BEPU Evaluation for APR1400 MSLB Accident using Artificial Intelligence

Salama Obaid Alketbi
Abd El Rahman Abou El Ala
Osama Alatawneh
Muhammad Wazif
and Aya Diab

Korean Nuclear Society (KNS)

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Nuclear Safety and Thermal hydraulics Lab

Department of Nuclear Power Plant

KEPCO International Nuclear Graduate School

OUTLINES

- INTRODUCTION
- METHODOLOGY
- BEPU MODEL
- ARTIFICIAL INTELLIGENCE MODEL
- RESULTS AND ANALYSIS
- CONCLUSION

INTRODUCTION

APR1400 main steam line break (MSLB) → postulated design base accident

- As a result of the accident, the heat removal by the secondary system is increases.
- The RCS is excessively cooldown which may in turn increase in core reactivity.
- As a result, departure from nucleate boiling (DNB) may occur, causing heat to buildup and the fuel temperature to increase which threatens the fuel integrity.
- AI is used as an alternative data-driven approach to predict the plant response during MSLB accident given the underlying uncertainties.
- The figure of merit (FoM) in this study is the MDNBR.

GOAL AND OBJECTIVES

- Explores the applicability of Artificial Intelligence (AI) to predict the MDNBR during APR1400 MSLB Accident.

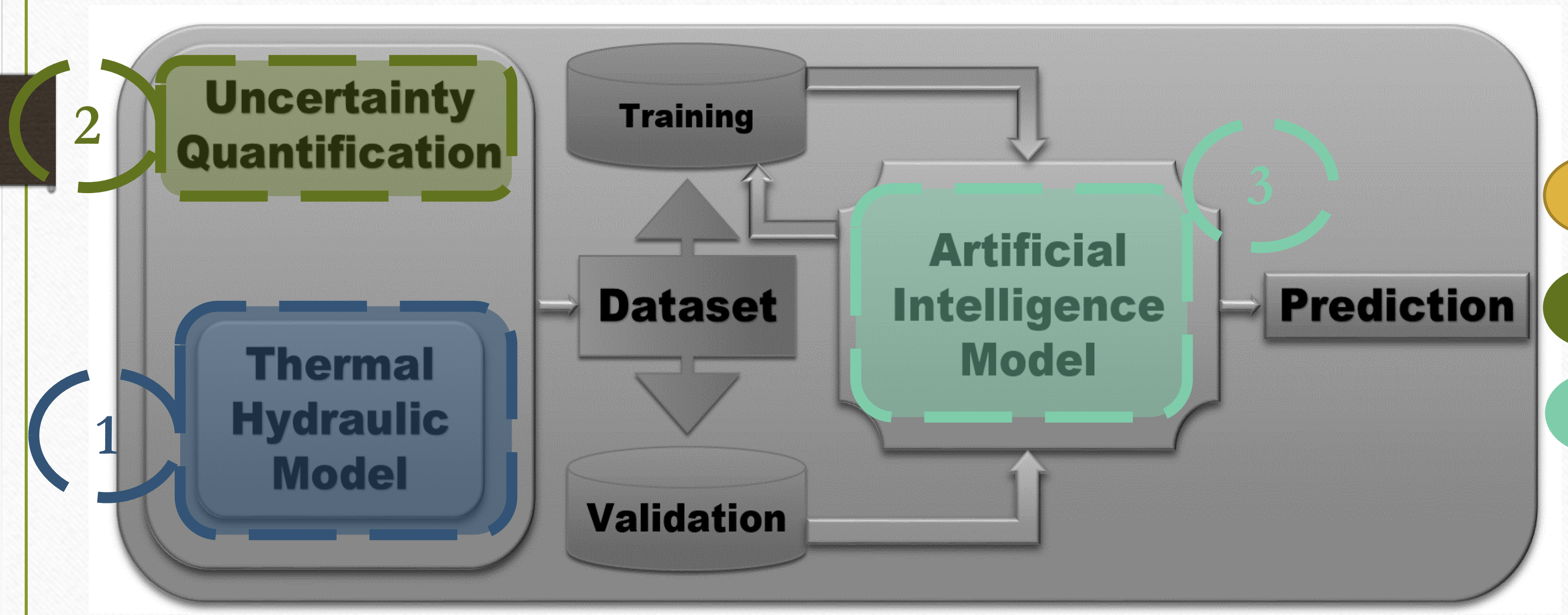
- To achieve it :

  - Develop BEPU model to provide a database of the thermal hydraulic response to train an Artificial Intelligence (AI) algorithm.

  - AI model is used as an alternative approach that relies on data-driven models to provide a fast design tool that can predict the MDNBR in APR1400 MSLB Accident.

METHODOLOGY

The methodology adopted in this work involves three building blocks:



1 Thermal hydraulic Model

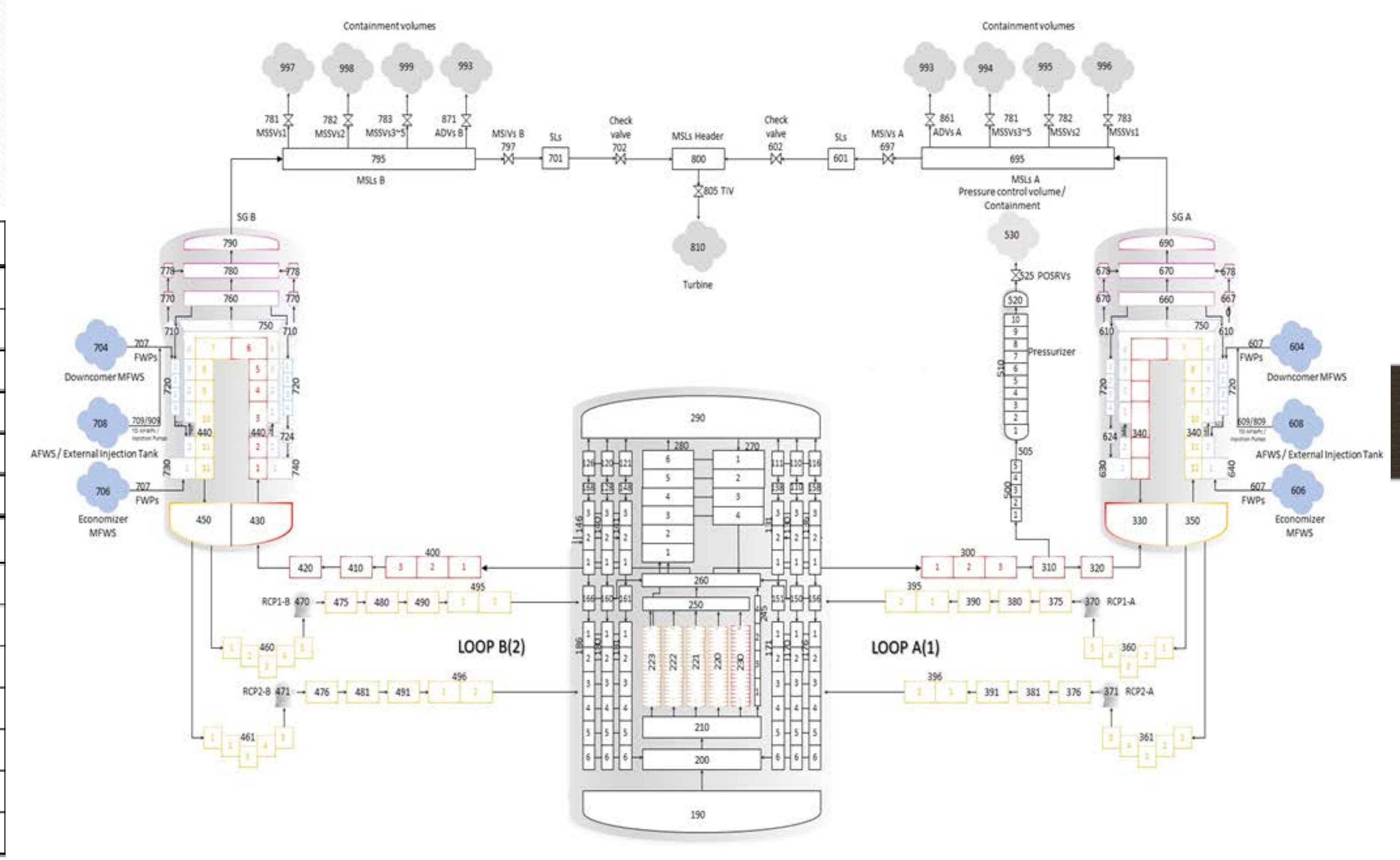
2 Uncertainty Quantification

3 AI Model

Thermal hydraulic model development

Reactor Coolant System (RCS)
Reactor Pressure Vessel (RPV)
2 Hot Legs
4 Cold Legs and four Reactor Coolant Pumps (RCPs)
Pressurizer (PZ)
Pressurizer Safety relief Valves (PRSVs)
Safety Depressurization System (SDS)
Secondary System
2 Steam Generators (SGs)
Main Feedwater System (MFWS)
Main Steam Line (MSL)
6 Secondary Main Steam Safety Valves (MSSVs)
2 Main Steam Line Atmospheric Depressurization Valves (MSL-ADVs)
2 Main Steam Line Isolation Valves (MSLIVs)
Turbine Bypass Valve (TBV)

APR1400 MSLB Systems and Components



APR1400 Nodalization

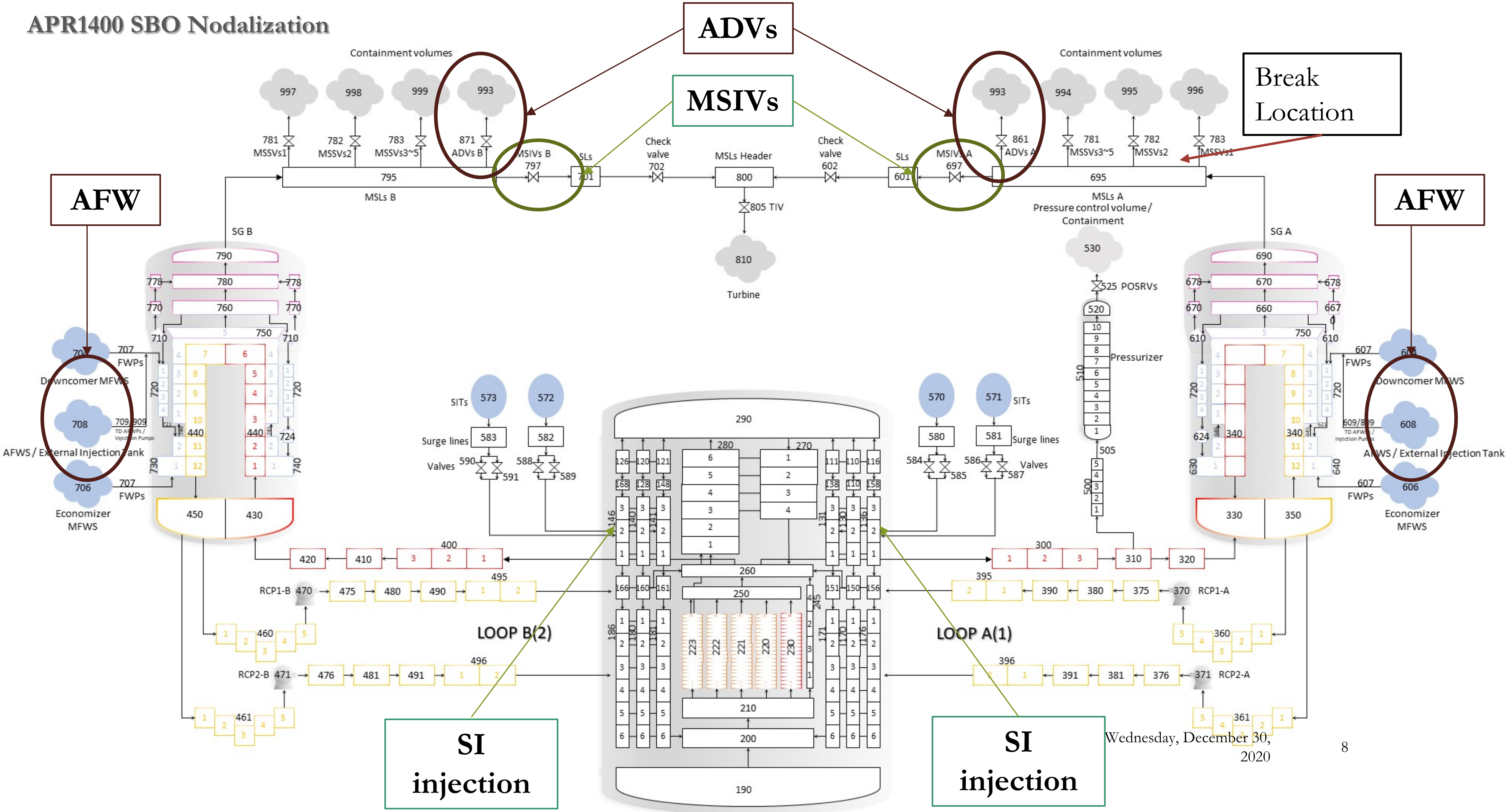
Thermal hydraulic model development

ACCIDENT SCENARIO

MSLB break → AFWP Starts for both SGs → Reactor Trip → MSIVs close → MFIVs close → Safety injection flow begins → Operator initiates cooldown (opens ADVs)

AFWP:	Auxiliary Feedwater Pump
RCP:	Reactor Coolant Pump
SG:	Steam Generator
MSIV:	Main Steam Isolation Valve
MFIVs:	Main Feedwater Isolation Valve

APR1400 SBO Nodalization

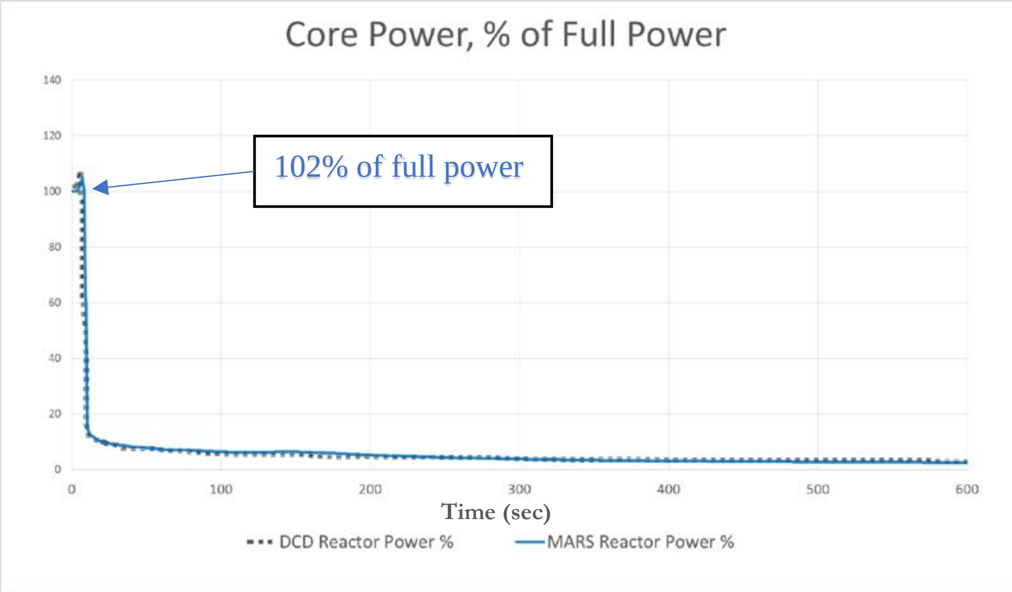


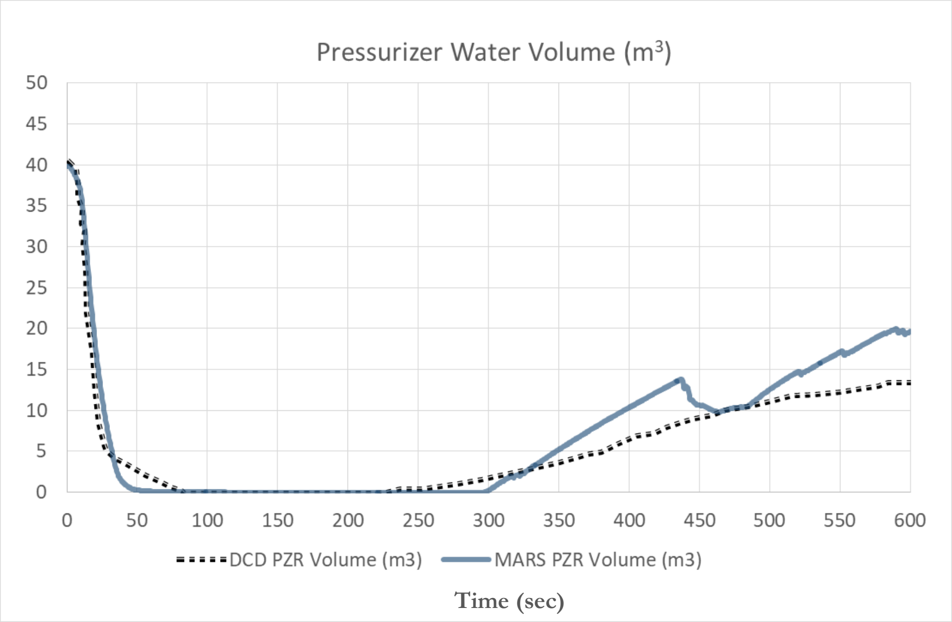
Thermal hydraulic model development

BASE CASE VALIDATION - Steady State

Parameter	Assumptions and Initial Conditions			
	DCD	MARS	Variance	%
Initial core power level, MWt	4,062.66	4,062.66	-	0.0%
Initial core inlet coolant temperature, (°K)	568.15	572.53	4.38	0.8%
Initial core mass flow rate, kg /s	19,344.44	19,668.00	323.56	1.7%
Initial pressurizer pressure, Mpa	16.04	16.40	0.36	2.3%
Initial pressurizer water volume, m3	39.91	39.87	(0.04)	-0.1%
Initial SG liquid inventory per SG, kg	124,113	125,820.00	1,707.00	1.4%
Blowdown fluid	Saturated steam	Saturated steam	-	-
Blowdown area for each steam line, m2	0.119	0.119	-	-
Loss of offsite power	Not assumed	Not assumed	-	-

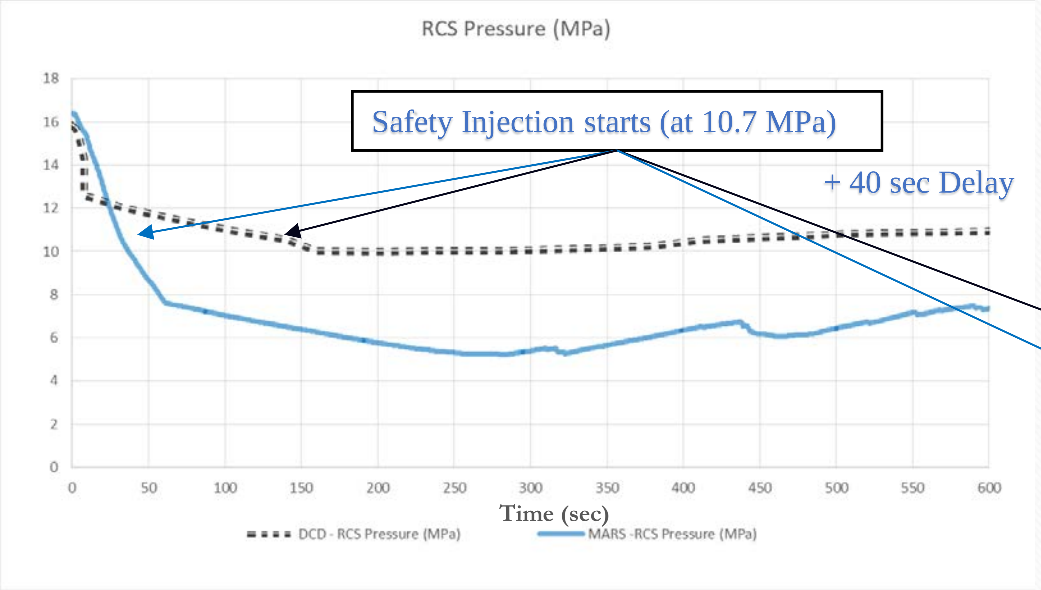
Thermal hydraulic model development

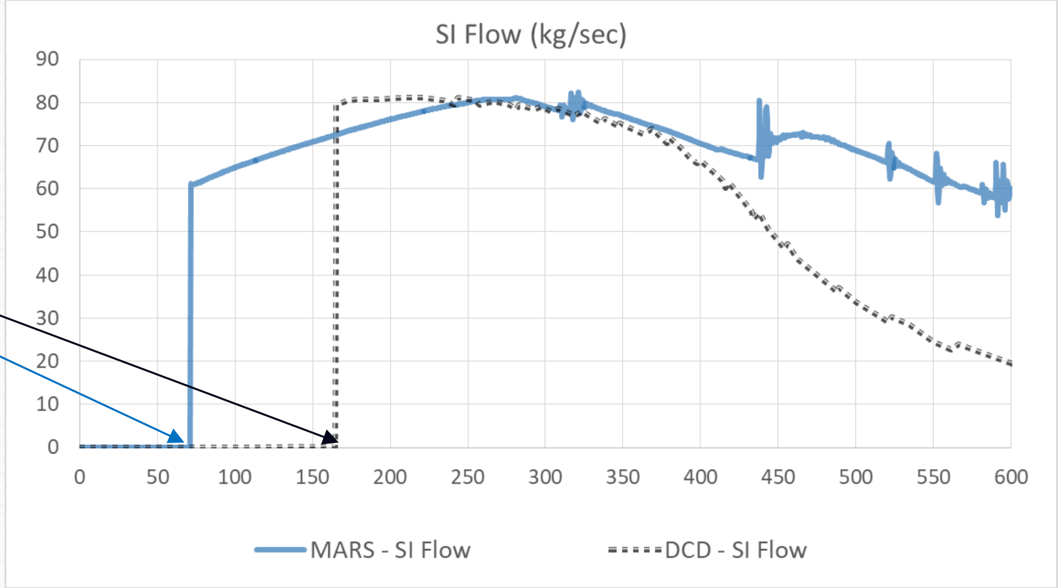




BASE CASE VALIDATION - Transient

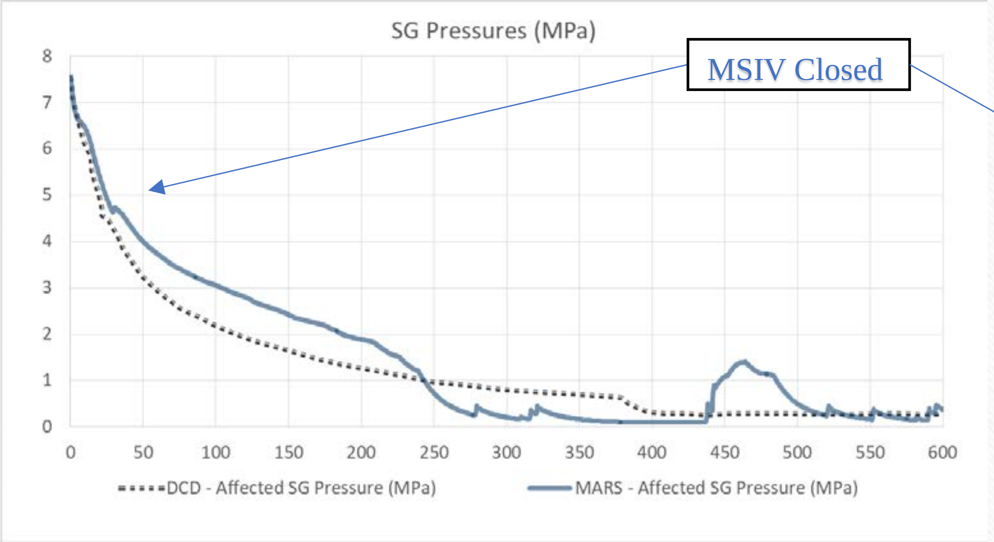
Thermal hydraulic model development



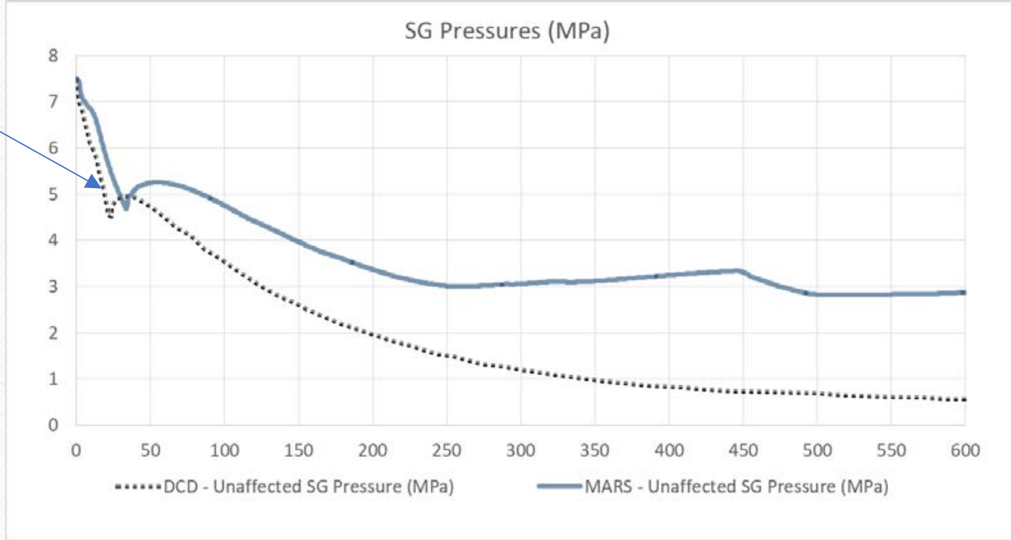


BASE CASE VALIDATION - Transient

Thermal hydraulic model development



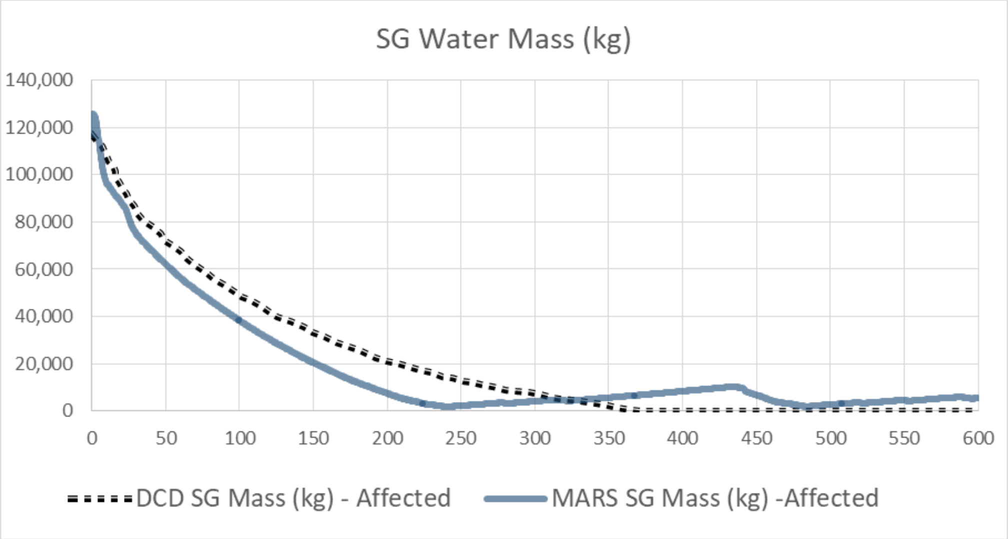
Affected SG



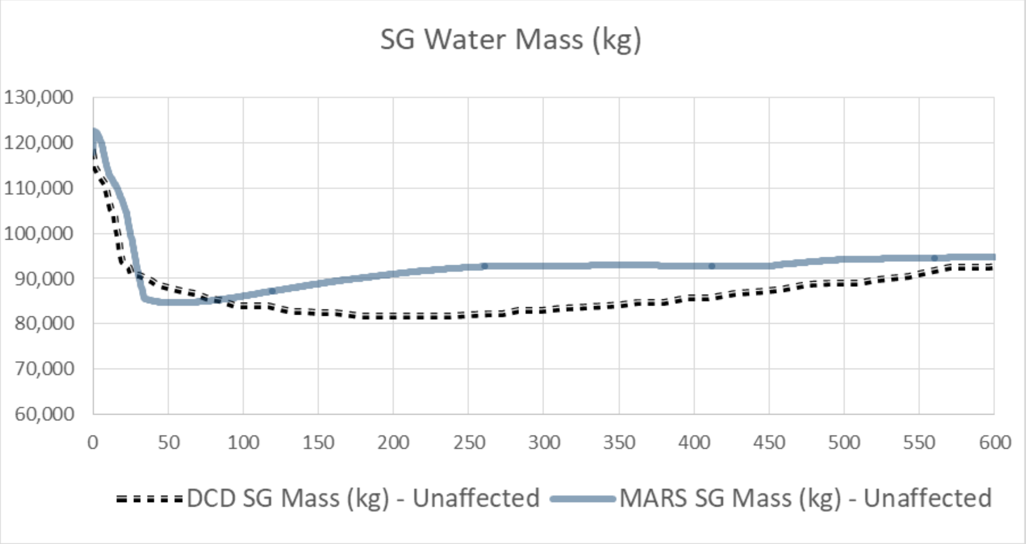
Unaffected SG

BASE CASE VALIDATION - Transient

Thermal hydraulic model development



Affected SG



Unaffected SG

BASE CASE VALIDATION - Transient

First Identifying input uncertainties

Second Propagating these uncertainties through a computational model (MARS-KS)

Third Performing statistical assessments on the resulting responses

Development of uncertainty quantification framework

Uncertainty parameters

No	Parameter	Distribution	Normalized			
			L	U	Mean	SD
1	SIT Temprature	Uniform	0.9	1.1	1	0.05
2	Core Decay Heat	Uniform	0.9	1.1	1	0.05
3	Core Conductivity	Uniform	0.9	1.1	1	0.05
4	Core Heat Capacity	Uniform	0.9	1.5	1	0.15
5	Break Area	Uniform	0.95	1.5	1	0.1375
6	Depressurization Valves Discharge Coefficient	Uniform	0.8	1.2	1	0.1
7	Break Discharge Coefficient	Uniform	0.6	1.4	1	0.2
8	Interphase heat transfer Coefficient	Uniform	0.9	1.1	1	0.05
9	Single phase Heat transfer coefficient	Uniform	0.9	1.1	1	0.05
10	Critical flow	Discrete	50	53	1	0.75
11	AFW flow rate	Uniform	500	800	1	75
12	MSIS setpoint	Uniform	851	975	1	31
13	Initial PZR pressure	Uniform	2000	2325	1	81.25
14	Initial SG inventory	Uniform	0.35	0.982	1	0.158
15	Safety injection delay time	Uniform	20	30	1	2.5
16	Initial PZR Liquid Volume	Uniform	0.219	0.6	1	0.09525
17	Flow Rate	Normal	0.01	1.01	1	0.25
18	Power	Normal	0.15	1.15	1	0.25
19	Inlet Temperature	Uniform	0.15	1.15	1	0.25
20	Subchannel Area	Normal	0.05	1.05	1	0.25
21	Nucleate boiling heat transfer coefficient	Normal	0.24	1.24	1	0.25
22	Interfacial drag coefficient (bubbly flow)	Normal	0.32	1.32	1	0.25
23	Interfacial drag coefficient (droplet flow)	Normal	0.26	1.26	1	0.25
24	Interfacial drag coefficient (film flow)	Normal	0.36	1.36	1	0.25
25	Outlet water pressure	Normal	0	0	1	0
26	Fuel pellet diameter	Normal	0.92	1.08	1	0.04
27	Cladding thermal conductivity	Normal	0.9985	1.0015	1	0.00075

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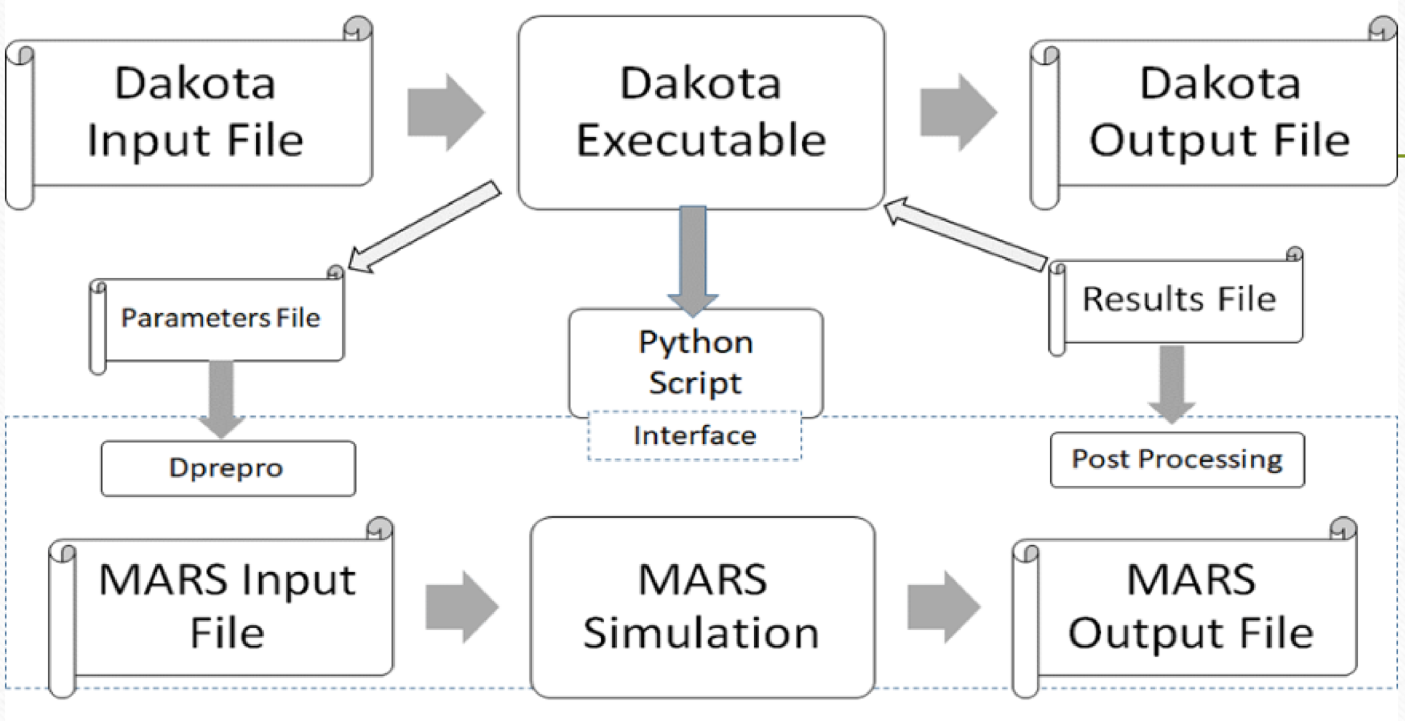
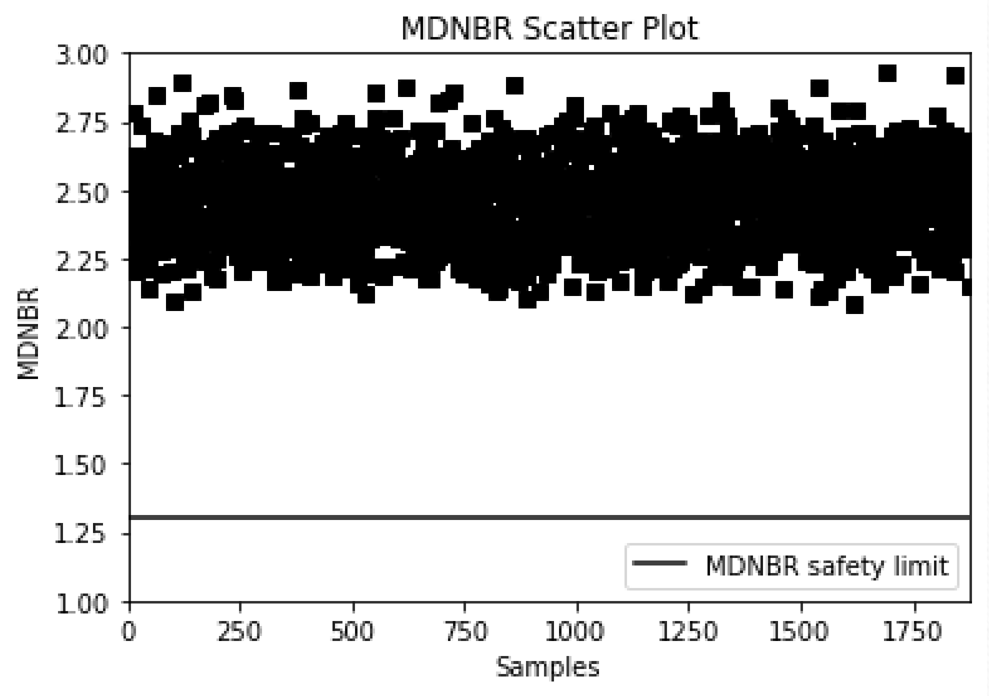
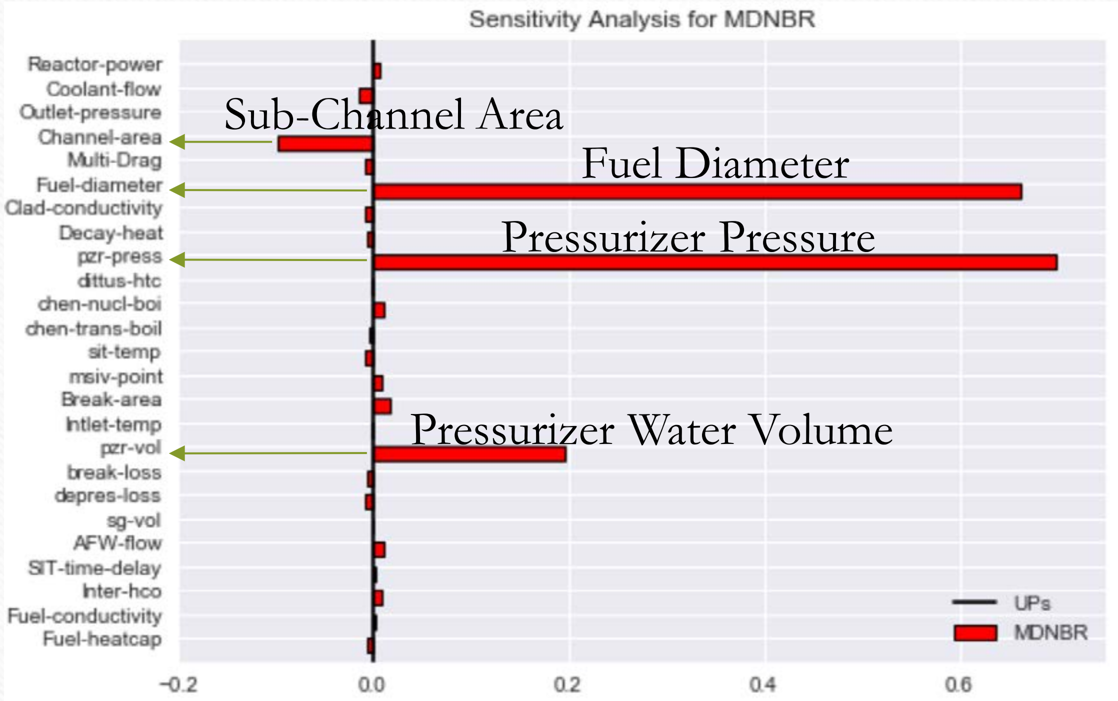
Development of uncertainty quantification framework



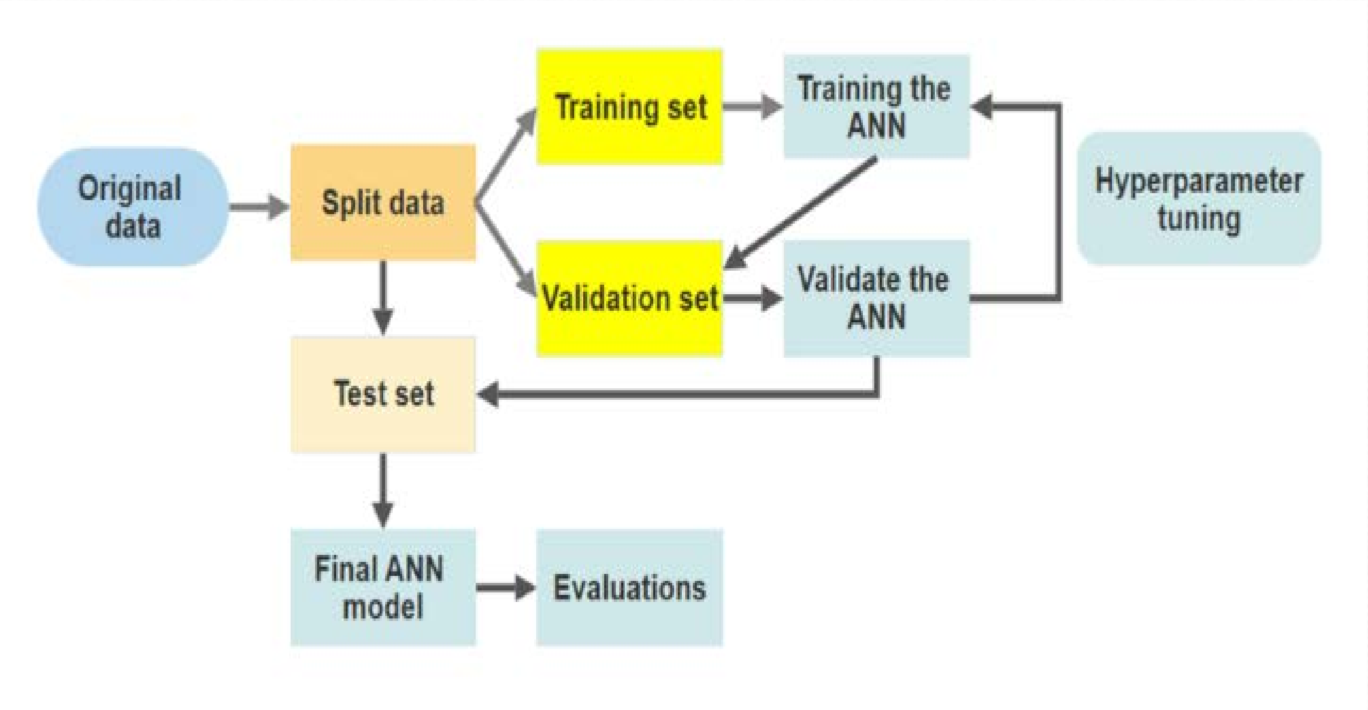
Uncertainty quantification framework

Result of the uncertainty quantification framework

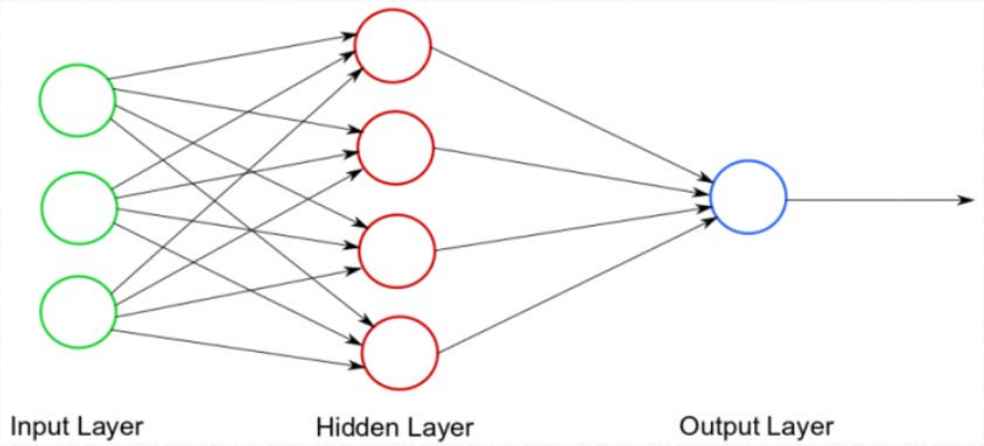




Artificial Intelligence AI Model



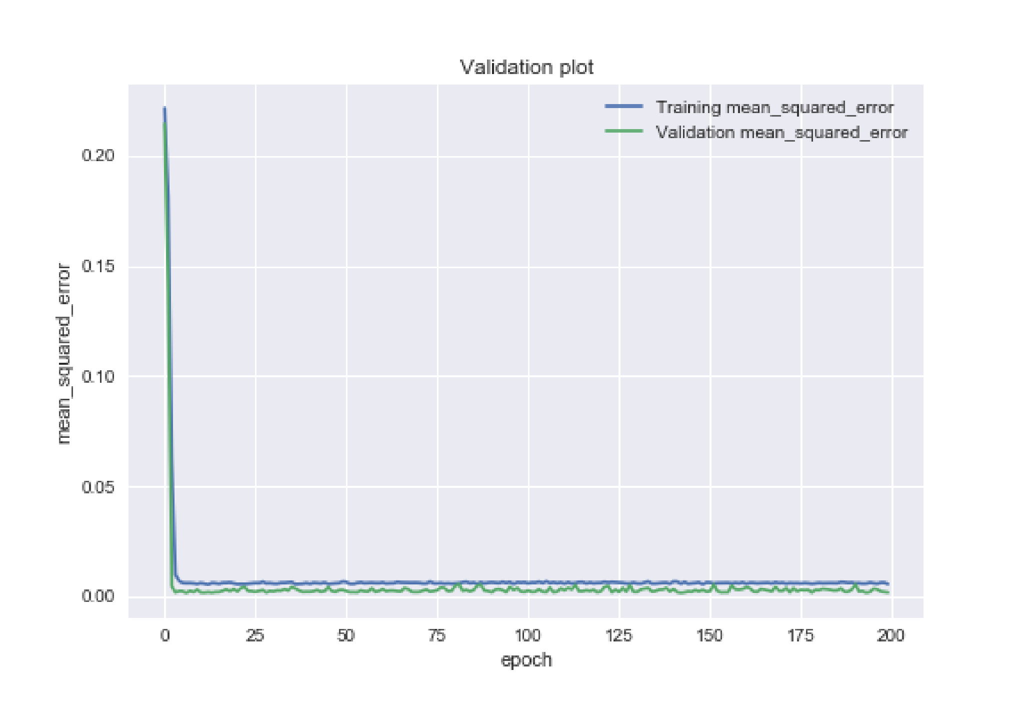
AI MODEL ARCHITECTURE



Hyperparameters dictionary

#	Hyperparameters	Search Boundary
1	Batch Size	2, 4
2	Hidden Layer Neurons	32, 64
3	Dropout Rate	0.6
4	Epochs	200
5	Optimizer	Adam, Nadam, RMSprop,SGD
6	Last Activation	relu, linear
7	Metric	mean_squared_error
8	Loss Function	mean_squared_error

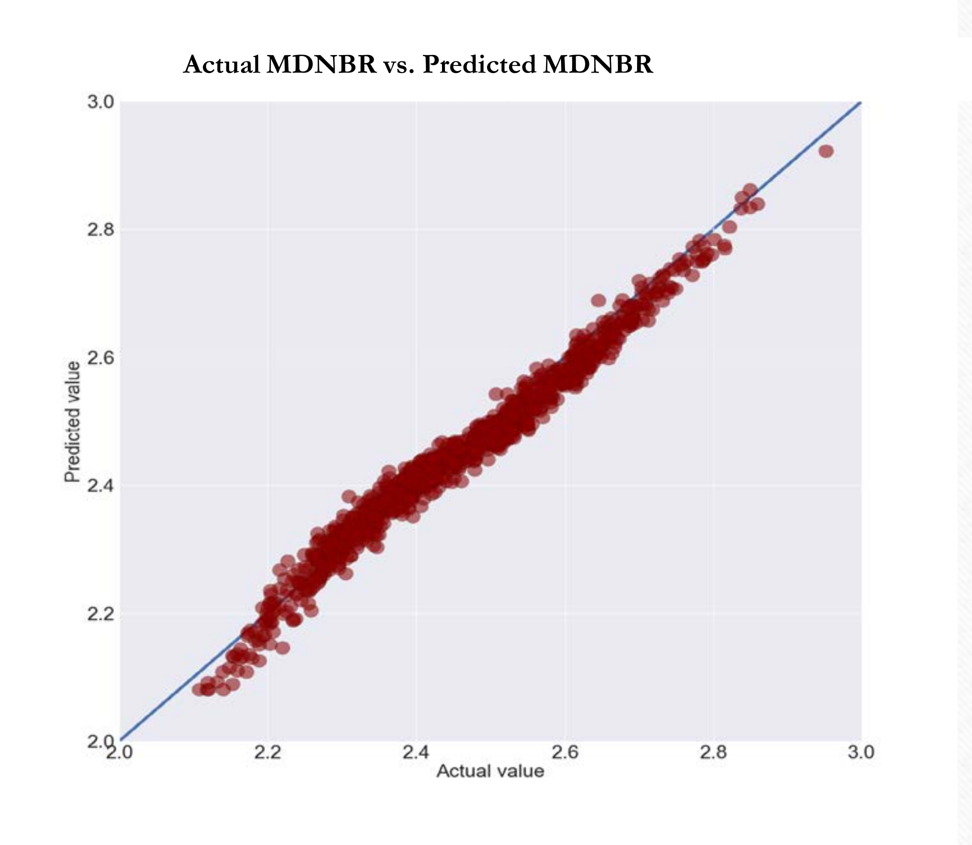
AI MODEL VALIDATION



mean_squared_error	**0.004629**
val_mean_squared_error	**0.000832**

Results and Analysis

#	Hyperparameters	Search Boundary
1	Batch Size	4
2	Hidden Layer Neurons	64
3	Dropout Rate	0.6
4	Epochs	200
5	Optimizer	SGD
6	Last Activation	relu
7	Metric	mean_squared_error
8	Loss Function	mean_squared_error



Conclusion

- The results of this research shows that APR1400 is robust enough to overcome MSLB accident.
- AI algorithm is capable of predicting MDNBR of APR1400 MSLB with very low error.
- Although the development of the AI algorithm is time-consuming; but once developed, the prediction can be obtained much faster than conventional deterministic methods.

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Thank You