Implementation of FLEX Operator Actions in PRA Models

Parthasarathy Chandran, Southern Nuclear Operating Company
(pchandra@southernco.com)
David L Moore, DL Moore Consulting
(dlmooreconsulting@comcast.net)
John Reddington, Empyrean Services
(jereddington@gmail.com)

Implementation of FLEX Operator Actions in PRA Models - Logistics

- Rob has been amazing to have accepted to present this paper on our behalf

- For any questions, comments or disagreements
  - Please feel free to contact us

- This presentation aims to provide the key steps used in
  - Developing a realistic model for the FLEX-related Human Failure Events (HFEs)
  - Implementation of the events using CBDTM/THERP

Implementation of FLEX Operator Actions in PRA Models - Driver

- One of the primary lessons learned from the Fukushima event
  - Understanding realistic risk drivers for the plant for a given hazard
- One way to gain insights about the realistic risk drivers
  - Building and maintaining a PRA model that reflects the as-built and as-operated plant
- In order to achieve this, PRA model needs to include implemented FLEX strategies to reflect the real drivers for
  - Core damage
  - Containment integrity
- Procedures and processes have been updated at plants to ensure plant operators and personnel can implement FLEX in any applicable accident scenario

Implementation of FLEX Operator Actions in PRA Models - Strategy

- Presentation is developed based on a work done for a BWR 4 plant with Mark I containments

- Overall FLEX strategy is divided into three stages
  - Phase 1 (from time 0 to about 10 hours)
    - Use the RCIC turbine-driven pump to maintain reactor vessel water level
    - Use the safety/relief valves to remove heat from the reactor vessel to the suppression pool
    - Use the hardened containment vent system (HCVS) to remove heat from the containment
  - Phase 2 (from 10 hours to 24 hours (or beyond))
    - Use portable pumps deployed to the intake structure area to pump river water to the Reactor Building
    - Deploy two portable diesel generators to power the 600V emergency switchgear
  - Phase 3 (beyond 24 hours)
    - Continue with the Phase 2 equipment, supplemented by offsite equipment from the NSRC

- The PRA model with FLEX only includes up to phase 2, as the plant reaches a safe and stable state with the implementation of phase 1&2 FLEX well beyond its mission time of 24 hours

Implementation of FLEX Operator Actions in PRA Models - Equipment

- Strategies depended on permanently installed equipment and portable equipment.

- Permanently installed equipment included
  - RCIC system for injection to the reactor vessel
  - Station batteries for interim power until the portable diesel generators are deployed
  - Critical instrument cabinets for power to the HCVS and vital instrumentation
  - RHR SW piping from the Intake Structure to the Reactor Building with installed connections for the portable river water pump and hoses
  - Connection boxes and switches to establish electrical power from the portable diesel generators to the emergency switchgear, including battery chargers and inverters
  - Air handling units for Main Control Room (MCR) cooling

- Portable FLEX/ELAP equipment is primarily stored in the FLEX storage facility or dome, and included
  - Redundant pumps to provide water from the river to the RHR SW piping
  - Redundant diesel generators to provide power to the emergency switchgear
  - Fans to provide ventilation for the Control Building electrical rooms
  - Hoses, cables, and miscellaneous equipment such as communication systems, portable lighting, batteries, food and water

Implementation of FLEX Operator Actions in PRA Models - Methodology

- Operator actions associated with FLEX and ELAP were evaluated in detail using the EPRI HRA Calculator
- Human error probabilities (HEPs) associated with these actions such as ones stated below were considered in the context of the SBO scenario
  - Overlapping nature of these actions
  - Minimum crew staffing and workload
  - Integrated nature of these actions
- Actions have been evaluated to ensure that the timing is based on the sequential and overlapping actions
- Plant performed a detailed staffing study as well as a validation and verification process of the strategy
- Analysis was performed with the assumption
  - Minimum staffing at the plant was initially available
  - For large external events, that the fire brigade leader and two system operators would be engaged in fire response duties for the first 3 hours
  - Emergency Response Organization (ERO) would not be staffed for the first 6 hours
- Values discussed in the presentation for HEPs are internal events type numbers

Implementation of FLEX Operator Actions in PRA Models - Sequence

- The operator actions below follows in the general flow of the FLEX timeframe

– OPHEELAP-COG :	Decision to implement the ELAP procedure
– OPHE-DEEP-SHED :	Extend the life of the station batteries
– OPHEELAP-DEP :	Depressurize to avoid the unsafe region of HCTL curve
– OPHEELAP-DEPMAIN :	Prevent depressurizing below the RCIC turbine working pressure
– OPHEELAP-DOOR-COG :	Decision to open doors to reduce heat up of the control building electrical rooms, and the MCR
– OPHEELAP-DOOR-CB :	Provide ventilation for the control building electrical rooms

Implementation of FLEX Operator Actions in PRA Models - Sequence

- OPHEELAP-DOOR-MCR : Provide ventilation for the MCR
- OPHEELAP-VENT : Maintain the suppression pool temperature such that RCIC can operate
- OPHEELAP-SWAP : Swap the suction of RCIC from CST to the suppression pool
- OPHEELPH2-PMP : Deploy the FLEX phase 2 river water pump
- OPHEELPH2-AC : Deploy the FLEX phase 2 600V portable diesel generators
- OPHEELPH2-CBHVAC : Opening the doors for the control building electrical rooms
- OPHEELPH2-MCRHVAC : FLEX river water pump to the MCR AHUs

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-COG
  - HEP represents the decision to implement the ELAP procedure
  - SBO procedure directs that the ELAP procedure be implemented
    - When it has been determined that no 4KV bus can be energized
    - If 50 minutes have elapsed and no 4KV bus is energized
  - Based on the clear guidance, specific ELAP training, and validated times, this cognitive HEP was determined to be highly reliable.

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHE-DEEP-SHED
  - Extend the life of the station batteries
  - Procedures direct actions to reduce and strip loads from the DC switchgear and buses
  - Initial load shed is directed by the SBO procedure
  - ELAP procedure then directs this “deep” load shed, which also involves venting the H2 gas from the main generator
  - Based on validated times (23 minutes) which consider
    - prior load shed
    - the cognitive action to enter the ELAP procedure
  - HEP : 2E-03

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-DEP
  - As the SBO progresses, the suppression pool (SP) will start to heat up
  - Based on the procedures, the operator is instructed to depressurize to avoid the unsafe region of HCTL curve
  - A well-trained action that will take place in two steps to prevent cooling down more than 100F per hour
  - HEP : 3E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-DEPMAIN
  - To prevent depressurizing below the RCIC turbine working pressure
  - New procedures to depressurize and maintain RPV pressure within 150-300 psig
    - Such that RCIC turbine can continue to operate
    - Involves opening an SRV when the pressure reaches 300 psig
    - Closing the SRV when approaching 150 psig
  - RPV pressure is monitored closely in any accident sequence, so this is a highly reliable action
  - Additionally, if the pressure goes too low, RCIC will stop, but then the pressure will rise such that RCIC can be restarted
  - If the pressure goes too high, although the HCTL limit may be violated temporarily, no immediate damage is done, and the pressure can be reduced back into the preferred range
  - HEP : 3E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-DOOR-COG
  - ELAP procedure directs the operators to open doors to reduce heat up of the
    - Control building electrical rooms
    - MCR
  - HFE represents the cognitive portion of these two actions
  - Increasing room temperatures would be obvious to the MCR operators, and the cognitive HEP was determined to be highly reliable

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-DOOR-CB
  - Execution actions for opening doors to provide ventilation for the control building electrical rooms are simple with procedures with maps indicating the doors to be opened
  - Based on validated times, HEP : 1E-04
- OPHEELAP-DOOR-MCR
  - Execution actions for opening doors to provide ventilation for the MCR are simple with procedures with maps indicating the doors to be opened
  - Tools and instructions are available to open the elevator doors
  - Based on validated times, HEP : 2E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-VENT
  - ELAP scenarios without AC power, the suppression pool will heat up since there is no heat removal from containment
  - To maintain the SP temperature such that RCIC can operate, the hardened containment vent system (HCVS) is opened to allow heat to be removed by boiling and venting
  - Action includes using an Argon cylinder to pressurize and pop the rupture disc
  - Based on validated times, HEP : 6E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELAP-SWAP
  - When the CST level is reduced to 1 foot, the operator must swap the suction of RCIC to the suppression pool
  - Automatic swap has been disabled by the operator in previous actions
  - Action is simple from the MCR, and is part of normal RCIC operation, not just ELAP
  - More than 6 hours have elapsed since the seismic event, so stress is reduced
  - Based on validated times, HEP : 2E-05

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELPH2-PMP
  - First major Phase 2 action for ELAP is to deploy the FLEX phase 2 river water pump
  - A redundant pump is available if the first pump is not available
  - Deployment includes following steps
    - Action starts as the routes are being cleared
    - Staging the main pump at the intake structure
    - Deploying the floating pump/suction units
    - Aligning the hoses to the RHRSW hose connections
  - Pumps must be working in about 13 hours to provide water to the MCR AHUs
  - Water is also used to start refill of the CST by 19 hours
  - Procedures include step by step instructions with photos of the connections
  - Based on validated times, HEP : 6E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELPH2-AC
  - Second major Phase 2 action for ELAP is to deploy the FLEX phase 2 600V portable diesel generators
    - Connect them to the 600V switchgear
    - Align the switches to charge the batteries
  - One portable diesel generator feeds the Div 1 switchgear of both units, and the other portable generator feeds Div 2 of both units
    - Third portable diesel generator is also available
  - Alternate connection points and staging areas are available depending on the haul routes selected
  - FLEX timeline starts 6 hours after the initiating event, and uses 13 hours from the initiating event for completion of this action for both Div 1 and Div 2 portable diesel generators
  - Procedure is detailed, with color coded connections for the cables
  - Based on validated times, HEP : 8E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELPH2-CBHVAC
  - Opening the doors for the control building electrical rooms will maintain acceptable temperatures for over 10 hours
  - ELAP procedures direct the operators, assisted by emergency response organization staff (ERO) to install portable FLEX fans to provide ventilation for the switchgear and inverter rooms for both units
  - Action is started 7 hours after the initiating event, and is to be completed by the 10th hour
  - Fans and cables are retrieved from the FLEX dome and staged on the ground floor of the control building
  - Procedure has a map indicating where the fans are to be placed, and the cables connected
  - Based on validated times, HEP : 2E-04

Implementation of FLEX Operator Actions in PRA Models - Actions

- OPHEELPH2-MCRHVAC
  - ELAP phase 2 cooling of the MCR depends on aligning the RHRSW lines
    - which are now being fed by the FLEX river water pump
    - to the MCR AHUs, which are normally fed by PSW
  - Connections are designed to use the FLEX hoses that are stored in the FLEX dome
  - Power for the MCR AHUs and water for the AHUs would become available in the 10 to 13-hour timeframe
  - Detailed procedure is available, and ERO staff would assist with the connections
  - Based on validated times, HEP : 3E-04

Implementation of FLEX Operator Actions in PRA Models - Summary

- Specific attention should be given to the operator actions associated with the implementation of the FLEX/ELAP strategies to the following :
  - Level of plant damage (important for external events), and time to clear routes for portable equipment deployment
  - Integrated and overlapping nature of the actions such that timing for the actions depended on earlier actions
  - Potential for spurious alarms, relay chatter, and damage to annunciator system
  - Communication systems availability
  - Quality of the procedures, especially given the potential stress
  - Training
  - Workload and minimum crew, and diversion of staff to potential fire response duties
  - Access for actions outside of the MCR