

e) Utilization of site and neighboring unit's technical means

Level 1

- assessment and selection of a site,
- developing the design on the basis of a conservative approach,
- maintaining in operable state of systems (elements) important to safety

To investigate and identify:

- the possibility to utilize technical means (materials and equipment) from other units in case of multiunit site with conditions, that it is not hazardous for their operation safety It should be considered if it will be necessary or not shut down neighboring unit (or units)

Note. *Not applicable for the case of SA on neighboring unit*

f) Conditions of possibility technical means using

Level 1

- assessment and selection of a site,
- maintaining in operable state of systems (elements) important to safety

To identify:

- the possibility of and accessibility for personnel to technical means needed for AM execution, considering conditions which may be in compartment and on the site as a result of initial event or in the course of accident progression (radiation consequences, fire, possible blockages, building construction's destruction, flooding, steaming).

[1] As defined in [3]

Preparation for development
Connection with Levels 1 and 2 elements (general scheme)

Elements forming Levels of DiD

Level 1

- assessment and selection of a site,
- establishing safe area as well as surveyed area around the NPP, where protective emergency measures shall be planned;
- developing the design inherent safety features of the RI;
- maintaining in operable state of systems (elements) important to safety by means of timely detection of deficiencies, undertaking preventive measures, replacement of equipment which reached the end of its service life

Level 2

- identification of deviations from normal operation and their correction;
- management with deviations.

Elements BDBAMG preparation stages

- evaluation of representative BDBA scenarios selection (initial events, including on-site IE)
- realistic (best estimate) method
– vulnerability places identification by PSA
– consideration of uncertainties
– structure of physical barriers, determination levels of severity
– means and methods of information acquisition for AM
– technological equipment of the unit capabilities
– containment
– ensuring by electricity supply
- utilization of site and neighboring unit's technical means

Such preparation may results in Levels 1 and 2 strengthening

Development of strategies and actions (1)
(connection with Levels 3 and 5)

a) *Transition to BDBAM actions (connection with Levels 3)*

Level 3

- ✓ preventing IEs from developing into DBAs and DBAs into BDBAs by use of SS;
- ✓ mitigation of accident consequences which could not be prevented by confining radioactive substances released.

generation of criteria for transition to BDBAMG actions

Level 4

✓ prevention of aggravation of beyond design basis accidents and mitigation of their consequences;

✓ ……

Development of strategies and actions:

* *criteria to start with BDBAMG actions*, i.e. parameters, conditions giving evidence, that Level 3 is surmounted

Note. *Actions in frames of BDBAMG may be initiated in parallel with Level 3 instructions execution, e.g. after scram.*

* *immediate actions,* should be stipulated after transition to BDBAMG, which relates to: "Control of reactivity and ensuring of reactor sub criticality"

Development of strategies and actions (2)

b) Strategy and actions on prevention (of severe accident) phase

➢ Strategy on prevention phase is directed at SF restoration and should provide :

- identification of state of the unit (*levels of accident severity*), based on directly observe or indirectly assessed parameters (symptoms),
- correspondence of relevant SF to *levels of accident severity*
- combining of all developed actions for SF recovery and ensuring in a sequence, which considers these functions prioritization.

➢ The necessity of simultaneous actions implementation of different SFs should be defined in strategy on the basis accidents analysis.

The criterion of accident progressing to severe phase and for subsequent transition to strategies on stage of severe accident management should be defined and established in BDBAMG.

Development of strategies and actions (3)

c) Strategies and actions on “mitigation of consequences” stage

➢ Strategies may be derived from ‘*candidate high level actions*’, which should provide protection of physical barriers (body of reactor vessel, steam generator pipes, containment) as well restoration of core cooling to the maximum possible extent or fragments of core debrises cooling.

➢ The limited number of parameters should be used for accident management and for identification of format and priorities of diagnostics. These parameters should be defined on the base of severe accidents phenomenology investigations.

➢ The following should be envisaged in the development of personnel actions:
- possible negative consequences of actions and also possibility of cliff edge effects;
- limitations for implementation of actions coursed by doze, physical, psycho- emotional loads on personnel and those who are involved in AM;
- actions, resulting from insufficient* number of personnel to carry out management actions.

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* as a result of injury, overexposure, death, desertion, etc.

Development of strategies and actions (4)

d) *Radiation situation. Start of Emergency planning of personnel and population protection (connection with Level 5)*

➢ The procedure ordering to start with implementation of "Emergency planning of personnel and population protection" should be specified in BDBAMG, i.e. **transition on Level 5**.
The criteria for implementation are numerical values of effective dose rates and (or) I^{131} volumetric activity in compartments air, on NPP's site, in sanitary protective zone and zone of radiation tracking, which corresponds to conditions of "Emergency preparedness" and "Emergency situation"

Level 4

✓ protection of the confinement system from destruction under design basis accidents and maintaining its serviceability;

✓ ……

appearance of criteria for transition to "Emergency planning...

Level 5

✓ implementation of emergency procedures on the NPP site and outside its boundaries;

Development of strategies and actions:

* in case of BDBA occurrence the procedure ordering introduction of "Emergency planning of personnel and population protection" should be developed in BDBAMG

Development of strategies and actions (5)

d) *Organizational structure of accident management*

➢ Administration and NPP operational staff

- analysis of the existing on NPP organizational structure for normal operation should be carried out for its maximal application in BDBAM
- allocation of rights, duties and responsibilities of individuals from operations staff should be defined for participation in BDBAM.
- the procedure should be developed to provide continuation of accident management in case if a new shift of NPP personnel and involved persons are not able to come on the NPP, in particular in long term of accident progression, which should identify the method of shift exchange.

➢ The means of communication and warning

The following should be checked and ensured:

- sufficiency of existing communication means, including duplication ones for organization of NPP management as well as systems of warning in conditions of normal operation, design basis and beyond design basis accidents;
- means for communication with external accident centers for NPP management in conditions of BDBAs for assessment of situation and decision making.

Development of strategies and actions (6)

d) *Organizational structure of accident management (cont.)*

- Involvement of external organizations for BDBAM and elimination of consequences

Tasks distribution between personnel and involved organizations defined in BDBAMG for realization of measures directed at accident consequences mitigation, i.e. termination of chain fission reaction and ensured nuclear fuel cooling.

In particular, NPP administration cooperation with Team for emergency assistance to nuclear plants (OPAS) is defined in correspondence with national regulations.

The issues of personnel and public protection in case of accidents at nuclear plants are settled in Russia in the frames of Unified National System for Prevention and Mitigation of Emergencies.

Overview of these issues is not the subject of this presentation.

Checking (verification) of applicability. Usage of simulator (1)

The final stage of BDBAMG development is *verification** of its applicability to confirm that BDBAMG is technically correct and provides proper consideration of human factor.

a) *Verification tasks*

Verification means resolving of two main tasks:

- ✓ to check usability, that means from one hand a sufficient level of specification, and from another, simplicity of understanding of instructions and other provisions in Guidance;
- ✓ to check correctness (precision) of instructions and provisions in Guidance, which should confirm it compatibility with technical means of the particular unit and also compatibility with personnel capabilities.

* In this presentation it means "*verification and validation*" in terminology of IAEA documents, e.g. SRS No. 32, IAEA, Vienna, 2004. However, in Russian regulatory framework term ***"validation"*** does not exist.

Checking (verification) of applicability. Usage of simulator (1)

b) *Usage of full-scale simulator*

➢ Different methods and means may be used for BDBAMG checking. Method of modeling on full-scale simulator (method MFSS) is mostly preferable from them due to that MFSS is based on software enabling modeling initial state of the unit and also accident progression, including relevant personnel actions.

➢ Challenges for MFSS applications, connected with limitations and uncertainties in severe accidents phenomenology knowledge as well with the level of software verification in relation to some separate effects:

✓possibility of steam explosion

✓repeated criticality,

✓hydrogen generation and distribution, including possibility of it detonation or deflagration,

✓ thermo-shock

The software of simulator should be able to model severe accident phase progression and NPP response in a *scale of real time* mode.

These may result in existing full-scale simulator software reprocessing.

Checking (verification) of applicability. Usage of simulator (2)

- Verification results may have feedback with BDBAMG, resulting in correspondent changes in it. For instance, if cliff-edge effects possibilities had not been investigated during preparatory phase, additional sensitivity analyses may be an input for this investigation. Possibilities of cliff-edge effects should be investigated as a result of possible degradation of equipment performance and of alternative mitigation strategies for a common plant symptom and containment challenge

- Supplemental analyses should also include a small set of cases examining damage plant states resulting from low frequency, high-consequence scenarios

Personnel training on BDBAMG actions (connection with Level 1)

Personnel training to BDBAMG actions
- learning;
- training

Level 1

- selection of personnel and ensuring the necessary level of its qualification for actions during normal operation and operational incidents including situations preceding accidents and accidents,..

➢ Personnel training for BDBAMG actions are carried out on the basis of a special training program which should include two sections – **theoretical and on-the-job (exercises) training:**

- *theoretical learning* provides the development of **knowledge**, which would serve as the basis for adequate decision-making with regard to SAM under conditions of exist uncertainties. *Thus, it is supposed that AM will be based not only on skills but also on knowledge*.

- *exercises* should include actions of personnel both in control room or reserve control room, as well as outside. Exercises outside control room should provide the development of **skills** of personnel to work in AM conditions, which during training should be as close as possible to what could be expected during an accident (poor visibility, fumigation, no light, flooding/ /destruction, increased level of radiation).

AM training at a severe stage should be included, on a periodic basis, in the scope of exercises on implementation of personnel and public protection action plans.

Thereby, the personnel qualification is maintained /improved.

Conclusion.

The qualitative implementation of all stages of preparation for development and development of BDBAMG provide this Guidance effectiveness (strength of Level 4) and at the same time provide strengthening of DiD as a whole.

Thank you for attention!