NON-PROPRIETARY

APR1400 DC PRA Model Conversion from SAREX™ to CAFTA™

2016.05.05

KHNP

Purpose

- Provide overview of Level 2 conversion process
- Present the results of the APR1400 DC PRA CAFTA model including comparison to SAREX model results
- Discuss CAFTA Quantification Process

Agenda

- Introduction
- Conversion Process Details
- Model Changes
- CAFTA Model Quantification Process
- Comparison to SAREX Results

Introduction

❖ Why convert?

- CAFTA V&V (EPRI Code)
- Industry/NRC familiarity with CAFTA
- Decrease quantification time
- CAFTA Level 2 solution generates Level 2 cutsets (SAREX generates PDS cutsets * CPLR)
- Issues with parametric uncertainty analysis for FPRA
- Combine all APR1400 DC PRA models under a single top logic model
  - ➢ supports PRA configuration control during plant design process

CAFTA Level 2 vs. SAREX Level 2

❖ CAFTA approach vs. SAREX approach

- CAFTA approach explicitly presents Level 2 phenomena events in cutsets. This allows importance, sensitivity, uncertainty, etc. on basic event/cutset level
- Same logic structure can be used for internal events, fire and flood with relatively minor alterations to quantification files

Introduction

❖ Status of conversion

- L1 FPIE and FP-FPRA converted
- L1 and L2 LSPD IE – in process
- L1 LPSD FPRA - created in CAFTA for DCD
- L2 LPSD FPRA – in process
- L2 FPIE and L2 FP-FPRA - Converted

❖ Plans for future conversion

- Near future - Internal flooding models
- Later - Seismic SMA

Introduction

	CAFTA	SAREX	% Inc.
FPIE CDF =	1.7E-06	1.3E-06	31.5%
FP-FPRA CDF =	1.9E-06	1.9E-06	0%
LPSD IE CDF =	TDB	2.6E-06	TBD
*LPSD FPRA CDF =	1.7E-06	None	N/A
FPIE LRF =	1.2E-7	1.1E-07	5.4%
FP-FPRA LRF =	1.1E-7 (SCA)	1.7E-07(SCA+MCA)	TBD**
*LPSD IE LRF =	1.2E-07	None	TBD
*LPSD FPRA LRF =	1.3E-07	None	N/A

*LPSD IE and FPRA created in CAFTA (i.e., no SAREX model)

**FP-FPRA LRF does not yet include MCA results

Conversion Details – Top Logic

- SAREX Level 2 Model was Manually Converted to a CAFTA Top Logic Fault Tree Model Ensuring:
  - Level 1 sequences explicitly linked to Level 2 systems
  - Relevant details of SAREX PDS event trees are considered in evaluation of CET and STC calculations
  - CET and DET rules are translated into CAFTA gate logic (combination of failure terms and success logic)
  - Source term category frequencies are properly calculated

Conversion Details – Top Logic (cont'd)

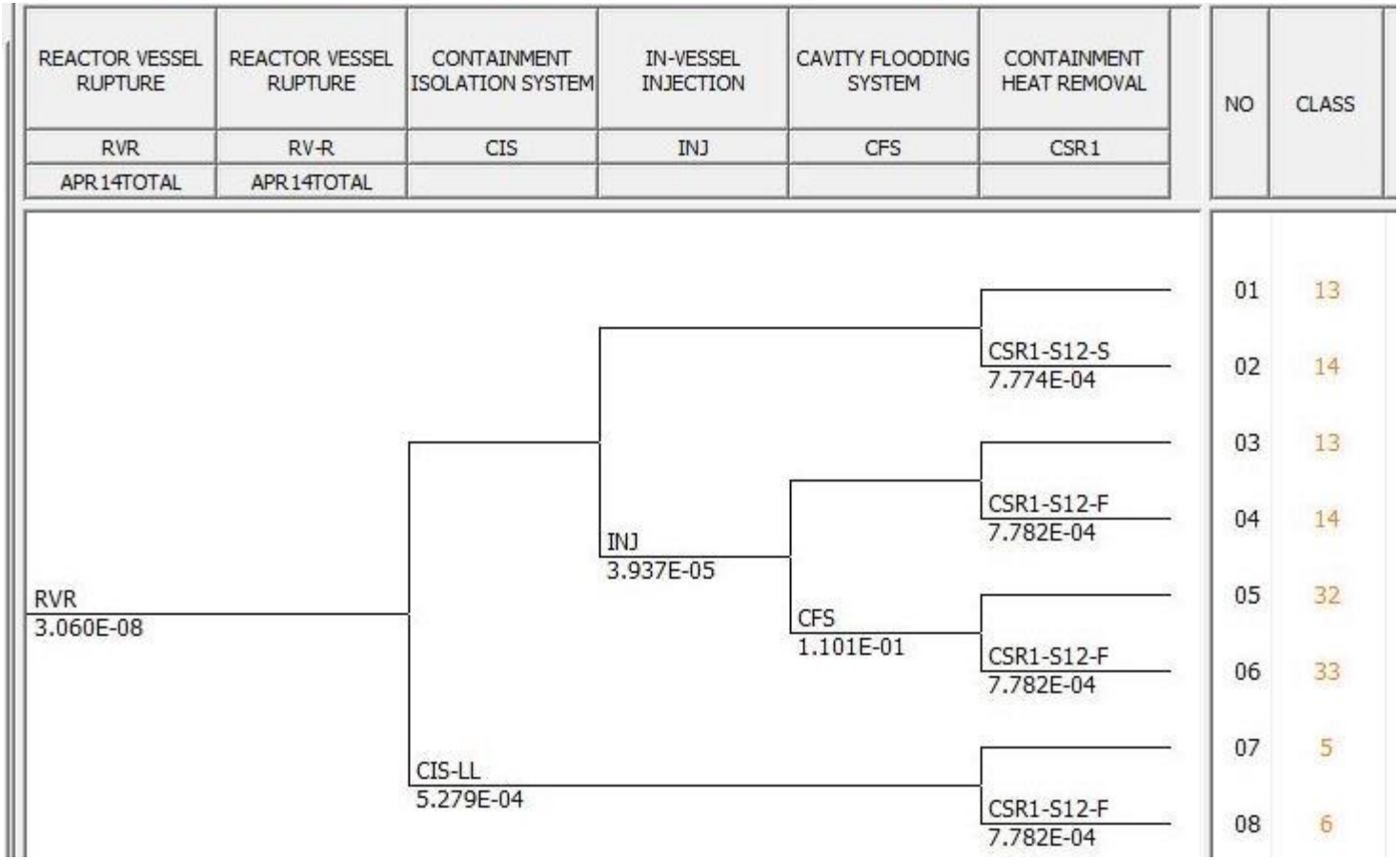
- MCR Evacuation top logic added for FP-FPRA
- All other FPIE accident sequence progression is not altered by fire, so no other unique FP-FPRA changes required to top logic

Conversion Details – Fault Trees

- SAREX Level 2 System Fault Trees were converted to CAFTA Fault Trees, similar to conversion of Level 1 system trees
  - SAREX fault trees exported in SETS format
  - SETS files imported into CAFTA
- CAFTA System Fault Trees Linked to CAFTA Top Logic Model
  - Simple automatic CAFTA “Merge” function
  - Fault tree gates linked directly to CET/DET logic

Conversion Details – CET/DET Modeling

- Initial attempt at Level 2 conversion was to recreate complete PDS event tree structure



Conversion Details – CET/DET Logic

- Number of PDS event tree sequences (~1300) was too large for CAFTA to process through CETs in a single top logic gate (would be possible running each case individually)
- Instead developed CET and DETs in CAFTA and related logic to Level 1 ET sequences and additional PDS gate logic as needed

Conversion Details – CET/DET Logic (Cont'd)

- CAFTA design is different from SAREX Level 2 code design
  - SAREX Level 2 uses fault trees for PDS modeling, but all CET and DET logic is either split fraction probabilities or true/false based on text rules of sequence attributes
  - CAFTA Level 2 is all fault tree logic for the sequence attributes or split fraction probabilities. Each node requires CAFTA gate.

L2 Conversion – SAREX Rules to CAFTA Logic

Example node of PDS diagram:

PDS Event LOCATRAN = LL (Large LOCA)

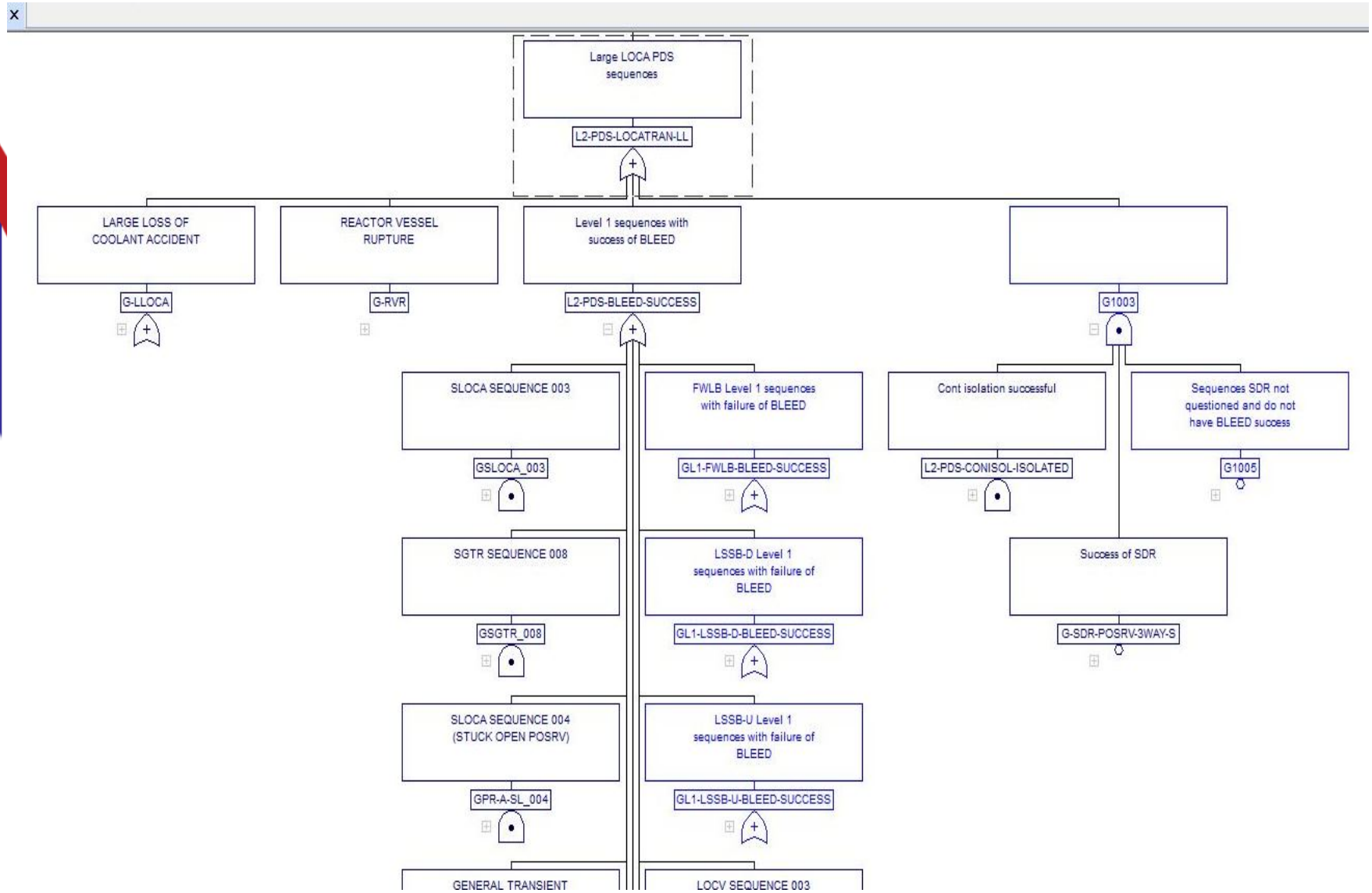
Binning rules in SAREX:

IF A:LLOCA=F;
IF A:RVR=F;
IF A:SDR=S;
IF A:BLEED=S;
THEN LL;

Brief discussion of translation of rules into CAFTA logic:

Logic developed as OR gate between LL, RVR, Level 1 sequences with success of BLEED, or PDS Event Tree sequences with success of rapid depressurization (SDR). The SDR is modeled as NOT SDR failure.

L2 Conversion – SAREX Rules to CAFTA Logic



L2 Conversion – SAREX Rules to CAFTA Logic

- PDS Diagram: Has 26 such nodes for which equivalent fault tree logic was developed
- DETs: RCSFAIL – 48 nodes; MELTSTOP – 28 nodes; DCF – 9 nodes; ECF – 28 nodes; CSLATE – 10 nodes; DBCOOL – 8 nodes; LCF – 57 nodes; BMT – 6 nodes; SGTR – 2 nodes; ISLOCA – 4 nodes; CONISOF – 2 nodes; RBCM – 4 nodes
- CET Diagram: 37 nodes (combined all CETs)
- STC Diagram: Used to manually assign the CET end states into the 21 STCs

Conversion Details – Reliability DB

- Level 2 CAFTA model shares the .RR database with the Level 1 model.
- Many discrepancies between the DCD Level 2 SAREX database (APR14-L2.MDB) and the CAFTA database. These will be resolved to ensure the proper values are used in the next update.

Conversion Details – Quant. Files

❖ FPIE Quantification Files

- FPIE Master Flag File (APR1400.flg) - same as Level 1
- FPIE Master Recovery File (APR1400.recv) – same as Level 1
- No FPIE Sequence Flag or Sequence Recovery Files
- Additions to the Mutually-Exclusive combinations for Level 2:
  - L2-PROB-CSRECSBS-YES * L2-PROB-CSRECSBS-NO
  - L2-PROB-DCOOL-NO * L2-PROB-DCOOL-YES

Conversion Details – Quant. Files (Cont'd)

❖ FP-FPRA Quantification Files

- **FP-FPRA Master Flag File (FP-FIRE-MASTER.flg) – Same as Level 1**

- **FP-FPRA Master Recovery File (MR-FP-FIRE-Level2.recv)**
  - ➢ **Identical to Level 1 recovery file except truncation level lowered to 1E-13 to create potential for 1E-13 solution**

Model Changes

❖ Modeling Error Corrections

- **ECSBS – In the SAREX model, a split fraction estimation of ECSBS was utilized in the MELTSTOP and CSLATE DETs. The fractions were set at 0.9 success / 0.1 failure. For the CAFTA model, these two events utilize the same gate logic to ensure that the probabilities are not applied twice (i.e., failure of ECSBS = 0.1 in MELTSTOP and failure in CSLATE = 0.1 must be a combined 0.1 failure of ECSBS and not 0.01.**

Model Changes

❖ Modeling Error Corrections (cont.)

- As noted, many basic event probability discrepancies exist and will be corrected. Correction was made to HEP for containment isolation since it had significant impact on LRF

- In DBCOOL DET, some COOL paths actually do not have water injection to the cavity, but the STC binning rules for CAVCOND = DRY/WET is based on DBCOOL = COOL or NOCOOLW. This should have referred to PDS event CAVCOND = WET or ERVC. The proper evaluation will be performed in the next update.

FPIE Comparison Review

Level 2 Conversion Results Comparison

❖ Overview

- Because of the differences in methodology (SAREX retains all of the PDS ET frequency, while CAFTA truncates at STC cutset level), there can not be an exact match of frequencies, especially for low frequency STCs

- Because some STCs in the CAFTA calculation currently can not solve at 1E-13/yr, there is some undercounting of the total frequency (FPIE: total CDF = 1.58E-6/yr; total frequency of all STCs = 1.54E-6/yr. This will be addressed for the next update.

- As in SAREX model, total L2 frequency will be slightly larger than L1 CDF

CAFTA Level 2 vs. SAREX Level 2

❖ Effects of CAFTA approach vs. SAREX approach

- SAREX approach truncates frequencies at PDS event tree level. Level 2 CET/DET split fractions do not affect truncation

- CAFTA approach truncates cutsets at the STC level. Therefore, some frequencies can drop below truncation when split fractions applied (e.g., if PDS ET truncation at 1E-13, SAREX will conserve entire frequency, but CAFTA 1E-13 truncation at STC level would truncate some cutsets with PDS ET 1E-13 * split fractions < 1.0). Therefore, STC frequencies more sensitive to CAFTA truncation, but truncating at E-12 or E-13/yr does not make significant difference to total LRF.

FPIE CAFTA/SAREX STC Comparison

FPIE Results	SAREX	CAFTA (draft)
Level 1 CDF (/yr)	1.30E-06	1.58E-06
Total Lev 2 freq (/yr)	1.31E-06	1.54E-06
Total LRF (/yr)	1.11E-07	1.16E-07
CPLR	8.40E-02	7.55E-02

- Because of the corrections to the Level 1 model made during conversion to CAFTA, total Level 2 frequency increased. Total LRF increased slightly, since most of the additional CDF went to Meltstop or No CF end state

- CPLR decreased because most of new CDF is not LRF

FP Fire SCA CAFTA/SAREX STC Comparison

FP Fire SCA Results	SAREX	CAFTA (draft)
Level 1 CDF (/yr)	1.70E-06	1.70E-06
Total Lev 2 freq (/yr)	2.07E-06	1.81E-06
Total LRF (/yr)	1.7E-07	1.1E-07(SCA only)

- CAFTA results presented do not include MCA results.

FPIE CAFTA/SAREX STC Comparison

STC	SAREX freq	CAFTA freq	% diff	Discussion of Difference in Frequency
STC-10	7.64E-07	9.45E-07	23.6%	Higher total CDF in CAFTA L1 conversion. Difference in frequency L2 vs. SAREX L2 is 1.8E-7/yr. Did not solve at 1E-13. Lowering STC-10 truncation will slightly raise the CAFTA STC-10 frequency. Diff in L1 CAFTA CDF vs. total L2 SAREX STC frequency is 2.7E-6.
STC-09	3.67E-07	4.10E-07	11.8%	Higher total in CAFTA model due to higher CDF in CAFTA Level 1 compared to SAREX Level 1. Similar to STC-10.
STC-01	5.33E-08	5.65E-08	6.0%	SGTR-initiated portion of this frequency has a negligible difference. The additional CDF in the CAFTA model yields some additional contribution to induced SGTR.
STC-21	2.96E-08	2.95E-08	-0.2%	Did not solve at 1E-13. Lowering the STC-21 truncation will slightly raise the STC-21 frequency. Error in SAREX in that the CSRECSBS factor was applied to twice (MELTSTOP and CSLATE DETs). This caused SAREX frequency to be underestimated.
STC-17	2.70E-08	2.67E-08	-1.1%	Did not solve at 1E-13. Lowering the STC-17 truncation will slightly raise the STC-17 frequency. Error in SAREX in that the CSRECSBS factor was applied to twice (MELTSTOP and CSLATE DETs). This caused SAREX frequency to be underestimated.
STC-02	2.41E-08	2.41E-08	0.0%	No difference to 3rd significant digit.
STC-11	1.33E-08	1.24E-08	-6.7%	Did not solve at 1E-13. Lowering the STC-11 truncation will slightly raise the STC-11 frequency.
STC-08	1.30E-08	1.46E-08	12.3%	Higher total in CAFTA model due to higher CDF in CAFTA Level 1 compared to SAREX Level 1. Similar to STC-10.
STC-07	1.14E-08	1.26E-08	10.5%	Higher total in CAFTA model due to higher CDF in CAFTA Level 1 compared to SAREX Level 1. Similar to STC-10.

FPIE CAFTA / SAREX STC Comparison

STC-19	4.01E-09	4.41E-09	10.1%	Error in SAREX in that the CSRECSBS factor was applied to twice (MELTSTOP and CSLATE DETs). This caused SAREX frequency to be underestimated.
STC-05	2.46E-09	2.59E-09	5.1%	Containment isolation failure. Higher total in CAFTA model due to higher CDF in CAFTA Level 1 compared to SAREX Level 1. Similar to STC-10.
STC-13	1.80E-09	1.69E-09	-6.1%	Absolute value of discrepancy is negligible. Attributed to differences in basic event values between CAFTA and SAREX model
STC-06	1.23E-09	1.69E-09	37.1%	Containment isolation failure. Higher total in CAFTA model due to higher CDF in CAFTA Level 1 compared to SAREX Level 1. Similar to STC-10.
STC-18	4.19E-10	3.07E-10	-26.7%	Absolute value of discrepancy is negligible. Attributed to differences in basic event values between CAFTA and SAREX model and CAFTA model cutsets being near truncation.
STC-04	6.49E-11	6.49E-11	0.0%	No difference to 3rd significant digit.
STC-03	5.31E-11	5.31E-11	0.0%	No difference to 3rd significant digit.
STC-14	4.28E-11	4.27E-12	-41.5%	Did not solve at 1E-13. Absolute value of discrepancy is negligible; expected to be resolved with lower truncation.
STC-20	1.19E-11	2.69E-11	-37.1%	Absolute value of discrepancy is negligible. Attributed to differences in basic event values between CAFTA and SAREX model and CAFTA model cutsets being near truncation.
STC-16	7.30E-12	2.20E-11	84.6%	Error in SAREX in that the CSRECSBS factor was applied to twice (MELTSTOP and CSLATE DETs). This caused SAREX frequency to be underestimated.
STC-12	0.00E+00	0.00E+00	N/A	No difference to 3rd significant digit.
STC-15	0.00+E00	9.17E-13	N/A	Error in SAREX in that the CSRECSBS factor was applied to twice (MELTSTOP and CSLATE DETs). This caused SAREX frequency to be underestimated.

Full Power Fire CAFTA/SAREX STC Comparison

Total LRF (SCA + MCA) in SAREX = 1.7E-7/yr

Total LRF (SCA) in SAREX = 1.5E-7/yr

Total LRF (SCA) in CAFTA (draft) = 1.1E-7/yr

- CAFTA draft LRF is lower due to model changes & HRA disc repancies.
  - SAREX fire model was based on SKN 3&4. CAFTA model contains all APR1400 model changes discussed in Level 1 conversion presentation end of last year
  - Some significant SAREX SKN 3&4 operator actions were updated in the L1 FPIE SAREX model (e.g., CCOPV-S-NSMV – 1.0E-1 changed to SIOPV-S-SIAS – 5.9E-3). However these were not updated in the L2 SAREX Fire model

Full Power Fire CAFTA/SAREX STC Comparison

- SAREX recovery file error: Did not credit PFOPH-S-UATBKR-LOCAL in fires that cause a LOOP, only in fires that act as transients and have induced LOOP. Therefore, some significant SAREX fire LRF cutsets should have lower frequency

- SAREX model did not credit operator action for Cont. Isolation in some fires for which the CAFTA model credits the actions. Discrepancy with CAFTA fire model will be resolved in updated fire HRA to ensure that the potential for a fire to impact an action is accurately evaluated

FPIE CAFTA / SAREX STC Comparison

- Conversion deemed correct based on:
  - The small difference in the FPIE total LRF, which is explained due to Level 1 corrections
  - Comparable FPIE CPLR, given higher CAFTA CDF in non-bypass sequences
  - Full Power Fire LRF is lower (draft MCA results being generated; other changes are due to use of updated model and HRA discrepancies)

- For completeness, the truncation will be lowered for STCs that are not solving at 1E-13/yr. Some enhancements will be made to improve efficiency of CAFTA solution

- Multi-Compartment Fire Analysis is being performed using the same logic

APR1400 DC PRA Model Conversion

❖ Conclusions

- Conversions to CAFTA did not introduce any significant impact on results other than fire analysis making use of latest model
- Now that the models are merged, there should be no longer be any configuration control issues between the models
- More changes expected in PRA update
- Items to complete
  - ➢ At-power fire MCA analysis solution
  - ➢ Optimize CAFTA Level 2 model for solution at lower truncation
  - ➢ Resolve discrepancies between SAREX/CAFTA databases and fire HRA