Design and development of code for emergency action level in a reprocessing plant

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Abstract. Emergency action level (EAL) development is an important tool of emergency decision-making support; EAL is an important basis for emergency response of reprocessing plants. The method recommended by DOE to determine EAL is emergency planning hazards assessment (EPHA). Based on the EPHA methodology, development method of EAL for a reprocessing plant was proposed and then the method was applied and the results were analyzed and utilized. Based on the EAL matrix of a reprocessing plant, an EAL code was designed, programmed and tested. Design of the code mainly includes data grouping, flowchart drawing, frame layer design and presentation layer design. Specifically, data was grouped into 25 groups based on the actual acquisition of data and requirements of judgments for EALs, and flowcharts includes the main flowchart, the automatic judgment flowchart and the manual judgment flowchart. The core judgment module of code for emergency action level in a reprocessing plant was coded by FORTRAN language, and the user interface was developed by Java language. EALs could be determined by relevant characteristic data. Tests are divided into internal tests of the functional module and third-party independent tests. The present results show that the code is exact and reliable, and then the code could be an important auxiliary tool for emergency preparedness and response.

1. Introduction

After the Fukushima nuclear accident, IAEA published Safety Standards General Safety Requirements No. GSR Part 7-Preparedness and Response for a Nuclear or Radiological Emergency [1], which explicitly required the use of EAL as one of the basis for nuclear and radiological emergency strategies. As early as 10 years ago, the Nuclear Safety Guideline HAD002/07 Emergency Preparedness and Response for Operators of Nuclear Fuel Cycle Facilities (Draft for comment) was put forward. Its latest version was approved and issued by the National Nuclear Safety Administration in November 2019 [2]. General guidelines for the development EAL of nuclear fuel cycle facility have yet to be enhanced in operability. Since 2016, several Chinese domestic scientific research institutions have continued to discuss and conduct preliminary EAL studies on nuclear fuel cycle facilities [3-7]. However, systematic introduction and in-depth practice of EAL development methods for reprocessing facilities have not been found. To sum up, more research has been done on the front end of the nuclear fuel cycle than on the back end; Qualitative analysis is more than quantitative analysis; Talk more than practice.

A specific EAL software for nuclear power plants or nuclear fuel cycle facilities has not been found, but EAL is generally integrated into the nuclear emergency decision system [8-10].
However, due to the experience feedback of Fukushima nuclear accident, the timeliness of emergency response requires EAL’s judgment and follow-up response as soon as possible. Therefore, research and development of EAL software for a reprocessing plant was carried out.

2. EAL development for a reprocessing plant
Based on the safety features of reprocessing plants as well as the features of functions and facility composition, two new identification categories, namely spent fuel pool accident (Category E) and high level liquid waste (HLLW) storage tank accident (Category W), are added in comparison with nuclear power plants and other nuclear fuel cycle facilities. Together with system failures (Category S), safety barrier downgrades (category F), abnormal levels of radiation or radioactive effluent (class A), and disasters and accidents (category H), there are six identification categories.

The Emergency Planning Hazard Assessment (EPHA) method recommended by US Department of Energy (DOE) was used to analyze the accident scenarios under six identification categories in a reprocessing plant.

Each accident scenario analysis has a process corresponding to its accident characteristics. For example, for hydrogen explosion accident in a HLLW storage tank, the main process of scenario analysis is shown in Figure 1.

![Figure 1. Main flow of scenario analysis of hydrogen explosion accident in a HLLW storage tank.](image)

The corresponding accident scenarios of each identification category were analyzed one by one, and the EPHA for the reprocessing plant was completed. The main results of EPHA in the reprocessing plant are shown in Figure 2.
In Figure 2, the accidents on the right of its Recognition Category, such as, “Failure of iodine filter in the dissolution exhaust system of head end” correspond to Category F.

Through EPHA of accident spectrum screened out from the reprocessing plant, the EAL matrix of the reprocessing plant was developed in combination with the historical research results and literature research results.

EAL under an initial condition is indexed sequentially according to different accidents/events in the table.

### 3. EAL code design for a reprocessing plant

An EAL code provides effective and rapid decision support for nuclear emergency response in reprocessing plants. Responders such as nuclear emergency response officers determine EALs though the convenient and effective algorithm of the code, and then emergency classification could be judged.

#### 3.1. Data grouping

The essence of an EAL code in a reprocessing plant is to digitize the developed EAL matrix so as to automatically judge the monitoring data such as process and safety data in a reprocessing plant, and then the corresponding emergency classification could be obtained.

There are many monitoring data related to process and safety involved in the reprocessing plant. For the convenience of judgment, these data are grouped according to the status of radioactive substances, the type of monitoring data, plant/equipment, and accidents/events.

During the development process, according to the actual data acquisition and EAL requirements, the data were divided into 25 groups, each group containing several logical variables and monitoring data.

#### 3.2. Flowchart

The basic flowchart of EAL code for a reprocessing plant was shown in Figure 3.

Figure 3 shows that Recognition Category should be chosen at first for judgement based on the specific facility and Initiating Condition. Then, EAL judgement criteria under the Initiating Condition should be adopted. After that, qualitative and quantitative results should be saved and judgement should be confirmed.

The flowchart of automatic judgment in the EAL code for a reprocessing plant was shown in Figure 4.

The flowchart of manual judgment in the EAL code for a reprocessing plant was shown in Figure 5.

Figure 4 shows that when correlate events are confirmed, judgement condition should be input, which would trigger calculation. Then, EAL matrix results would be displayed. Finally, the code trigger reset and recover judgement.
Figure 5 shows that when correlate events are confirmed, screening items should be input, which would trigger judgement. Then, EAL matrix results would be displayed. Finally, the code trigger reset and recover judgement.

![Flowchart](image)

**Figure 3.** The basic flowchart of an EAL code for a reprocessing plant.

**Figure 4.** The flowchart of automatic judgment in the EAL code for a reprocessing plant.

**Figure 5.** The flowchart of manual judgment in the EAL code for a reprocessing plant.
3.3. The framework layer

The main navigation design idea is that the relevant function points were stored in the navigation. The platform navigation is divided into global navigation, local navigation, auxiliary navigation, contextual navigation, friendly navigation, etc., and different navigation features are applied in the appropriate scenes of this system.

The interface design idea is that the function points determined by the structure layer were applied in the specific interface. The interface design determines that this function is recognized by the user on the interface, and functional interface operations are the most common behavior of users. At the same time the interface elements were made easier to get, and cascading panel, text box, drop-down box, select button, submit button, table and other basic interface elements were used.

The design idea of information is to provide users with the information to use the interface correctly.

The design idea of indicator identification is to help the user fully understand and locate the system position the user is in and the system position the user will assign to the system next, through the emergency classification judgment addition, designations of judgment criteria and condition selection, navigation bar.

3.4. Presentation layer

Design style is the same as the main interface design style, it is often said the unified style tonality of the whole vision.

Typesetting performance is the proper arrangement of words, tables, graphics, pictures, etc, which make the layout to achieve beautiful visual effect.

The space between the plates will give the page a sense of breathability and spaciousness.

Widget performance are applied to computer software, including program identification, data identification, command selection, mode signal or toggle switch, status indication, etc. Maintain proportion coordination of widget s, unity of shape and radian, consistency of ICON style.

Picture performance were control and unification of high definition and style of images, identification of brand tonality was also considered.

Color performance was unification of overall color style and brand style.

Font performance was that font is the center of information expression.

4. EAL code development for a reprocessing plant

The core judgment module of the EAL code for a reprocessing plant was coded by FORTRAN language, and the user interface of the code was developed by Java language.

In the code interface, all conditions can be selected under all accident conditions and judgment can be made either manually or automatically.

5. EAL code tests for a reprocessing plant

Tests of the code were divided into two independent stages. First, after the core judgment module coded by FORTRAN language, the function test of this module was carried out.

Then, a third party was invited to run an independent test.

5.1. Internal test of function module

The test follows the Specification for computer software test documentation (GB/T 9386-2008) [11]. All initial conditions of all accident types of A, F, H, S, E and W identification categories were tested. Tests were based on the developed EAL matrix. If input conditions of the code and the EAL matrix are the identical, whether the derived EAL of the code are consistent with the corresponding contents of the EAL matrix is tested. Identical input conditions include identical identification category, identical accident type and identical initial condition.

Test examples and results are divided into normal condition and emergency situation as follows.
5.1.1. Normal condition. When all inputs are the default values, it represents the initial state. At this time, the working condition is normal, and the output result is no emergency as in Table 1.

Table 1. The normal condition result.

| Content | RC | ID | IC | EAL | EC |
|---------|----|----|----|-----|----|
| Result  | N  | 0  | 0  | 0   | N  |

An explanation of each symbol in the above table is given in Table 2.

Table 2. The symbolic meaning of tests results.

| Symbol | Meaning |
|--------|---------|
| RC     | Recognition Category, including Category N (no category), Category S, Category F, Category H, Category A, Category E, Category W |
| ID     | The accident type serial number in the RC to which it belongs |
| IC     | The initiating condition serial number |
| EAL    | Emergency action level |
| EC     | Emergency classification, including no emergency (N), Unusual Event (U), Alert (A), Site Area Emergency (S), General Emergency (G) |

5.1.2. Examples that constitute an emergency situation. Hydrogen explosion accident in a HLLW storage tank is taken for examples.

1. Example 1. Input conditions: Acousto-optic alarm occurs when the hydrogen concentration in the HLLW storage tank reaches 4%.

   Output result: EAL1-WU5 as in Table 3.

Table 3. Example 1 for hydrogen explosion accident in a HLLW storage tank.

| Content | RC | ID | IC | EAL | EC |
|---------|----|----|----|-----|----|
| Result  | W  | 5  | 5  | 1   | U  |

2. Example 2. Input conditions: A hydrogen explosion accident occurs with normal purification in the red zone.

   Output result: EAL1-WA5 as in Table 4.

Table 4. Example 2 for hydrogen explosion accident in a HLLW storage tank.

| Content | RC | ID | IC | EAL | EC |
|---------|----|----|----|-----|----|
| Result  | W  | 5  | 5  | 1   | A  |

3. Example 3. Input conditions: A hydrogen explosion accident occurs with failure purification in the red zone showed by pressure differential indicator, and the iodine concentration is \(1.7 \times 10^3\) Bq/m\(^3\) while the aerosol concentration is \(2.6 \times 10^7\) Bq/m\(^3\).

   Output result: EAL1-WS5 as in Table 5.

Table 5. Example 3 for hydrogen explosion accident in a HLLW storage tank.

| Content | RC | ID | IC | EAL | EC |
|---------|----|----|----|-----|----|
| Result  | W  | 5  | 5  | 1   | S  |
4. **Example 4.** Input conditions: A hydrogen explosion accident occurs with failure purification in the red zone showed by γ detector, and the iodine concentration is $1.7 \times 10^4$ Bq/m$^3$ while the aerosol concentration is $2.6 \times 10^8$ Bq/m$^3$.

Output result: EAL1-WG5 as in Table 6.

| Content | RC | ID | IC | EAL | EC |
|---------|----|----|----|-----|----|
| Result  | W  | 5  | 5  | 1   | G  |

More examples will not be listed for lack of space.

All the test results show that all the test outputs are in line with the expectation, which proves that the function module was coded correctly.

5.2. **Third party independent test**

System integration test, function test and performance test on the software under specified conditions were carried out. Three documents are referenced [12-14]. Bugs in the code were found by tests, the correctness, completeness, safety and quality of the code were verified. Then an accurate judgment about whether the code meets the original design could be made.

5.2.1. **Test examples**

1. **Console-automatic judgment.** Initial default values in all input boxes is “-10”, while all single boxes are selected “No” by default.

   When the basic collected data doesn’t reach the emergency situation threshold value, the calculation result will not be generated even if the automatic calculation time is reached.

   When the basic collected data reach threshold values of Emergency Standby (ES)/ Plant Emergency (PE)/ Site Area Emergency (SAE)/ Offsite Emergency (OE), the calculation result will be generated showing an alarm accident of Emergency Standby (ES)/ Plant Emergency (PE)/ Site Area Emergency (SAE)/ Offsite Emergency (OE) if the automatic calculation time is reached.

   Functions of console-automatic judgment are implemented normally, tests found no defects.

2. **Red oil explosion accident.** When the data of the judgment module is not modified, after the calculation, the conditional selection will display “Normal”.

   When the solution temperature in MLLW Evaporator $\geq 125^\circ$C, and the steam is failed to cut off automatically or the cooling water can’t pass through the jacket, after the calculation, the conditional selection will display “EAL1-SU5” accident.

   Other conditions are no longer presented in limited space.

3. **Hydrogen explosion accident in a HLLW storage tank.** When the data of the judgment module is not modified, after the calculation, the conditional selection will display “Normal” too.

   When the hydrogen alarm device alarms and the hydrogen concentration in the HLLW storage tank reaches 4%, after the calculation, the conditional selection will display “EAL1-WU5” accident.

   Other conditions are no longer presented in limited space either.

   These are only a few examples in the test process. Since space is limited, the rest of the test cases will not be described.

5.2.2. **Test summary**

1. **Test execution record.** The test execution record is shown in Table 7.
Table 7. Test execution record.

| Test Type       | Module Amount | Case Amount | Execution Amount | Qualified Amount | Defective Amount |
|-----------------|---------------|-------------|------------------|------------------|------------------|
| Acceptance Test | 2             | 115         | 115              | 115              | 0                |

2. **Statistical analysis of defects.** No defects were found in current version tests. The third-party test results show that the code is correct with reliable operation.

6. **Conclusions**

In the early stage, EPHA methodology proposed by US DOE was absorbed and improved for a reprocessing plant, and then EAL matrix were developed in the reprocessing plant according to the accident spectrum.

Then, according to the decided EAL matrix and the characteristics of a reprocessing plant, drawing lessons from development of emergency auxiliary decision support code for nuclear power plants, an EAL code for a reprocessing plant was designed, developed and tested. The code not only includes all potential accidents of a reprocessing plant, but also covers main quantitative characteristic indication of the accidents.

Both completed internal test of functional modules and ongoing third-party test have shown that the code was correctly coded, and it runs reliably, and it could be used as an effective tool for emergency preparedness and response in a reprocessing plant.

References

[1] IAEA 2015 Preparedness and Response for a Nuclear or Radiological Emergency, GSR Part 7. Vienna: IAEA

[2] NNSA 2019 Emergency preparedness and response for operators of nuclear fuel cycle facilities, HAD002/07-2019. Beijing: NNSA

[3] Jing Wu, Bo Dong, Wencai Ma and Jing Huang 2016 Methodology of developing the emergency action levels of uranium conversion facility Nuclear Power Engineering 37(supplement 1), 111

[4] Zheng Youheng 2016 Study on Nuclear Fuel Element Plant Emergency Action Level University of South China Hengyang, Hunan

[5] Li Tao, Huang Jing and Zhao Yulong 2018 Application and Research on Methodology of Developing the Emergency Action Levels of Nuclear Cycle Facility Proceedings of the Symposium on Nuclear Fuel Cycle Safety July 23-27, Bazhou, Hebei, 3

[6] Feng Jilian 2019 Development Emergency Action Level for a Nuclear Fuel Front-end Facility The first Nuclear Critical Safety Technology and Management Experience Symposium of China National Nuclear Corporation Ltd Baotou, Nei Mongol: Center for Nuclear Critical Safety in China National Nuclear Corporation Ltd, CNNC North Nuclear Fuel Element Ltd, : 171

[7] Huang Shuming, Ji Yunzhe and Shu Weipeng 2018 Discussion on Development Methodology of Emergency Action Level for a Spent Fuel Reprocessing Facility China Science and Technology Achievements 7 34

[8] Yang Yapeng, Zhang Jiangang and Tang Rongyao 2015 Development of integrated nuclear emergency command and decision support system for nuclear power plant Radiation Protection 35(5) 274

[9] Bai Zhiquiang 2019 Construction and Application of Hainan Changjiang Nuclear Power Plant’s Emergency Auxiliary Decision System China Nuclear Power 12(2) 223

[10] Lan Haijian, Liu Zhenjun and Wang Gang 2019 Research and Application of Emergency Decision-making Support System for High Temperature Gas-Cooled Reactor Automation Panorama 12 89
[11] National Committee of Standardization of Information Technology 2008 GB/T 9386-2008 Specification for Computer Software Test Documentation. Beijing: Standards Press of China

[12] China Institute for Radiation Protection 2020 Test Scheme of Code for Emergency Action Level in a Reprocessing Plant. Taiyuan: China Institute for Radiation Protection

[13] China Institute for Radiation Protection 2020 Test Plan of Code for Emergency Action Level in a Reprocessing Plant. Taiyuan: China Institute for Radiation Protection

[14] China Institute for Radiation Protection 2020 Procedural Design Specification of Code for Emergency Action Level in a Reprocessing Plant. Taiyuan: China Institute for Radiation Protection