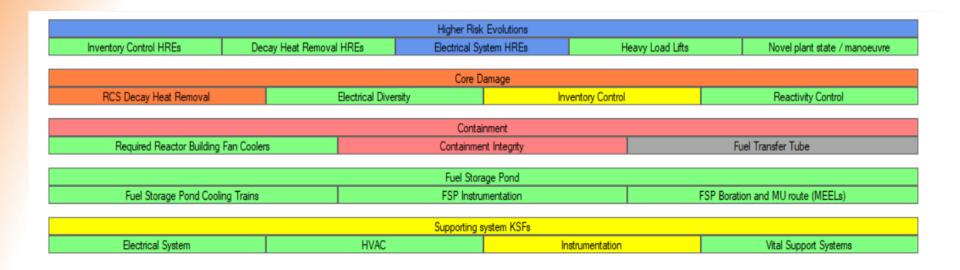
Design and Development of an Outage Planning and Risk Model



Ruth Freedman



Project Overview

- Sizewell B currently use ORAM for outage planning and management
 - Qualitative risk assessment model (QLRA) based on Defence in Depth (DiD) principles
 - Software no longer supported
 - Approach requires judgement, difficult to assign rules consistently
- Jacobsen developing a new model in RiskWatcher to replace the ORAM model
 - Integrate probabilistic and deterministic models in RiskWatcher
 - Based on Tech Specs and updated Minimum Essential Equipment Lists (MEELs)
 - Developed in line with international best practice based on research and guidance from the EPRI Configuration Risk Management Forum



Why Defence in Depth?

- During outage need to be able to perform refuelling, testing and maintenance whilst maintaining nuclear safety
 - A relatively dynamic situation, passing through multiple configurations
 - Different configurations or outage activities will impact plants ability to support key safety functions
 - Careful planning in advance to achieve optimum schedule whilst minimising time spent in reduced DID conditions
 - Quick response required to emergent conditions
- Communicating risk and required actions
 - Rapid visualisation using DID models
 - Meaningful measure of risk to managers and operators during the outage
 - Focuses management attention
 - General awareness on plant at time of increased risk
 - Can immediately understand if an action or activity will challenge a safety function
 - Understand dependencies (impact of support systems on KSFs)
 - Can link coloured endstates to recovery actions and configuration risk procedures



DID for Shutdown

- DID approach for shutdown first set out in NUMARC 91-06
 - Key Safety Functions
 - Decay Heat Removal Capability (including SFP)
 - Inventory Control
 - Reactivity Control
 - Containment Closure
 - Electrical Power Availability
 - Higher Risk Evolutions
 - Activities or configurations in which the plant is more susceptible to an event causing the loss of a KSF
 - Contingency planning and compensatory risk management actions linked to endstates to maintain or restore DID



DID for Shutdown

- NUMARC DID approach widely implemented across the industry and was used at Sizewell in the development of the ORAM model
- More recently EPRI have set up the Configuration Risk Management Forum and have developed guidance for QLRA assessments
 - Enables peer review and assessment of quality of approach
 - Consistency across the industry
 - Implementation of best practice
- Since the original guidelines were published, the understanding of the risks has evolved. Additional safety functions are now typically tracked:
 - Decay Heat Removal Capability
 - Inventory Control
 - Reactivity Control
 - Containment Closure
 - Electrical Power Availability

- Vital Support Systems
- Spent Fuel Pool
- Instrumentation
- HVAC

Techniques for reporting the overall outage risk have also improved to ensure they
 are more meaningful



Defence In Depth Metrics

COLOR	METRIC	STATUS OF SAFETY FUNCTION
GREEN	ACCEPTABLE	Very high or maximum level of DID. Lowest risk level. Configurations with this DID do not require additional actions to manage risk (i.e. normal work controls are sufficient).
YELLOW	REDUCED	Adequate DID. Slightly elevated risk level, but still relatively low risk. Configurations with this DID may take actions to minimize the duration of exposure and/or implement compensatory actions to reduce risk.
ORANGE	MINIMAL	Reduced DID. Elevated risk, but tolerable for short durations. Configurations with this DID require detailed planning for the configuration including compensatory actions to minimize exposure time, and contingency planning to restore and/or protect alternate means of supporting the safety function. Typically represents the case where a single failure will result in loss of DID for the safety function.
RED	UNACCEPTABLE	Unacceptable DID characterized by the inability to support the safety function. Risk is unacceptably high and not tolerable for any duration. Typically represents a state that will not be planned for or entered voluntarily.

At Sizewell this is translated to entering an LCO condition (which does not necessarily mean inability to support the safety function)

Jacobsen analytics ENGINEERING RISK SOLUTIONS

Source: EPRI 1016231 – Development of a shutdown QRA Standard Dec 2007

Colour	DiD State	Technical Specification and MEELs Compliance
Green	Adequate	Tech Spec compliant and MEELs compliant (if MEELs contain additional requirements) OR In LCO condition that is not time limited, subject to completing the routine surveillance. Toggle must have been selected to acknowledge LCO condition
Yellow	Reduced	Tech Spec compliant (but not MEELs) OR In LCO condition with ACT >= 31 days. Toggle must have been selected to acknowledge LCO condition
Orange	Minimal	In LCO condition with ACT between 24 hours and 31 days. Toggle must have been selected to acknowledge LCO condition OR Operational Commitment not met
Red	Unacceptable	In LCO condition with ACT >= 24 hours and no toggle selected OR In LCO condition with ACT < 24 hours
Grey	N/A	Plant is in a state for which the compliance assessment is not applicable. For example, when the plant is at power, the metrics all show as grey

Proposed End State Metrics for Sizewell RiskWatcher Model



Sizewell model development

- End state criteria have been consistently applied to every Tech Spec and MEELs requirement and presented in tabular format to aid fault tree development.
- Have included nested indicators down to component level (red = inoperable, green = operable)
- MEELs have undergone a thorough review by station (supported by quantitative RW calculations)
- New approach for presenting overall risk based on EPRI guidance, KSFs split into frontline and secondary KSFs and grouped into plant metrics

			Indicator								
Level	Indicator	Modes	Description	Grey	Red	Orange	Yellow	Green	Components	Fault Tree	Notes
							At least one level 2			6 DD DU	
						At least one level 2	indicator is yellow	All level 2		\$_DD_DH \$_DD_DH_O	
		Mode 5	RCS Decay Heat	Mode not	At least one level 2	indicator is orange	(and none are orange	indicators are		\$_DD_DH_Y	
1	1	Mode 6	Removal	applicable	indicator is red	(and none are red)	or red)	green		\$ DD M0-4 G	
										cohe	sen
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Plant Metrics

- Core Damage (Analogous to Level 1 PSA risk metric)
 - Combination of Decay Heat Removal, Inventory Control and Reactivity Control.
 - One yellow KSF can be averaged to overall green if at least 2 other KSFs are green.
 - Red or orange conditions are not average to lower risk in high-level metric.
- Containment (Analogous to Level 2 PSA risk metric)
- Spent Fuel Pool
- Secondary KSFs (Supporting systems)
 - Shows the highest risk end state of all the contributing KSFs
 - Must avoid 'double counting'. If front-line system is yellow because of its support system, we don't want to count this reduction in DID twice when calculating outage risk.



Higher Risk Evolutions (HREs)

- "Higher Risk Evolutions"(HREs) are:
 - Outage activities, plant configurations or conditions during shutdown where the plant is more susceptible to an event causing the loss of key safety function.
- EPRI guidance suggests increasing risk level by 1 or 2 during HRE
 - For SZB tool, HREs will be displayed as separate indicators on the DID interface using the blue colour
 - This will be a clear indicator to the operator of an HRE but will not mask any other information shown in the KSF indicators
 - MEELs and Tech Specs more restrictive for mid-loop so don't want to 'double count'
 - Power supplies which cannot be EDG backed will be assumed to fail when an Increased risk of LOOP or National Grid activities HRE is applied

				Higher Risk Evolutions					
	Inventory Control HREs	ĺ	Decay Heat Removal HRE	S		Electrical System HREs		Heavy Load Lifts	Novel plant state/manoeuvre
Draining of the Reactor Coolant System Level below 25% in the Pressuriser	Filling up from 965mm below flange to >25% in the pressuriser or from Mid-loop to 965mm below flange	Whilst at 965mm below flange in Mode 6 Head On, to start of filling of refuel pool, Mode 6 Head Off.	Whilst at 965mm below flange to Mode 5	All operations at Mid-loop to completion of Not Intact	National Grid activities	Increased risk of LOOP	Integrated Safeguards Actuation Testing (ISATs)		



DiD Over Time

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Input Overview	Systems and Sub-systems	Note De	efence-in-Depth over Tin	le			
Risk Evaluation	Higher Risk Evolutions						
Risk Evaluation	Inventory Control HREs						
Defence-in-Depth	Decay Heat Removal HR	Es					
Test Times	Electrical System HREs						
Test Times	Heavy Load Lifts						
Equipment Importance	Novel plant state/manoeu						
	Core Damage						
	- RCS Decay Heat Remove	al 🛛					
	Electrical Diversity						
	- Inventory Control						
	Reactivity Control						
		·					+
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	Event History Log						
	Note Event time point	Event	ID	Description	Last Edit	Edited By	State
	24/09/2019 11:34:27	EF ON	HRE_31_EP1	National Grid activities	24/09/2019 11:34:34	sa	
	24/09/2019 11:32:40	Config. ON	XX_3.7.13.D	Toggle 3.7.13.D-24 applied - CAS accumulators	24/09/2019 11:32:49	sa	
	24/09/2019 11:31:09	TAKE OUT	1KK-T06B	**DID ONLY** CAS Accumulator 1KK-T06B	24/09/2019 11:31:20	sa	
	24/09/2019 11:31:09	TAKE OUT	1KK-T06A	**DID ONLY** CAS Accumulator 1KK-T06A	24/09/2019 11:31:20	sa	
	24/09/2019 11:29:29	Config. ON	EJ_TRAINA	RHR Train A running in Modes 4-6 (shutdown)	24/09/2019 11:29:40	sa	
	24/09/2019 11:26:25	TAKE OUT	1KJ-K02-2	EDG 2 ENGINE 1KJ-K02-2	24/09/2019 11:26:43	sa	
	24/09/2019 11:26:25	Config. OFF	KJ_SEIS_2	EDG2 not claimed in seismic event	24/09/2019 11:26:43	sa	
				EDG2 not claimed in seismic event		sa	
	24/09/2019 11:26:09	Config. ON	KJ_SEIS_2	EDG2 not claimed in seismic event	24/09/2019 11:26:18	Sd	
	24/09/2019 11:26:09 24/09/2019 11:25:59	Config. ON Config. ON	KJ_SEIS_2 EN_A	RBS pump A aligned for RHR operation	24/09/2019 11:26:18 24/09/2019 11:26:06	sa	



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Input Overview				PCS Deeper	Heat Removal	1		Electrical		Cole I		nventory Cont	ml				Paneti	vity Control		Equipm	ent out	of Service	
			Province Required Province											1	Note ID		Description						
Risk Evaluation			Steam Audian Required Steam CAS Required Safety ECP.RCP DBUE Refuel Pool													1EJ-I			AT REMOVAL PUMP A 1EJ				
Defence-in-Depth		Required RHR trains	Generators - Auxiliary Condensate Veneratori accumulator HHSI and Woldoop injection Seal Make-up Clean up Pump IOC RWST HHSI/CVCS Dilution Emergency is aligned to curve Storage Overated s and CVCS Transmitten Mection pump Pump IOC RWST /BATs Block											RWST	1KJ-I	K02-2	EDG 2 ENGINE	1KJ-K02-2					
Test Times			is aligned to TDAFW Sitem Storage System Tanks Peleir sand CVCS pumps Tiansmitters Accumulator (0C 1370.1) (MEELs) (0C 1370.1) (MEELs) 1370.8)																				
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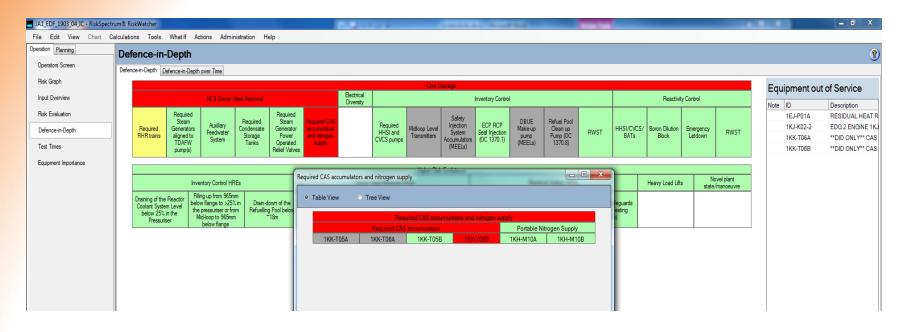
- Main screen
 - MEELs requirement for DHR not met (yellow colour)
 - Some requirements not applicable in current plant configuration (grey)
- Pop-up
 - Required pump not EDG backed (yellow colour)
 - One pump out of service but not required (red colour does not propagate up)
 - One pump not aligned for this function (grey colour)



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File Edit View Chart Calculations Tools What If Actions Administration Help

Operation Planning	Def	ience-ii	n-Depth											
Operators Screen	Defer	nce-in-Depth	Defence-in-De	pth over Time										
Risk Graph										Core	Damage			
Input Overview				RCS Decay	Heat Removal			Electrical Diversity				Inventory Co	ntrol	
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Test Times		TH T T U UII O	TDAFW pump(s)	System	Tanks	Operated Relief Valves	nitrogen supply		pumps	Transmitters	Accumul s (MEE	ator 100 1370		1370.8)
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							(H)	/EES Sep grou	ip 2 (EDG Bac	ked for MEEL	.s)			
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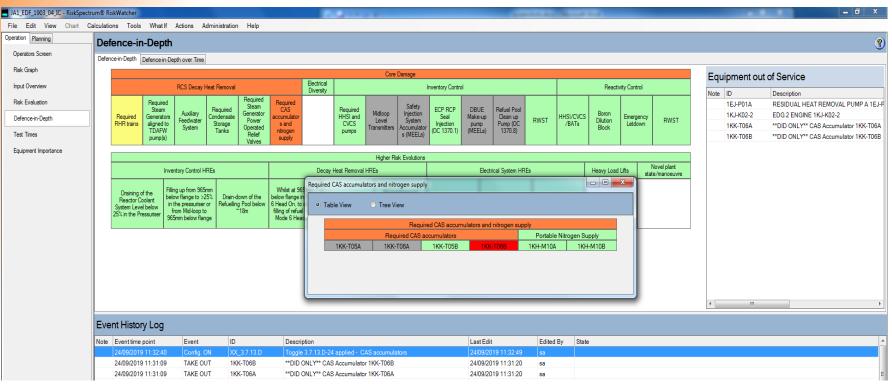


- Main screen
 - Tech Spec requirement not met (red)
 - MEELS requirement not met as per example 1 (yellow)
 - Some requirements not applicable in current plant configuration (grey)
- Pop-up
 - Required accumulator inoperable (red)
 - Two accumulators not required (grey)



					Core E)amage					
emoval			Electrical Diversity				Inventory Control				
quired Jensate prage anks	Required Steam Generator Power Operated Relief Valves	Required CAS accumulators and nitrogen supply		Required HHSI and CVCS pumps	Midloop Level Transmitters	Safety Injection System Accumulators (MEELs)	ECP RCP Seal Injection (OC 1370.1)	DBUE Make-up pump (MEELs)	Refuel Pool Clean up Pump (OC 1370.8)	RWST	HHSI/CV BATs
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- Main screen
 - In Tech Spec condition with action completion time of less than 31 days and more than 24 hours (orange)
 - MEELS requirement not met as per example 1 (yellow)
 - Some requirements not applicable in current plant configuration (grey)
- Pop-up
 - Toggle applied (orange)
 - Required accumulator inoperable (red)
 - Two accumulators not required (grey)



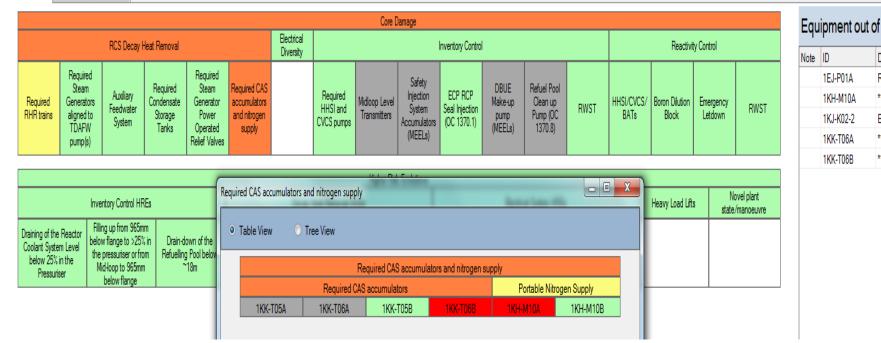
								Core	Damage								
		RCS Decay	Heat Removal			Electrical Diversity			l	nventory Contro	l				Reacti	vity Contro	bl
Required RHR trains	Require Stean Generat aligned TDAF\ pump(n Auxiliary ors Feedwater to System	Required Condensate Storage Tanks	Required Steam Generator Power Operated Relief Valves	Required CAS accumulator s and nitrogen supply		Required HHSI and CVCS pumps	Midloop Level Transmitters	Safety Injection System Accumulator s (MEELs)	ECP RCP Seal Injection (OC 1370.1)	DBUE Make-up pump (MEELs)	Refuel Pool Clean up Pump (OC 1370.8)	RWST	HHSI/CVCS /BATs	Boron Dilution Block	Emerge Letdov	ncy vn
								Higher Ri	sk Evolutions								
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Defence-in-Depth

Defence-in-Depth Defence-in-Depth over Time



- Main screen (as example 3)
- Pop-up
 - As example 3 PLUS a required nitrogen supply inoperable (red)
 - Toggle applied 31 days to restore nitrogen supply (yellow).



							Core E)amage						
	RCS Decay	Heat Removal			Electrical Diversity				Inventory Contro					
Require RHR tra	Auxiliary Feedwater System	Required Condensate Storage Tanks	Required Steam Generator Power Operated Relief Valves	Required CAS accumulators and nitrogen supply		Required HHSI and CVCS pumps	Midloop Level Transmitters	Safety Injection System Accumulators (MEELs)	ECP RCP Seal Injection (OC 1370.1)	DBUE Make-up pump (MEELs)	Refuel Pool Clean up Pump (OC 1370.8)	RWST	HHSI/CVCS/ BATs	Bord

			1.2					
Inventory Control HREs	Kequ	ired CAS accumulators	and nitrogen supply			from a loss of		
Draining of the Reactor Coolant System Level the pressuriser or from Refuelling Por	the	Table View 🔘	Tree View					ľ
Pressuriser Mid-loop to 965mm ~18m			Re	quired CAS accumu	lators and nitrogen su	pply		
below flange			Required CAS	accumulators		Portable Niti	rogen Supply	
		1KK-T05A	1KK-T06A	1KK-T05B	1KK-T06B	1KH-M10A	1KH-M10B	



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Risk Graph									Core Damage									Equipment	t out of	Service		
Input Overview			RCS Decay	Heat Removal		Ele	ctrical rersity			Inventory Cor	trol				Reacti	ivity Control		Note ID		Description		
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Defence-in-Depth	Re	quired Gener R trains aligne TDA	ators Auxiliary	Condensate Storage	Generator Power	accumulator s and	HHSI	and CS _	Midloop Injecti Level Syste	m Seal	Make-up pump	Clean up Pump (OC	RWST	HHSI/CVCS /BATs	Boron Dilution Block	Emergency Letdown	RWST	1KJ-K02- 1KK-T06/		DG 2 ENGINE 1KJ-K *DID ONLY** CAS Ad		
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		tem Level below in the Pressurise	from Mid-loop t 965mm below fla	o 0 Doe	ng Pool below ~18m	filling of refuel pool Mode 6 Head Off.	of below flange 5	to Mode	completion of No Intact	t INational Gnd	activities					-	_					
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 - HRE ٠
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 - Exar
- Pop-up ٠
 - Pow HRE
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	Core Da	amage											Eau	ipment ou	ut of Service
Inventory Control						Reactivity Control						Note	-	Description	
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	Level	System	Seal Injection											1KJ-K02-2 1KK-T06A	EDG 2 ENGINE 1KJ-K02-2 **DID ONLY** CAS Accumula
		Accumulator s (MEELs)	(OC 1370.1)											1KK-T06B	**DID ONLY** CAS Accumula
														TRICTOOD	DID ONET CAS Accumula
	Higher Risk	Evolutions													
y Heat Removal HREs				Electrical System HREs							el plant anoeuvre				
Whilst at 960mm M															
	Mid-loo	All operations at Mid-loop to completion of Not	National Grid activities		Increase	Require	ed HHSI and	CVCS pumps	CS pumps						
	Inta	act				⊙т	able View	Tre	e View						
						Descri	ption				Note	Status			
						🗏 Req	uired HHSI	and CVCS p	umps						
						-⊞ H	HSI Train A								
							HSI Train B								
							HSI Train C								
							HSI Train D								
								A and suppo							
								B and suppo	rting systems	\$					
							VCS Flowp		DM	о т					
				Las	Edit			rom the BATs	and RMUW	81					
ivities				24/0	9/2019 1		·⊞ BAT Sup ·□ RMUWS								
24 applied - CAS	accumulato	ors		24/0	9/2019 1										
AS Accumulator 1KK-T06B 24/09/2019			9/2019 1	- 1BL-T01											
AS Accumulator 1KK-T06A 24/09/2019 1			1BL-P01A / 1PG-S020												
ning in Modes 4-6 (shutdown) 24/09/2019 1			1BL-P01B/1PG-S028												
KJ-K02-2 24/09/201			9/2019 1	IBC-FCV0110B and supporting systems											
d in seismic event				24/0	9/2019 1			3-FCV0110B	a supporting	1 37310111					
d in seismic event				24/0	9/2019 11										



Thank You!

			Higher Risk Evolutions					
Inventory Control HREs	Decay Heat Remo	val HREs	Electrical System HREs	Heavy Load Lifts		Novel plant state / manoeuvre		
			Core Damage					
RCS Decay Heat Removal		Electrical Diversity		Inventory Control		Reactivity Control		
			Containment					
Required Reactor Building F	an Coolers		Containment Integrity		Fuel Transfer Tube			
			Fuel Storage Pond					
Fuel Storage Pond Coolin	g Trains		FSP Instrumentation		FSP Boration and MU route (MEELs)			
			Supporting system KSFs					
Electrical System		HVAC		Instrumentation		Vital Support Systems		

