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IDENTIFICATION AND ANALYSIS OF HUMAN ACTIONS IN CASE OF SGTR INITIATING EVENT

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Identification and modeling of human actions, from safety point of view is an important part of human reliability analysis of Probabilistic Safety Assessment (PSA). In case of SGTR, human actions have significant effect on the safety and radioactive releases. The human actions, isolation of defective steam generator (IFSG), pressure balance between primary and secondary side (OAPB) and reactor cool down and depressurization (OACD) were modeled and analyzed in this study. Probabilities associated with these human actions were estimated using Standardized Plant Analysis Risk associated with Human (SPAR-H) with generic data. HEPs are 0.0564, 0.0952 and 0.1059 for IFSG, OAPB and OACD respectively. Human error probabilities were the major contributors to core damage frequency of SGTR.

Keywords: SGTR, PSA, Risk analysis, Safety, Core damage frequencies

1. Introduction

Human actions and their performance have significance on reliability of safety systems and successful mitigation of accidents. According to the references, there are substantial interactions between operating team and plant systems in case of SGTR and it was shown for Sequoyah nuclear power plant that SGTR is a major contributor to the latent cancer risk in the vicinity of the plant [1]. The major contribution to the risks due to accidents at nuclear power plants is because of human error, which is identified from the event analyses. Many analysts had showed that contribution to risk due to human failures/errors could be as high as 50 % in case of full power operations and as high as 70 % in case of low power and shutdown operations (outage) [2]. So important human interactions to the overall risk in accident sequences should be identified, analyzed and incorporated into safety analysis in a traceable manner [3]. The impact of the success and failure of human actions in case of SGTR is discussed in this study.

2. SGTR Events and Human Actions at NPPs in World

Steam generator tubes become more prone to fail towards the end of their life to Outer Diameter Stress Corrosion Cracking (ODSCC), high cyclic fatigue failures, loose part wear and Primary Water Stress Corrosion Cracking (PWSCC). At U.S nuclear power plants, tube failure events have been occurring once per year, which is relatively higher frequency than other (Design Basis Accidents) DBAs and require more attention of operator. A number tube failure events of U.S NPPs with reference to human actions are discussed in this section.

2.1. Point beach unit 1

USNRC (1980) evaluated the operator actions to cope with SGTR accident happened at Point Beach Unit 1 (1975). The operator interventions to minimize the releases and mange the accident were as follow:

- Ramping down the unit to manual trip to avoid the actuation of Power Operated Relief Valves (PORVs) and Safety Valve
- Successful diagnosis of affected steam generator and its isolation
- Rapid cool down and depressurization of primary coolant (less than 2 hours)

2.2. Surrey unit 2

The operator actions, during SGTR at Surry Unit 2 (330 gpm), to isolate the affected steam generator, cool down and depressurization of primary coolant were appreciated by USNRC, as the defective steam generator (A) was isolated with in 18 minutes after its diagnosis and pressure

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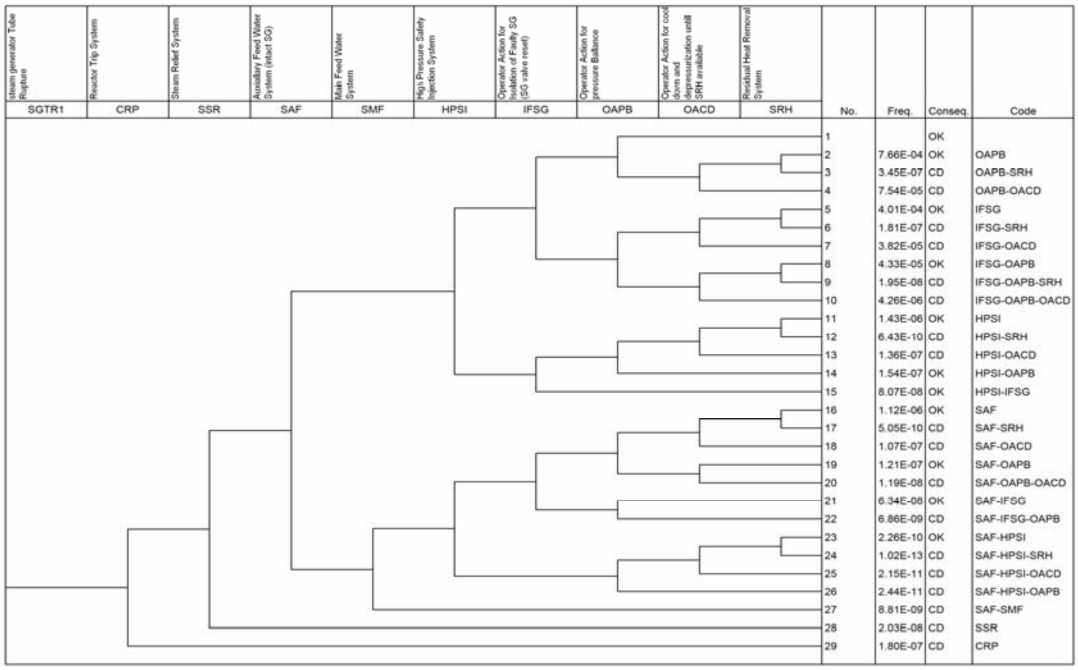

Figure 1. Event tree of steam generator tube rupture initiating event.

between primary and secondary sides was balanced within 70 minutes. USNRC showed reservation and objections on the operation of loop A and loop B reactor coolant pumps, as reactor coolant pump B was tripped after few minutes of reactor trip while the loop A reactor coolant pump was operational during the transient.

2.3. Prairie island unit 1

Human actions on rapid pressure drop of primary side due to SGTR at Prairie Island Unit 1 (two loop plant) were also observed. Due to the large rupture size and rapid pressure decrease rate, operators were unable to isolate the defective SG and reactor coolant system (primary) pressure was brought to 6.3 MPa during 1 hour (61 minutes), which was the pressure of the defective steam generator at that point in the transient. This was a successful step to terminate the radioactive release. The reactor coolant cool down took a lot of time because of natural circulation, as reactor coolant pumps were tripped early in the transient [4].

2.4. Ginna unit 1

During SGTR at Ginna Unit 1, operators were successful to isolate the defective steam generator of loop B in the early stage of accident but their efforts to cool down and depressurize the primary system was not efficient.

3. Human Actions and HRA

The classification and modeling of human actions in PSA is based on situation and plant operating mode, in which they take place. In human reliability analysis (HRA) operator actions are categorized on the basis of initiation of initiating events like pre-accident actions, post accident actions and actions causing initiating events. But in this particular study of SGTR accident, human actions are post accident and these are selected on the basis previous experiences, studies and emergency operating procedures (EOP). The operator actions selected to cope up the SGTR event are following:

1. Isolation of defective SG (IFSG)
2. Operator Action for Pressure Balance (OAPB)
3. Operator Actions for cool down and depressurization of Primary coolant (OACD)

The modeling and sequences of these operator actions are shown in the SGTR event tree (Fig. 1).

Isolation of defective steam generator (IFSG) is important action for decision making process. The defective steam generator can be identified on the bases of:

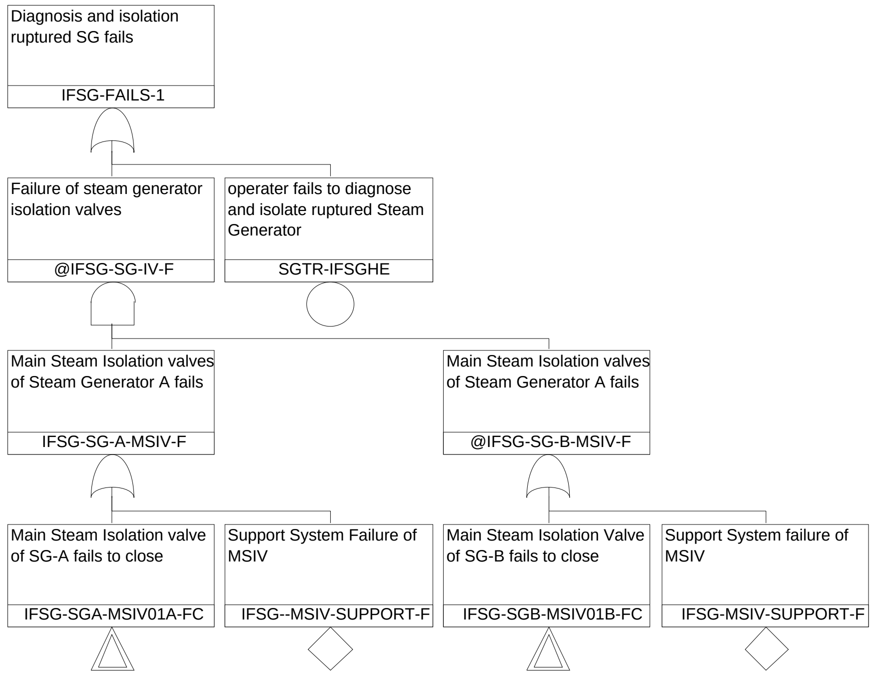

Figure 2. Fault Tree of IFSG (Operator Action for Isolation of ruptured steam generator).

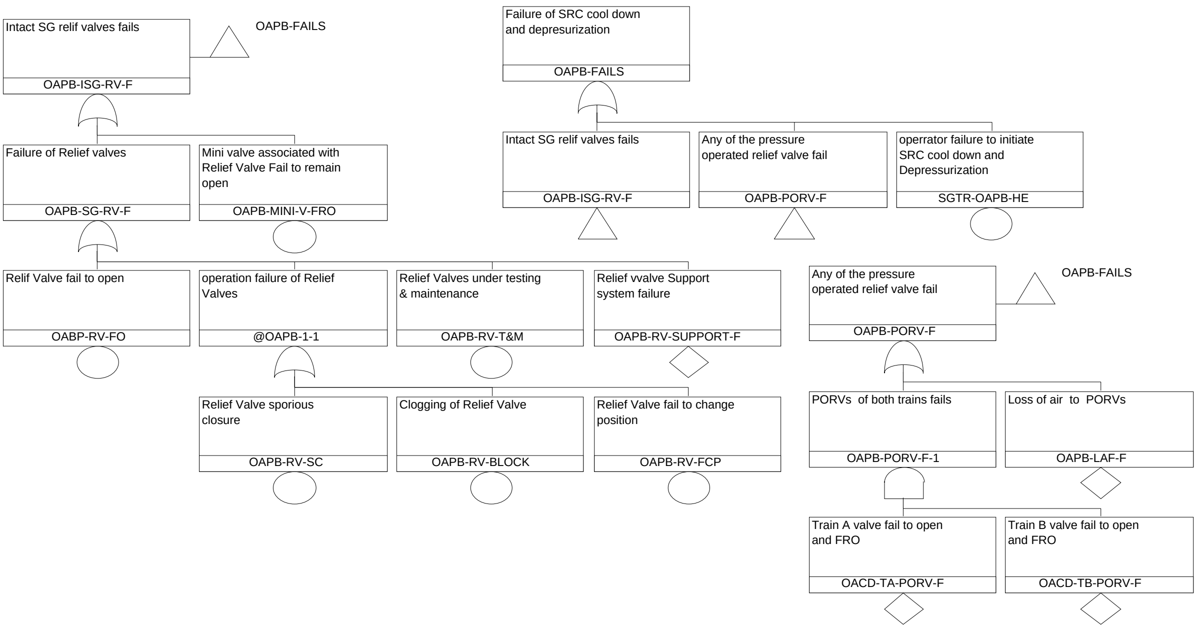

Figure 3. Fault tree of OAPB (Operator action for pressure balance between primary and secondary side).

i. Radioactivity of samples taken from SGs

ii. Steam generator level

Radioactivity and steam generator level of faulty steam generator will be high than others.

The ruptured steam generator is isolated by performing the following actions:

a. Verify the closure of ruptured SG PORV and raise set point to 87.5 %

b. Close main steam isolation valve (MSIV) of ruptured SG and its by pass valve
c. Confirm/ close the ruptured SG blow down isolation valve
d. Close the drain valve of ruptured SG
e. Confirm the isolation of main feed water line
f. Close auxiliary feed water if the water level in ruptured SG is greater than 9.10 m to keep U-tubes submerged.

OAPB is the balancing action of pressure on both primary and secondary side to minimize the associated risk of radioactive release through power operated relief valve on the secondary side. The pressure balance is performed in two steps:

1. Reactor coolant is cool down keeping sub cooling margin of 27 °C, by :
a. Dumping steam in condenser from intact SG, if condenser is available.
b. Using PORV of intact SG, if condenser is not available.
2. Reactor coolant system is depressurized to minimize break flow and refill pressurizer, when reactor coolant temperature reaches the required temperatures of Table 1. Depressurization of primary system is performed by:
a. Pressurizer spray, if reactor coolant pump is running.
b. Pressurizer PORV, if reactor coolant pump has stopped.

OACD is the long term cooling and depressurization till SRH is available. During the execution of this action, reactor coolant system pressure is kept less than ruptured SG pressure by 0.29-0.59 MPa for leakage reduction. RCS pressure is controlled by pressurizer heaters or one of the following valves [6]:

a. Normal pressurizer spray (If reactor coolant pump is running)
b. Pressurizer auxiliary spray valve (if letdown is established)
c. Intermittently open of pressurizer PORV

Standardized plant analysis risk associated with human (SPAR-H) technique is used to analyze and perform HRA of the above actions. The assumptions made concerning these actions to coop up SGTR are:

- Operating crew diagnoses the SGTR event correctly.
- Intact SG is available for cool down, if ruptured SG is isolated.
- Feed water supply to intact SG is available.
- When reactor is brought to cold shut down mode, the event will be terminated.
- Generic data was used to perform HRA

In this study, eight performance shaping factors (PSFs) were considered for full power operation SPAR-H framework, which highly influence the human performance. These factors are available time, stress and stressor, experience and training, complexity, ergonomics (including human-machine interface), procedures (written), fitness for duty and work process. Human error probability in case of diagnosis and action are as follow:

$$HEP_D = PSFs \times HEP_{N/D}$$
$$HEP_A = PSFs \times HEP_{N/A}$$
$$HEP_T = HEP_A + HEP_D$$

Where:

HEP_D: Human error probability for diagnoses

HEP_A: Human error probability for post diagnosis actions

HEP_T: Total human error probability

$HEP_{N/A}$: Nominal HEP for post diagnosis actions

$HEP_{N/D}$: Nominal HEP for diagnosis

Dependencies were incorporated in operator actions based on failure of previous actions or headers.

Table 1. Core outlet temperature corresponding to pressure of defective SG.

Sr. No.	Ruptured SG Pressure (MPa)	Core out let temperature (°C)
1	7.8	268
2	6.8	259
3	5.8	248
4	4.9	237
5	3.9	223

4. Results and Discussion

Human failure probability of isolation of ruptured steam generator was evaluated 5.64 E-2, as shown in Table 2. The mean unavailability of IFSG was predicted of the order of 5.64E-02, which is obvious from the unavailability of header that major part of unavailability comes from the human error probability (HEP). If isolation of ruptured SG is failed along with the failure of long term cooling by residual heat removal system as shown in Sequence 6 (Fig. 1), the contribution to core damage frequency is 3-4 % with frequency of the order of 4.81E-06.

Table 2. Human error probability (HEP) estimated using SPAR-H method.

Operator Actions	Description	HEP_D (Diagnosis)	HEP_A (Action)	Total HEP*
IFSG	Identification & Isolation of Ruptured SG	0.032	0.0244	0.0564
OAPB	Initiation of rapid SRC cool Down & Depressurization	0	0.047	0.0952
OACD	SRC cool down till SRH available	0	0.0589	0.1059

* Total HEP also includes the dependencies on the previous actions.

Failure of human action to balance the pressure between primary and secondary sides came out to be 9.52E-02. This action is dependent on previous action (isolation step), which was incorporated. The mean unavailability of OAPB header was estimated as 1.08E-01, which was contributed by hardware failure of systems/equipments used to perform the required action as well as human error. The failure of two successive operator actions i.e failure of OAPB and OACD (sequence 4) is leading to highest contribution to core damage, which is almost 59 % with CDF of 7.54E-05. In fact these both actions perform the cooling of reactor coolant system. As a result this sequence has potential to impact CDF, if it was not recovered properly.

OACD action has same nature of impacts as imposed by OAPB like cool down and depressurization but with different objective:

1. OAPB objective is to have pressure balance between primary and secondary side to minimize the radioactive leakage
2. OACD is mainly for the cool down and depressurization till SRH is available

Human error probability of OACD is greater than others, as it comes later in headers sequence and is dependent on the previous actions. The value of HEP in this case is 0.1059. The fault tree for OACD header was developed and mean unavailability was estimated of the order of 9.55E-02. Sequence 4 and 7 in figure 1 are forming a major part of CDF, which is because of human error probability of OACD.

5. Conclusions

Human actions in case of SGTR were addressed in this paper and analyzed using SPAR-H technique.

If IFSG failure occurs, it will not lead to core

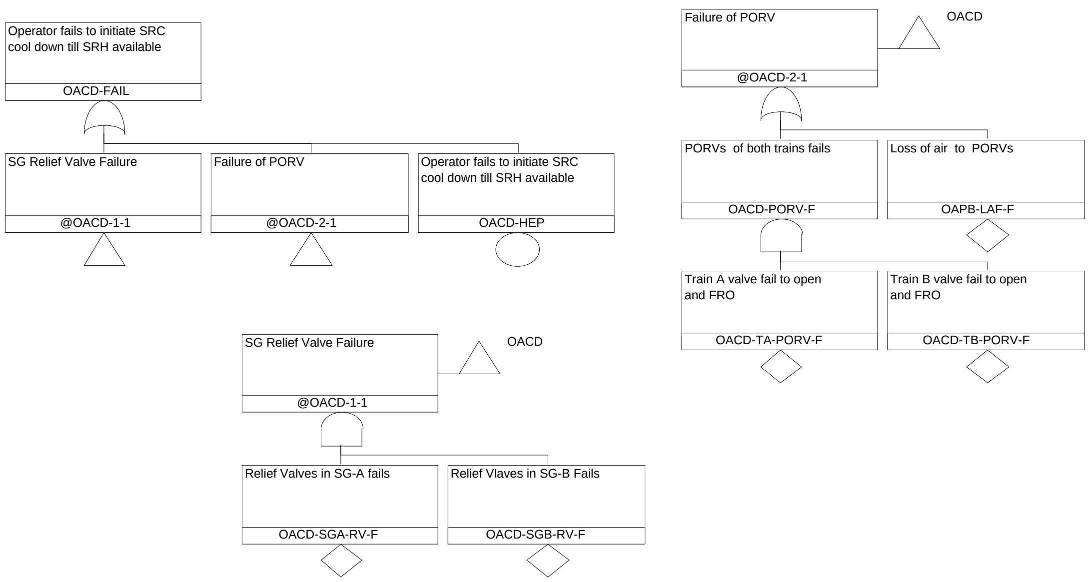

Figure 4. Fault tree for OACD (Operator action for cool down and depressurization of RCS till SRH available).

damage (shown in sequence 5) but it will cause radioactive releases and dispersion in environment.

Reduction of differential pressure between primary and secondary will be the next effort to reduce the radioactive leakage. Single failure of OAPB will not be the threat for core, if SG cooling and high pressure safety injection is available.

Unlike other action, OACD will ultimately be responsible to cool down and reduce pressure of reactor coolant system till entry condition of residual heat removal system. Its failure will impose threat to CD.

In order to reduce the impact of Human actions on core damage frequency, human error rates must be minimized.

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