# Cable Selection and Detailed Circuit Analysis on Plant under Construction

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*Electrical analysis and circuit failure mode likelihood analysis has performed for APR1400 NPP under construction. It was first time to perform electrical analysis using NUREG/CR-6850 methodology for APR1400. Cable Raceway Database system had been developed for fire probabilistic risk assessment. Cut-off date applied to design drawings and data to maintain consistency, because of continuous design change during under construction. Cable Selection, detailed analysis, and circuit failure mode likelihood analysis had been performed. There was no risk significant electrical cable routing design. Also fire probabilistic risk assessment result shows the APR1400 design regarding the fire protection is safe enough to meet the safety goal.*

## I. INTRODUCTION

The objectives of the fire Probabilistic Risk Assessment (PRA) are to estimate the contribution of internal fires to the overall plant Core Damage Frequency (CDF) and Large Release Frequency (LRF) to identify any plant specific vulnerability to fire-induced accidents, and to provide insights for plant design and construction.

Risk due to internal fire has been one of the major concerns for design and operation of nuclear power plants. Korea has performed fire PRA for all plants (nuclear power plants in operation and under construction) by fire PRA implementation guide (FPRA IG, Ref. 1). In the meantime, NUREG/CR-6850 (Ref. 2) was issued and applied to operating plants in U.S. One of the differences between FPRAIG and NUREG/CR-6850 is the electrical analysis (cable selection and detailed circuit analysis) and circuit failure mode likelihood analysis. These are important tasks in NUREG/CR-6850 (Ref. 3) fire PRA methodology, because it takes lots of manpower and effects to interfacing and following tasks.

NUREG/CR-6850 fire PRA methodology is applied to Korean Advanced Pressurized Reactor (APR) 1400 nuclear plant under construction for the first time. Electrical analysis and circuit failure mode likelihood analysis are performed with current design data at the time of analysis. This paper will focus on the difference approach, result and insight between under construction plant and operating plant, rather than general approach and procedures, which are same with NUREG/CR-6850.

## II. Cable Selection

The purpose of this task is to identify the circuits and cables associated with the fire PRA equipment and the cable routing/location of the identified circuit and cables. These relationships can then be used to determine the fire PRA equipment potentially affected by postulated fires at different plant locations.

NUREG/CR-6850 provides the approach for selecting the cables as six steps as below.

- Compile and Evaluate Prerequisite Information and Data
- Select fire PRA Circuits/Cables
- Identify and Select fire PRA Power Supplies
- Perform Associated Circuit Review
- Determine Cable Routing and Plant Locations
- Fire PRA Cable List and Target Equipment Location Reports

Analysis was performed for APR1400 under construction plant. The differences between operating plant and characteristic of APR1400 will be described in the following sections.

### II.A. Prerequisite Information

Proper cable and raceway database system (CRS) was not available to identify cable routing and location. There was a cable database for electrical design, but raceway location is not identified by fire compartment. CRS was developed to perform fire PRA. To develop CRS, cut-off date was applied to cable route data and raceway design. Raceway drawings (cable tray plan and cable conduit plan) are reviewed and marked-up to identify raceway locations per room for further application and fire compartment change. Suffix (e.g. -01, -02) had been added to raceway number to distinguish raceway which passes through the multi room. Cable route data had been connected to above raceway location in CRS to identify cable routing and location per room. The example of CRS is shown in Figure 1 and Table I.

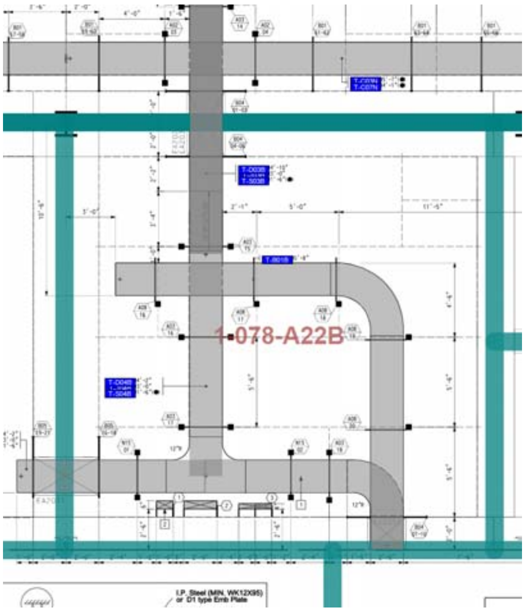


Fig. 1. Example of Marked-up Cable Tray Plan.

TABLE I. Example of Cable Routing Data in CRS

| Cable Number | Sequence | Raceway Number | Room Number | Note |
|---|---|---|---|---|
| 431-C-01-X-X-X-A | 1 | 313-K-01-X04A-01 | 100-C02B | |
| 431-C-01-X-X-X-A | 2 | 313-B-01-X01A-01 | 100-C02B | |
| 431-C-01-X-X-X-A | 3 | 313-K-01-X03A-01 | 100-C02B | Embedded |
| 431-C-01-X-X-X-A | 4 | 313-K-01-X03A-02 | 130-C01 | Embedded |
| 431-C-01-X-X-X-A | 5 | 313-K-01-X03A-03 | 106-C01 | Embedded |
| 431-C-01-X-X-X-A | 6 | 313-K-01-X03A-04 | 128-C01 | Embedded |
| 431-C-01-X-X-X-A | 7 | 313-K-01-X03A-05 | 115-C02 | Embedded |

### II.B. Selection of Fire PRA Cables and Circuits

Cables are selected per fire PRA equipment and its failure mode. Drawings associated with fire PRA equipment (cable block diagram, control logic diagram, piping and instrumentation diagram, schematic diagram, single line drawings, and so on) are reviewed to find out associated circuit and cable effect to equipment response. Additional control cabinets, local control panel and power supplies were found during cable selection, and it feeds back to fire PRA equipment selection task.

APR 1400 plant has digitalized instrument and control system. There are redundant and diverse manual control methods in the Main Control Room (MCR), such as soft control, dedicated control, and diverse manual control. Cables associated with redundant and diverse manual control are identified and selected per fire PRA equipment's failure mode. Most of control cables, which are connected between MCR and local control cabinet, are screened out for spurious operation, because those cables are mainly fiber optic cables.

Additional circuitry information such as power supply configuration (grounded AC, ungrounded AC with or without control power transformer, ungrounded DC), and target cable configuration (thermoset-insulated conductor cable, thermoplastic-insulated conductor cable, metal foil shield wrap cable, armored cable, fiber optic) are corrected for following detailed circuit analysis and circuit failure mode likelihood analysis. 6444 cables are selected for 1784 fire PRA equipment. Table II shows the example of cable selection result.

TABLE II. Cable Selection Result

| Fire PRA Equipment | Failure Mode | Cable Number | Cable Description | Selection | Screen-out Basis | From Equipment | To Equipment | Note |
|---|---|---|---|---|---|---|---|---|
| 433-V-0410 | Spurious Open | 433-C-01-A-J-A-A | Control Cable | Y | | 433-V-0410 | 433-W-501A | |
| 433-V-0410 | Spurious Open | 433-C-01-A-J-B-A | Control Cable | Y | | 433-W-501A | 839-E-EA07A-K1 | |
| 433-V-0410 | Spurious Open | 433-C-01-A-J-C-A | Control Cable | Y | | 839-E-EA07A-K1 | 433-W-001A | |
| 433-V-0410 | Spurious Open | 433-C-01-A-J-D-A | Control Cable | Y | | 839-E-EA07A-K1 | 745-J-LX12A | |
| 433-V-0410 | Spurious Open | 433-C-01-A-J-E-A | Control Cable | Y | | 433-J-JZ-0410A | 433-W-001A | |
| 433-V-0410 | Spurious Open | 433-C-01-A-J-F-A | Control Cable | Y | | 433-W-001A | 745-J-LX12A | |
| 433-V-0410 | Spurious Open | 745-C-01-C-S-M-A | Control Cable | N | Fiber Optic Cable. This cable cannot cause spurious operation. | 745-J-LX12A | 752-J-PA03A | Safety Soft/Dedicate Control |
| 433-V-0410 | Spurious Open | 745-C-01-D-S-M-A | Control Cable | N | Fiber Optic Cable. This cable cannot cause spurious operation. | 745-J-LX12A | 752-J-PA03A | Safety Soft/Dedicate Control |

## III. Detailed Circuit Analysis

After quantitative analysis, mainly switchgear breakers, Motor Operated Valve (MOV), and Solenoid Operated Valve (SOV) are selected to detailed circuit analysis. Equipment type, equipment status (normal position, fail position, and required position), failure modes, associated circuit configuration, and reference drawings are reviewed and confirmed. Schematic drawing, elementary wiring diagram, and associated drawings are used to find out equipment/circuit response by cable hot short or short to ground. Analysis had been performed by cable wire scope; it means equipment/circuit responses are identified as each cable's wire level. The example of detailed circuit analysis is shown in Table III.

TABLE III. Example of Detailed Circuit Analysis

| FPRA Equipment | Cable Number | Fault Consequence | Comment |
|---|---|---|---|
| 451-V-000X | 451-C-10-X-X-X-A | Spurious Open | Solenoid Control Cable<br>Inter-cable hot short on wire #N1 will energize the solenoid to remain in open position<br>(Inter-cable hot short must come from the same power source, because this circuit is a ungrounded DC circuit) |

## IV. Circuit Failure Mode Likelihood Analysis

The purpose of this task is to develop probabilities for fire-induced circuit failures leading to spurious component operation. The probabilities of hot short developed are based on method and data contained in NUREG/CR-7150 (Ref. 6). If cable type information (thermoset-insulated conductor cable, thermoplastic-insulated conductor cable, metal foil shield wrap cable, armored cable, and fiber optic) is not available, it assumed as the worst case.

Ground fault equivalent hot short had been included as failure mode for determining the probability of a hot short for ungrounded DC or ungrounded distributed AC circuits. "Dedicated conduit" condition is not considered, because electrical design is not completed. External hot short is always assumed for conservative analysis. Table IV shows the example of fire-induced circuit failure probabilities.

Hot short duration was considered for SOV and Air Operated Valve (AOV). NUREG/CR-7150 provides data for duration of hot shorts. That is, circuit testing performed by the NRC indicated that the majority of hot short connects will burn themselves out in a matter of minutes. When the hot short dissolves, the component will revert back to its fail safe position, provided the component has these features. AOV's and SOV's will have a fail-safe position which indicates how the valve will fail upon loss of motive power or control power. Hot short duration was considered for 125 VDC powered SOV's and AOV's. Hot short duration was credited by multiplying the probability for spurious operation by the spurious hot short duration conditional probability from table 6-3 in NUREG/CR-7150, resulting in a single value for the active hot short. Table V shows the fire-induced circuit failure probability after consider hot short duration.

TABLE IV. Fire-Induced Circuit Failure Probability

| Component ID | Component Type | Cable No | AC or DC Control Circuit | Single or Double Break Control Circuit | Grounded Control Circuit | Control Power Transformer | Probability | NUREG/CR 7150 Table Reference |
|---|---|---|---|---|---|---|---|---|
| 521-V-0109 | SOV | 521-C-08-A-J-A-A | 125 VDC | Single Break | No | No | 5.60E-01 | Table 4-1 |
| 521-V-0109 | SOV | 521-C-08-A-J-D-A | 125 VDC | Single Break | No | No | 5.60E-01 | Table 4-1 |
| 521-V-0109 | SOV | 521-C-08-A-J-A-A | 125 VDC | Single Break | No | No | 5.60E-01 | Table 4-1 |
| 521-V-0109 | SOV | 521-C-08-A-J-D-A | 125 VDC | Single Break | No | No | 5.60E-01 | Table 4-1 |

TABLE V. Fire-Induced Circuit Failure Probability after Considering Hot Short Duration

| Component ID | Component Type | Cable No | Component Function | Allowed Time for Hot Short Duration | Aggregate Probability for Hot short | Spurious Operation Duration Conditional Probability | Total Spurious Component Probability |
|---|---|---|---|---|---|---|---|
| 521-V-0109 | SOV | 521-C-08-A-J-A-A | Fail Open (De-energized) | 7 Min. | 5.60E-01 | 2.20E-02 | 1.23E-02 |
| 521-V-0109 | SOV | 521-C-08-A-J-D-A | Fail Open (De-energized) | 7 Min. | 6.30E-01 | 2.20E-02 | 1.39E-02 |

## V. CONCLUSIONS

It was the first time to perform Electrical Analysis using NUREG/CR-6850 Methodology for APR1400. It was found that there was no risk significant electrical cable routing design through the detailed circuit analysis and circuit failure likelihood analysis. Also the Fire PRA result shows the APR1400 design regarding the fire protection is safe enough to meet the safety goal.

## REFERENCES

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