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DNC Simulation Results and Risk Assessment

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July 2019

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DNC Simulation Results and Risk Assessment

LWRS LIGHT WATER REACTOR SUSTAINABILITY

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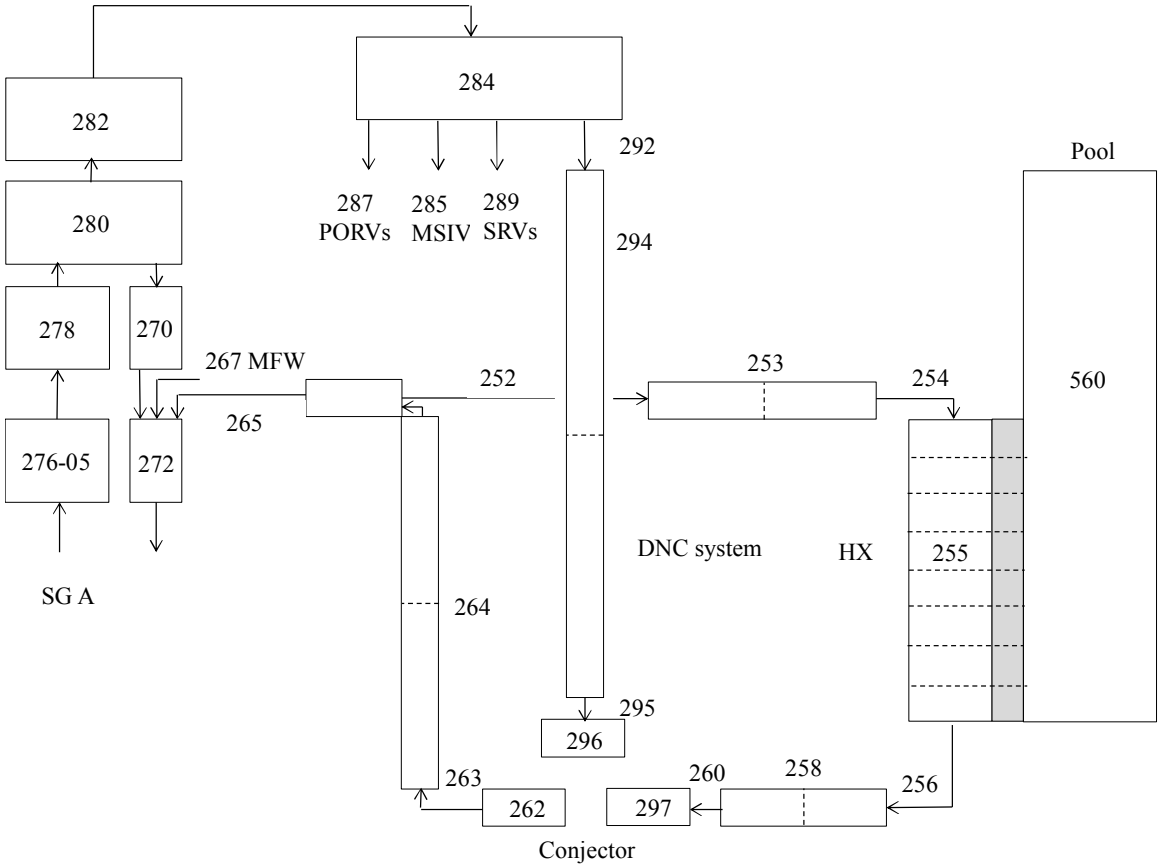
Overview

- **Thermal-hydraulic and risk assessment analyses of the Dynamic Natural Convection (DNC) system during a station blackout (SBO) in a PWR were performed**
  - Surry, a three-loop Westinghouse PWR, was chosen for analysis
  - A RELAP5-3D model developed for plant level scenario-based risk analysis for Enhanced Resilient PWR was used
  - The RELAP5-3D model was modified to represent the DNC system
  - DNC system was modeled in PRA for risk assessment
- **Three SBO scenarios were investigated**
  - Nominal RCP seal leakage (21 gpm/pump, equivalent to a 0.23 inch diameter break)
  - Maximum RCP seal leakage (480 gpm/pump, equivalent to a 1.1 inch diameter break)
  - Pressurizer PORV sticks open (nominal RCP seal leakage)
- **Effects of DNC failures were considered**
- **A generic PWR PRA model was used in DNC risk assessment**

RELAP5-3D DNC Model



- Passive heat rejection from SG to pool
- One DNC loop per SG, with a common pool
- Steam mixes with cold water from the HX in the conjector and generates the head for natural circulation
- Most of the water recirculates to the HX, remainder enters the SG
- RELAP5-3D model of the DNC system is based on correlations developed from small-scale experiments

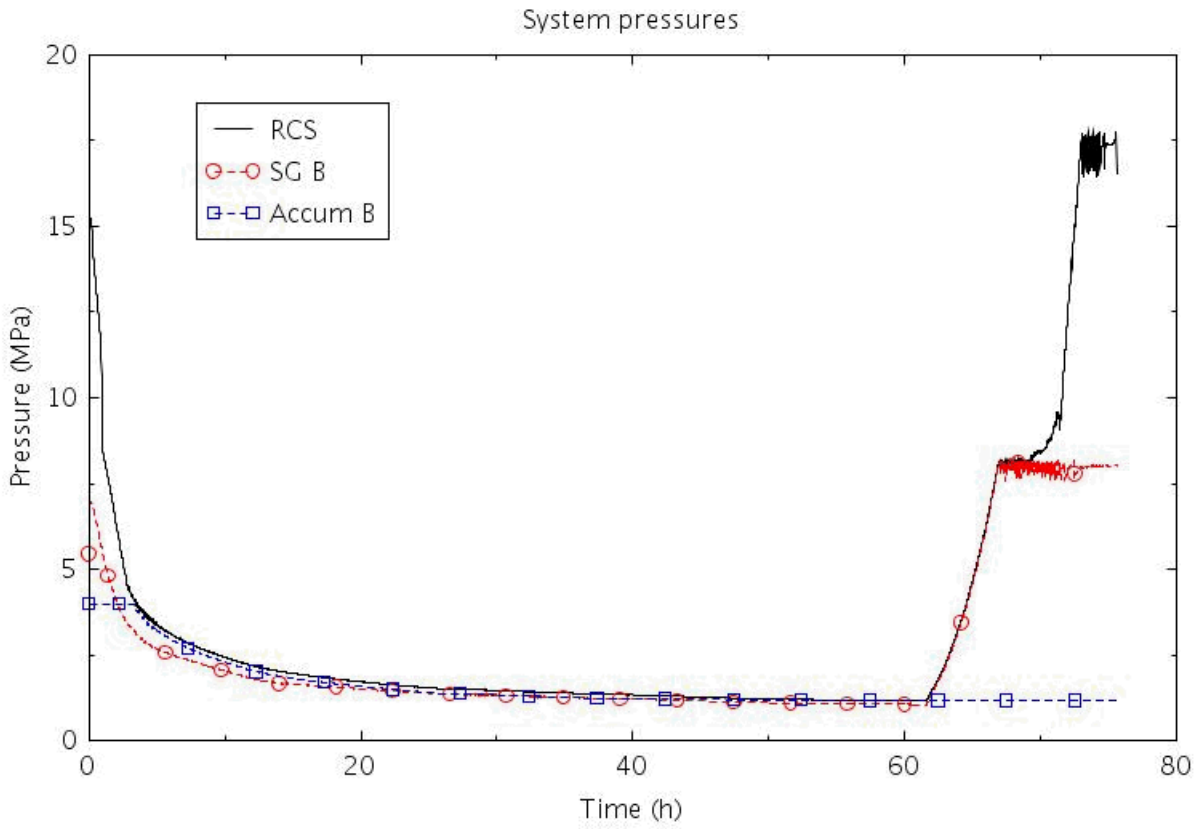
Comparison of SBO without and with DNC

	Leakage (gpm /pump)			
	21		480	
Event	Time (hr:min)			
	Without DNC*	With DNC	Without DNC*	With DNC
SBO occurs	0:00	0:00	0:00	0:00
TD-AFW / DNC FW begins	0:01	0:00	0:01	0:00
Operator begins SG cooldown	1:30	N/A	1:30	N/A
Accumulators begin to inject	2:30	3:16	2:10	1:38
Batteries depleted	4:00	4:00	4:00	4:00
SGs empty	8:16	71:30	N/A	N/A
Core begins to uncover	9:30	73:38	4:40	12:51
Core damage	10:32	75:36	5:25	14:10

* From INL/EXT-18-51436

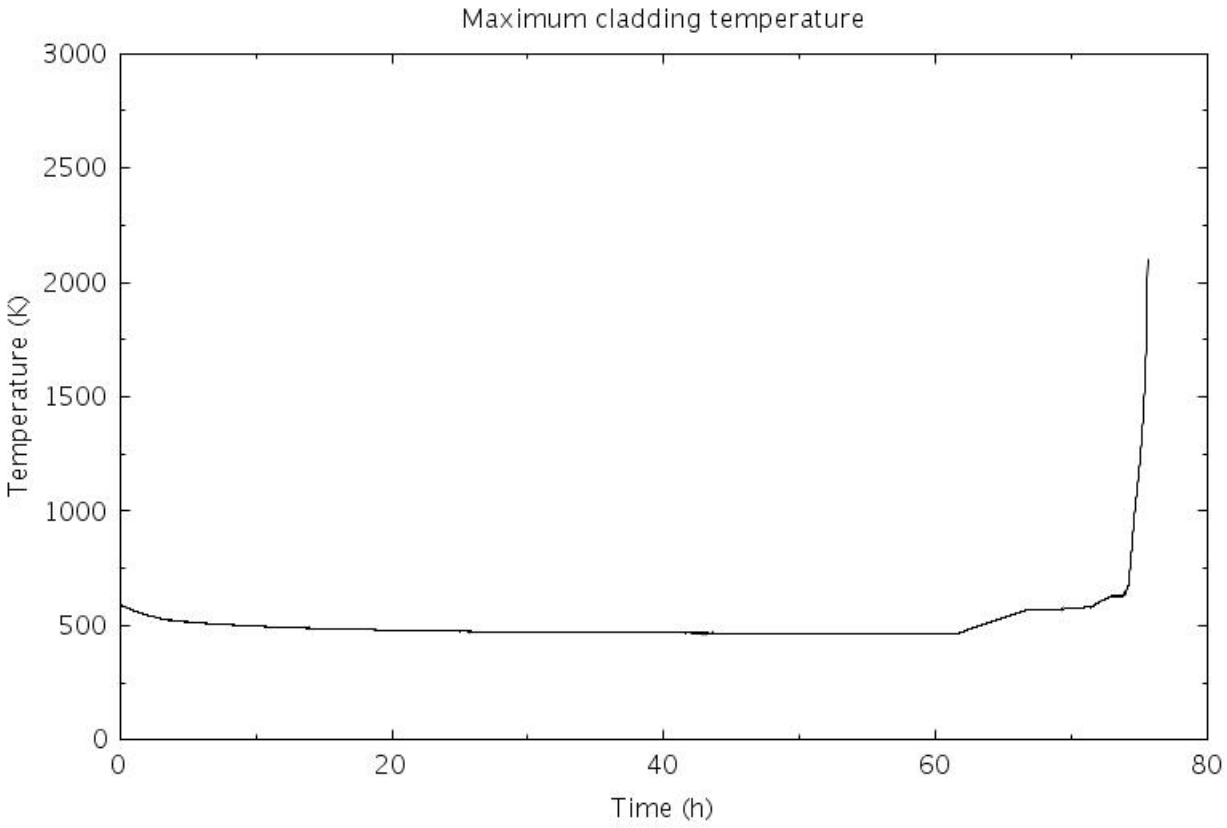
- The DNC is effective in increasing the coping time compared to traditional AFW

SBO results with DNC (21 gpm/pump)



- Automatic depressurization of RCS and SGs with DNC

SBO results with DNC



- Core damage at >72 h

A PORV failure is not significant because its first opening is so late

PORV operation	Normal	Stuck
Event	Time (hr:min)	
SBO occurs	0:00	0:00
DNC FW begins	0:00	0:00
Accumulators begin to inject	3:16	3:16
Batteries depleted	8:00	8:00
Accumulator flow ends	56:25	56.25
SGs empty	71:30	71:30
Pressurizer PORV sticks open	N/A	72:45
Core begins to uncover	73:38	73:26
Core damage	75:36	74:28

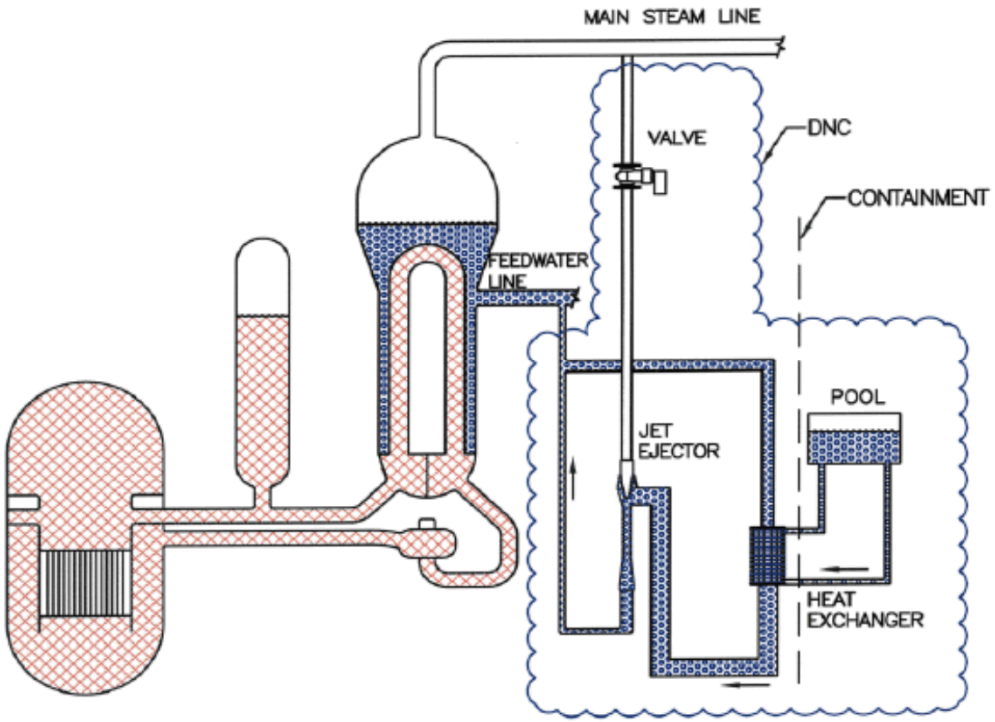
Failures in opening DNC steam valves were evaluated for the SBO

	Time to core damage (hr:min)		
Number of operable DNC systems	3	2	1
Nominal leakage (21 gpm/pump)	75:36	75:31	74:55
Maximum leakage (480 gpm/pump)	14:10	6:29	2:59

- The number of operable DNC systems did not affect the time to core damage significantly at nominal leakage
- The impact of DNC failures was much larger at maximum leakage
- Even though the DNC systems efficiently remove core decay heat via the SGs, they cannot make up for inventory lost during a LOCA
- The DNC systems become less effective as the break size increases

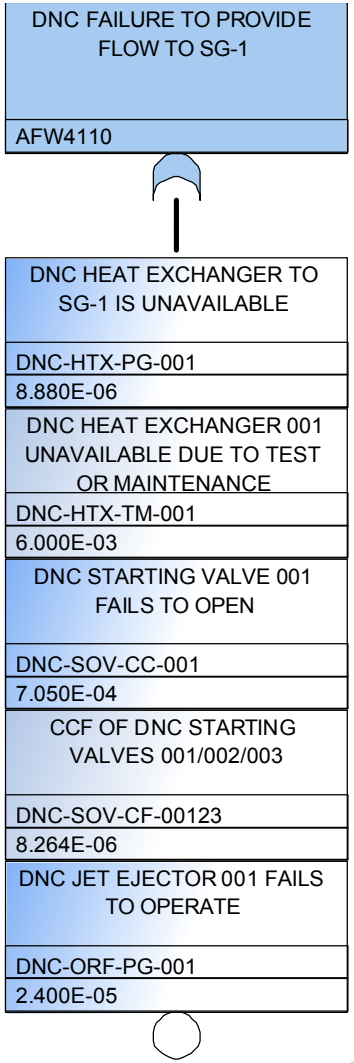
Modeling DNC System in PRA

- DNC system represents a passive system design for removing remove decay heat
- DNC system schematic diagram was used (the design is not finalized yet)
- One DNC loop per SG, with a common heat sink
  - Steam valve
  - Jet ejector
  - Heat exchanger



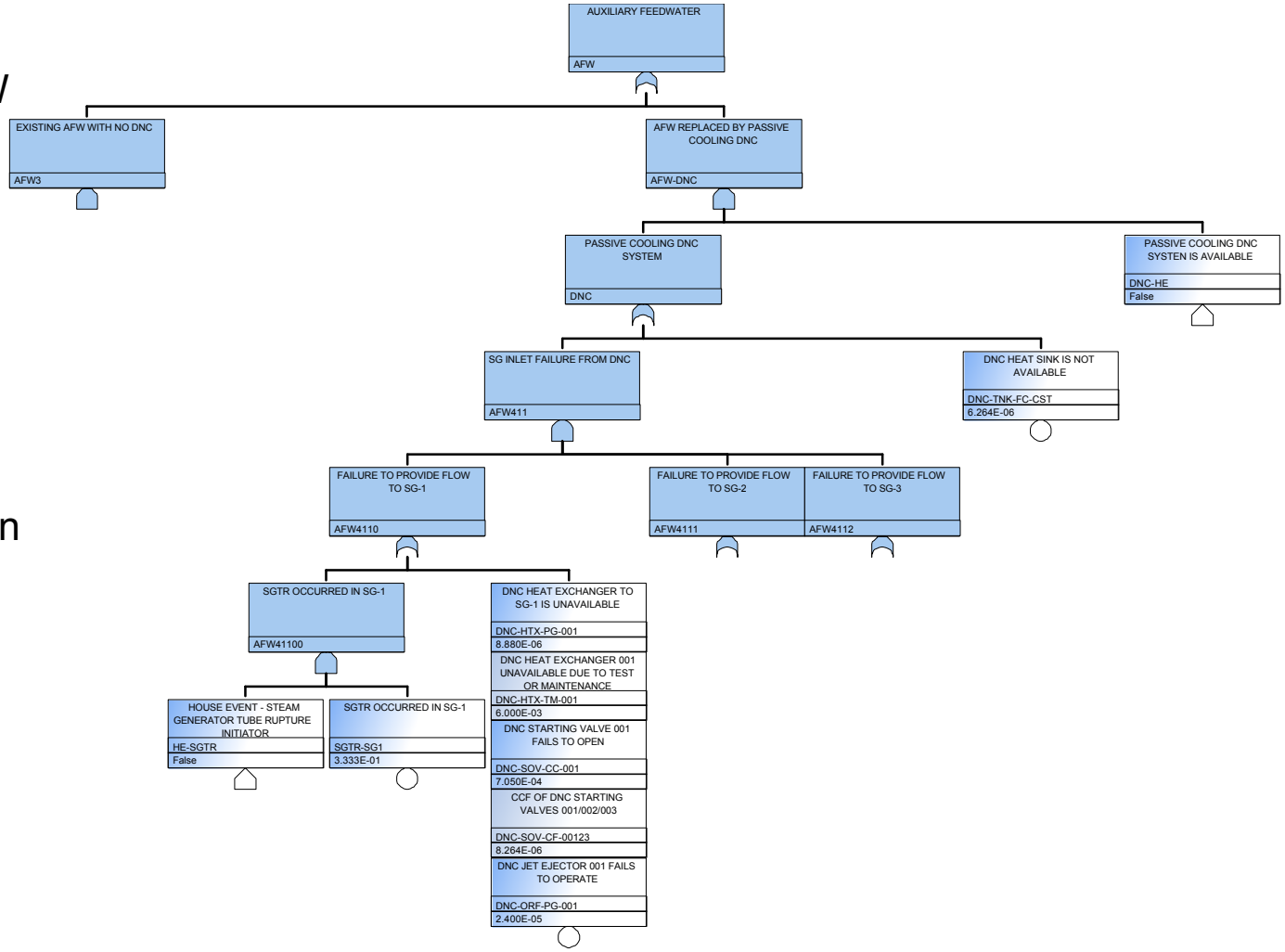
Modeling DNC System in PRA

- In this study, DNC system is modeled in PRA to fully replace AFW system
- Failures of DNC to provide flow to one SG include
  - DNC starting valve fails to open – independent failure
  - DNC starting valve fails to open – CCF
  - Jet ejector fails to operate
  - Heat exchanger fails to operate
  - Heat exchanger is unavailable due to test or maintenance
  - Heat sink (tank) is not available
- Unreliability and unavailability data uses the NRC 2015 Parameter Estimation Update



Modeling DNC System in PRA

- DNC system is incorporated into AFW fault tree
- DNC-HE is a house event to turn on DNC/turn off AFW (or vice versa)
- With this change, event trees can remain as they are



DNC Risk Impact – Baseline CDF

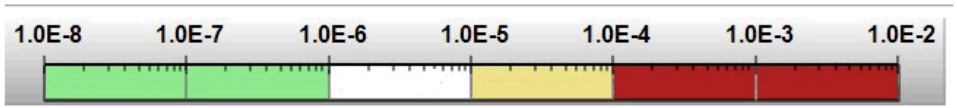
- DNC impact on baseline CDF

ET	CDF No DNC	CDF with DNC	ΔCDF	ΔCDF%
INT-LOOPGR (232 Seqs.)	1.07E-06	4.61E-07	-6.06E-07	-56.8%
INT-LOOPPC (232 Seqs.)	6.21E-08	2.20E-08	-4.01E-08	-64.6%
INT-LOOPSC (232 Seqs.)	4.57E-07	1.84E-07	-2.72E-07	-59.7%
INT-LOOPWR (232 Seqs.)	6.89E-07	3.11E-07	-3.78E-07	-54.8%
Total	2.28E-06	9.79E-07	-1.30E-06	-57.0%

- Although T-H analysis was conducted only on SBO and SLOCA scenarios, DNC system is expected to provide decay heat removal function in other accident scenarios

DNC Risk Impact – SDP Case

- Significance Determination Process (SDP) is used to estimate risk significance of licensee performance problems
- Provide risk insight to help NRC determine the safety significance of inspection findings for the Reactor Oversight Process (ROP)



Incremental CCDP				
SDP Color	Green	White	Yellow	Red
Safety Significance	Very Low	Low to Moderate	Substantial	High
NRC Action Matrix	Column I	Column II	Column III	Column IV
NRC Increased Oversight/Inspection		Special Inspection	Augmented Inspection	Incident Investigation

DNC Risk Impact – SDP Case

- SDP Case: EDG-A failed to start, inoperable from 5/10/2019 9:00 AM to 5/19/2019 9:00 AM for 9 days
  - EDG-A failed to start (EPS-DGN-FS-DGA, P=2.86E-3 -> 1)

	Without DNC	With DNC	Delta	%
Baseline CDF	3.12E-05	2.28E-05	-8.34E-06	-27%
CDF'	8.64E-05	4.51E-05	-4.13E-05	-48%
Duration (day)	9	9		
CCDP	1.36E-06	5.48E-07		
SDP Color	White	Green		

- In this case, DNC design means a gain of about
  - **10 days** before crossing **1E-6 White** threshold
  - **98 days** before crossing **1E-5 Yellow** threshold

	Without DNC	With DNC	Delta	Benefits
t(CCDP=1E-6), day	7	16	**10**	$$
t(CCDP=1E-5), day	66	164	**98**	$$$

Conclusions

- **Thermal-hydraulic and risk assessment analyses of the DNC systems during an SBO were performed**
  - The DNC systems provide a large increase in coping time
    - About 65 hours for nominal RCP leakage
    - About 8 hours for maximum RCP leakage
  - Even though the DNC systems efficiently remove core decay heat via the SGs, they cannot make up for RCS inventory lost during a LOCA
    - The DNC systems become less effective as the break size increases
- **The DNC systems reduce the LOOP/SBO CDF by about 60%**
- **In a postulated SDP case, the DNC systems could increase the time before CCDP cross the SDP White and Yellow color threshold**
  - A gain of 10 days for a CCDP of 1.0e-6 (SDP White color threshold)
  - A gain of 98 days for a CCDP of 1.0e-5 (SDP Yellow color threshold)