Application of STAP to ESF-CCS

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Application of STAP to ESF-CCS

INTRODUCTION

Introduction

- For developing the I&C system of a nuclear power plant, more than thousands reports had been produced and had to be traceable through the lifecycle from the system requirements.
- Hazard analysis of complex systems(systems of systems) with traditional methods (FTA, HAZOP) was extremely difficult to justify the safety.
- Most hazards came from the wrong interaction of the components (SW, HW, Human).
- We applied the new hazard analysis technique (STPA) based on the new accident causality model (STAMP).

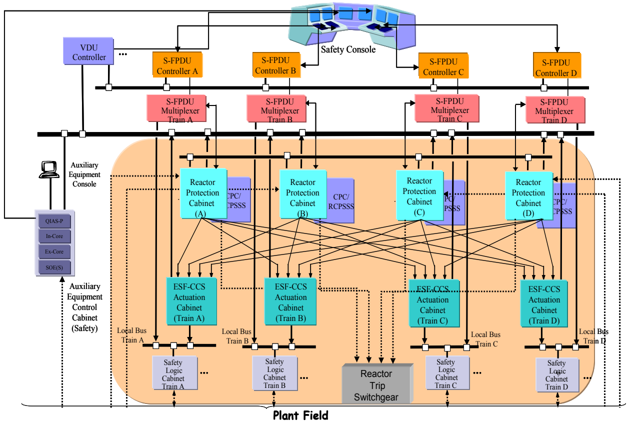
Application of STAP to ESF-CCS

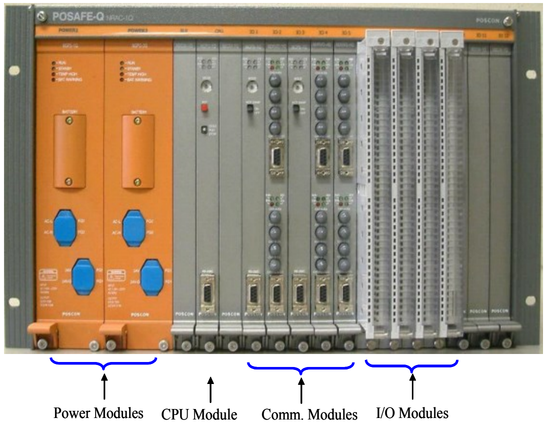
BACKGROUND

Background

Korea Nuclear I&C System (KNICS)

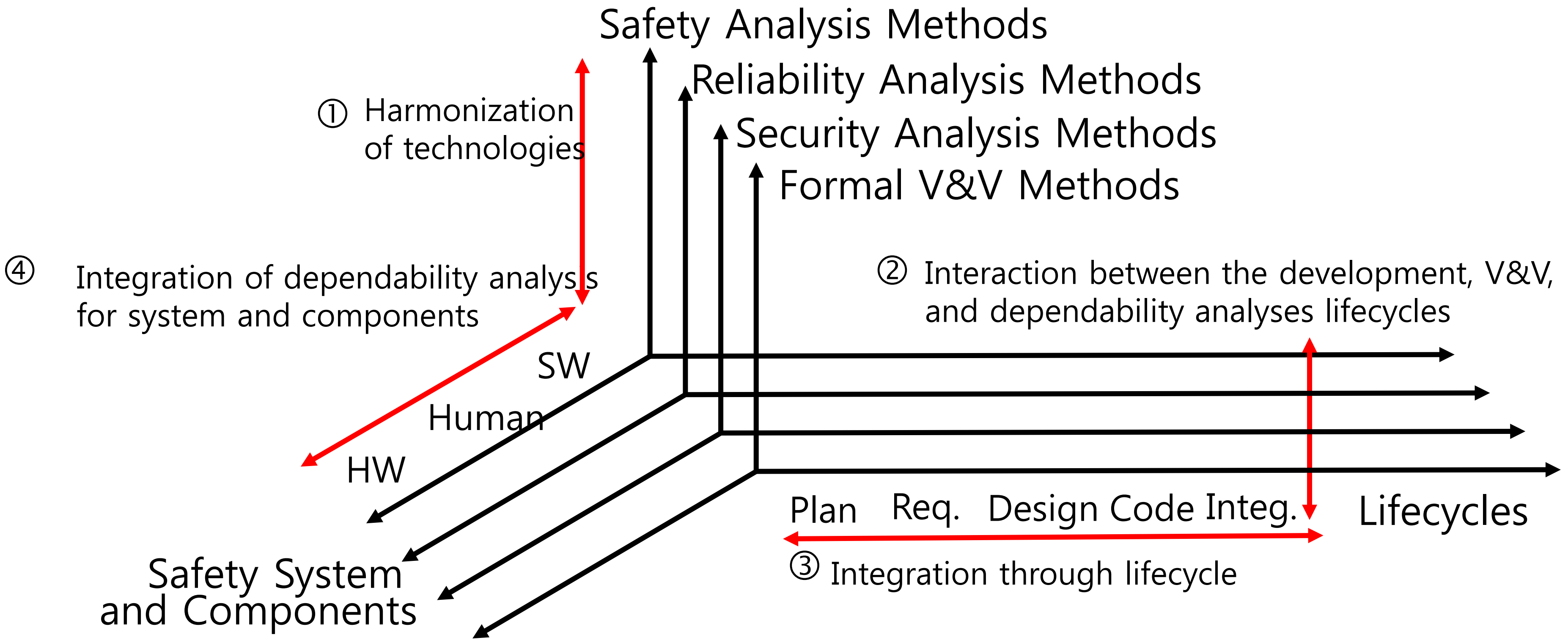
- Instrumentation and Control (I&C) systems and equipment for APR1400 Nuclear Power Plant (NPP)
- Period: July 2001 ~ April 2008 (7 years)
- Target
  - Fully digitalized I&C systems development for APR1400 (Shin-Ulchin units #1&2)
  - I&C upgrade for existing NPPs


Safety Console
VDU Controller
S-FPDU Controller A
S-FPDU Controller B
S-FPDU Controller C
S-FPDU Controller D
S-FPDU Multiplexer Train A
S-FPDU Multiplexer Train B
S-FPDU Multiplexer Train C
S-FPDU Multiplexer Train D
Auxiliary Equipment Console
QIAS-P
In-Core
Ex-Core
SOE(S)
Auxiliary Equipment Control Cabinet (Safety)
Reactor Protection Cabinet (A)
Reactor Protection Cabinet (B)
Reactor Protection Cabinet (C)
Reactor Protection Cabinet (D)
CPC/ CPSSS
CPC/ RCPSSS
ESF-CCS Actuation Cabinet (Train A)
ESF-CCS Actuation Cabinet (Train B)
ESF-CCS Actuation Cabinet (Train C)
ESF-CCS Actuation Cabinet (Train D)
Local Bus Train A
Local Bus Train B
Local Bus Train C
Local Bus Train D
Safety Logic Cabinet Train A
Safety Logic Cabinet Train B
Safety Logic Cabinet Train C
Safety Logic Cabinet Train D
Reactor Trip Switchgear
Plant Field



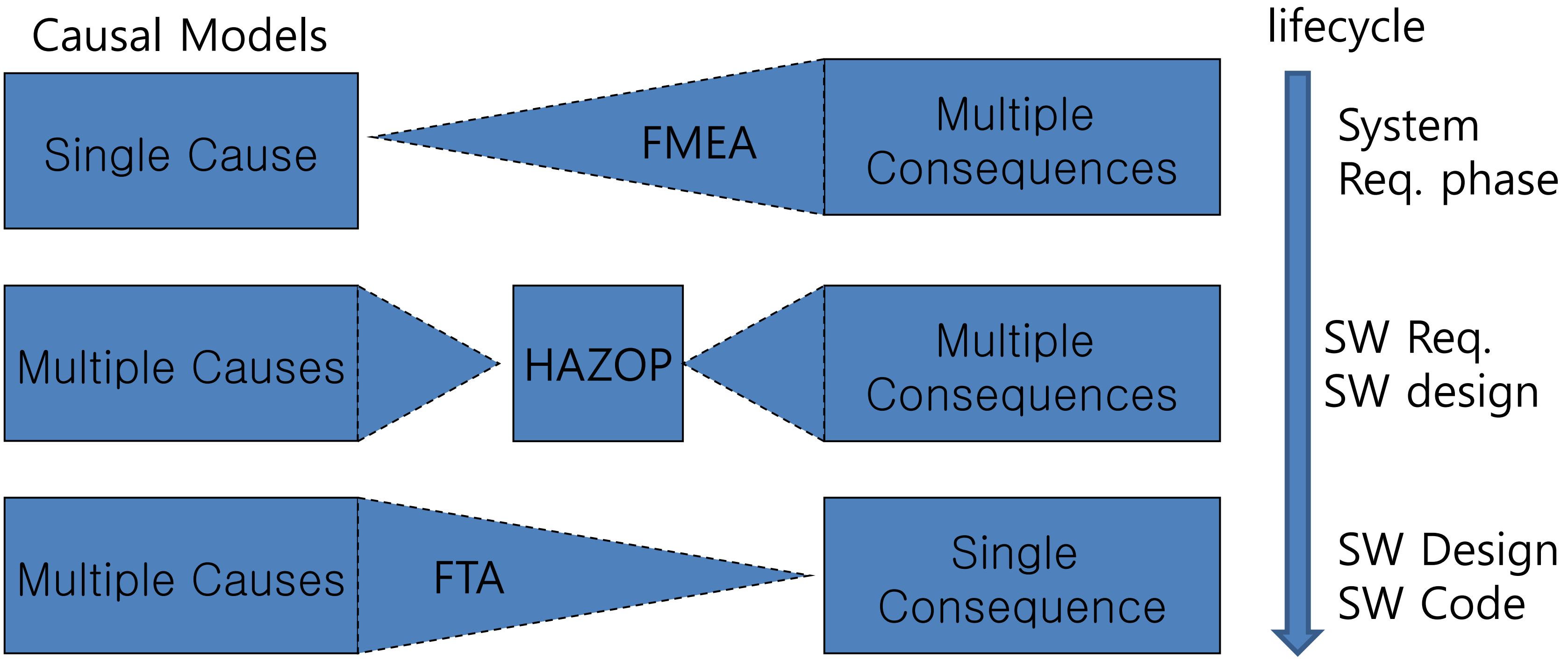
Background

KNICS Dependability Engineering


Safety Analysis Methods
Reliability Analysis Methods
Security Analysis Methods
Formal V&V Methods
① Harmonization of technologies
④ Integration of dependability analysis for system and components
② Interaction between the development, V&V, and dependability analyses lifecycles
SW
Human
HW
Safety System and Components
Plan
Req.
Design
Code
Integ.
Lifecycles
③ Integration through lifecycle

Background

Hazard Analysis of KNICS



ESF-CCS

- Engineered Safety Features-Components Control System
- To mitigates the consequences of design-basis or loss-of-coolant accident
- 8 Operational Functions

Function	Description
SIAS	Safety Injection Actuation Signal
CIAS	Containment Isolation Actuation signal
MSIS	Main Stream Isolation Signal
CSAS	Containment Spray Actuation Signal
AFAS	Auxiliary Feed-water Actuation Signal
CREVAS	Control Room Emergency Ventilation Actuation Signal
FHEVAS	Fuel Handling Area Emergency Ventilation Actuation Signal
CPIAS	Containment Purge Isolation Actuation Signal

ESF-CCS

Dependability of ESF-CCS

- Failure Mode and Effects Analysis (FMEA)
  - Reg. 1.70
  - IEEE Std. 352
- SW Hazard Analysis
  - IEEE Std. 7-4.3.2
- Unavailability Analysis (FTA)
  - MIL-HDBK-217F
  - NUREG-0492

Application of STAP to ESF-CCS

APPLICATION OF STAP

Application of STPA (0)

- Target: Three functions
  - **SIAS**, CSAS, and CREVAS
- Application process
  1. Identify hazardous states of the system.
  2. Develop the control structure of the system.
  3. (STPA Step 1) Identify the potential for inadequate control of the system that could lead to a hazardous state.
  4. (STPA Step 2) Determine how each potentially hazardous control action identified in step 1 could occur.

Application of STPA (1)

SIAS

Providing Emergency coolant w/ boron

- Hazard
  - Reactor core is damaged because the SIAS does not operate when the 4 events—LOCA, 2ndHSL, S/WP-Ex, or REA—occur.
- Safety constraint
  - The SIAS must operate when the 4 events—LOCA, 2ndHSL, S/WP-Ex, or REA—occur.

LOCA	Loss Of Coolant Accident
2ndHSL	Second Heat Sink Loss
S/WP-Ex	Steam- and Water-pipe explosion
REA	Rod Ejection Accident

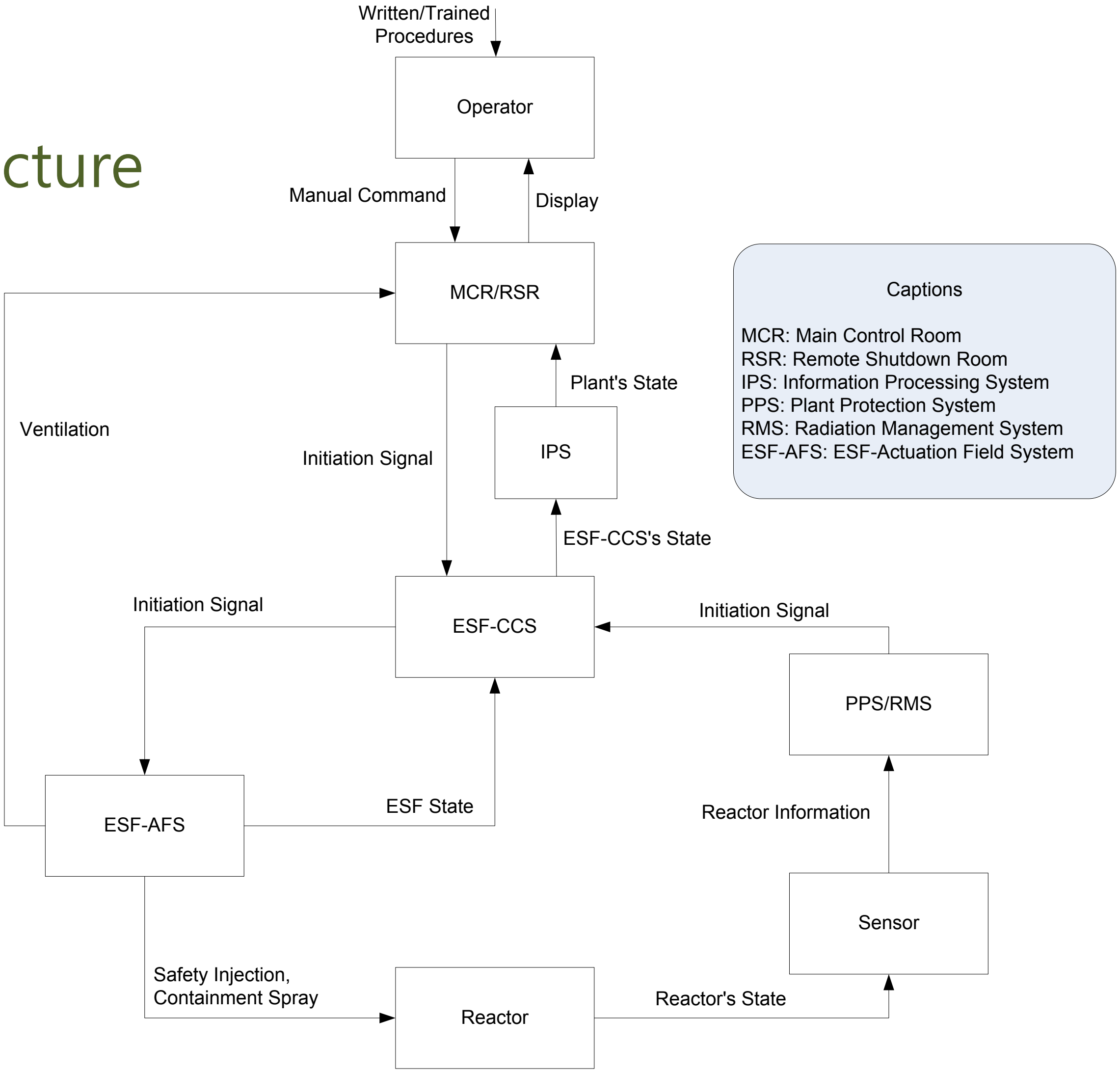
Application of STPA (1-1)

Hazards and Safety Constraints

Function	Hazard	Safety Constraint
SIAS	Reactor core is damaged because the SIAS does not operate when the 4 events—LOCA, 2ndHSL, S/WP-Ex, or REA—occur.	The SIAS must operate when the 4 events—LOCA, 2ndHSL, S/WP-Ex, or REA—occur.
CSAS	Heat removal and fission clean up fail when the three events—LOCA, S/WP-Ex, or the SIAS—occur.	The CSAS must operate when the three events—LOCA, S/WP-Ex, or the SIAS—occur.
CREVAS	Maintenance of pressure in a main control room fails when the two events—High-level radioactive at air intakes of MCR or the SIAS—occur.	The CREVAS must operate when the two events—High-level radioactive at air intakes of MCR or the SIAS—occur.

Application of STPA (2)

Safety control structure for the ESF-CCS

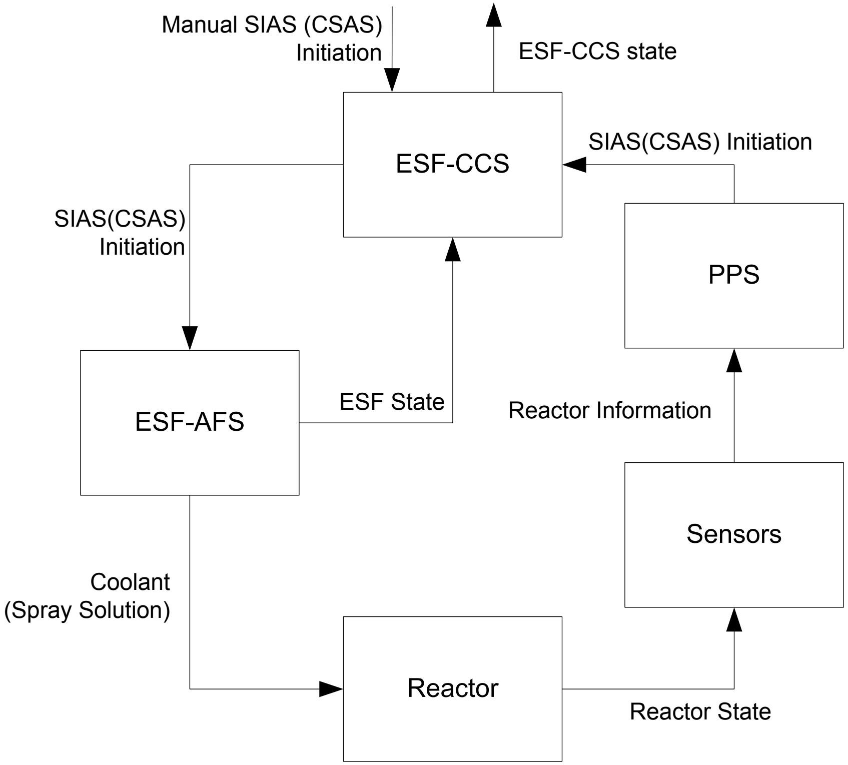


Captions

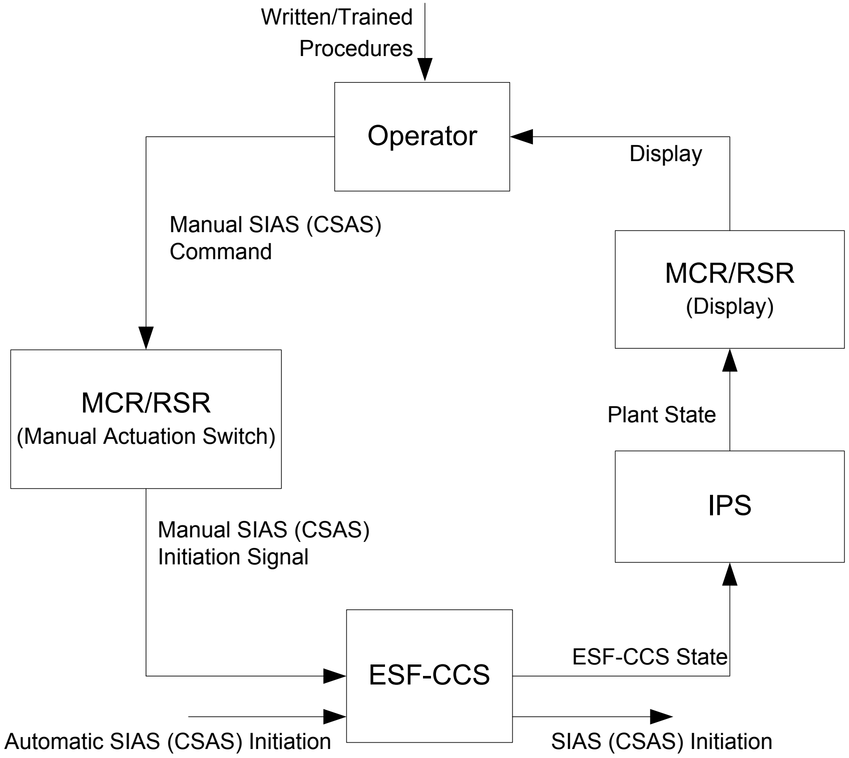
MCR: Main Control Room
RSR: Remote Shutdown Room
IPS: Information Processing System
PPS: Plant Protection System
RMS: Radiation Management System
ESF-AFS: ESF-Actuation Field System

Application of STPA (2-1)

Safety control structure for the SIAS/CSAS by the PPS

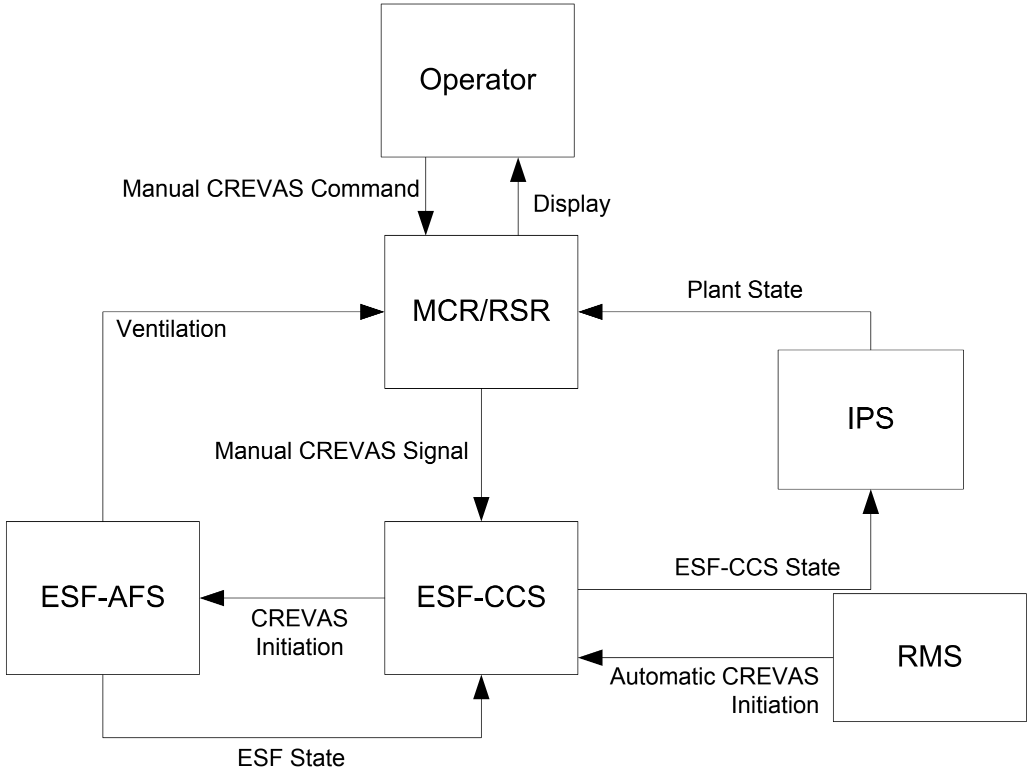


Safety control structure for the SIAS/CSAS by the Operator


Written/Trained Procedures
Operator
Display
Manual SIAS (CSAS) Command
MCR/RSR (Display)
MCR/RSR (Manual Actuation Switch)
Plant State
IPS
Manual SIAS (CSAS) Initiation Signal
ESF-CCS
ESF-CCS State
Automatic SIAS (CSAS) Initiation
SIAS (CSAS) Initiation

Application of STPA (2-2)

Safety control structure for the CREVAS



Application of STPA (3)

Hazardous behaviors of SIAS

Control Action	Not Providing Causes Hazard	Providing Causes Hazard	Wrong Timing or Order Causes Hazard	Stopped Too Soon or Applied Too Long
SIAS ON (From ESF-CCS to ESF-AFS)	**Not providing SIAS ON when LOCA occurs (a1)** Not providing SIAS ON when 2ndHSL occurs (a2) Not providing SIAS ON when S/WP-Ex occurs (a3) Not providing SIAS ON when REA occurs (a4) Not providing SIAS ON when Manual SIAS Initiation occurs (a5)	Not hazardous	When LOCA occurs, ESF-CCS waits too long to turn SIAS ON (c1) When 2ndHSL occurs, ESF-CCS waits too long to turn SIAS ON (c2) When S/WP-Ex occurs, ESF-CCS waits too long to turn SIAS ON (c3) When REA occurs, ESF-CCS waits too long to turn SIAS ON (c4) When Manual SIAS Initiation occurs, ESF-CCS waits too long to turn SIAS ON (c5)	SIAS ON stops before coolant is not provided enough (d1)

Application of STPA (3-1)

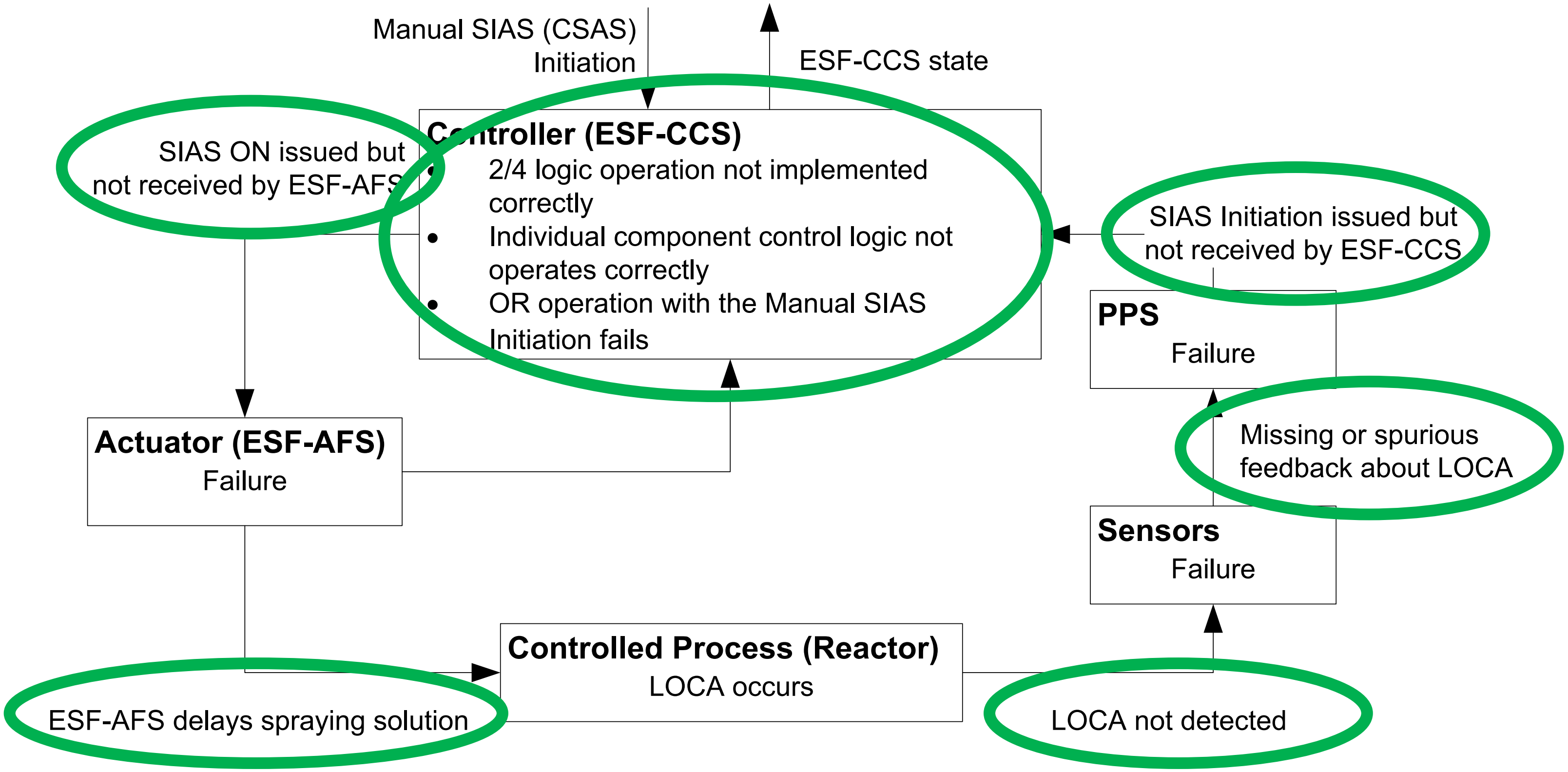
Hazardous behavior of SIAS (Full)

Control Action	Not Providing Causes Hazard	Providing Causes Hazard	Wrong Timing or Order Causes Hazard	Stopped Too Soon or Applied Too Long
SIAS ON (From ESF-CCS to ESF-AFS)	Not providing SIAS ON when LOCA occurs (a1) Not providing SIAS ON when 2ndHSL occurs (a2) Not providing SIAS ON when S/WP-Ex occurs (a3) Not providing SIAS ON when REA occurs (a4) Not providing SIAS ON when Manual SIAS Initiation occurs (a5)	Not hazardous	When LOCA occurs, ESF-CCS waits too long to turn SIAS ON (c1) When 2ndHSL occurs, ESF-CCS waits too long to turn SIAS ON (c2) When S/WP-Ex occurs, ESF-CCS waits too long to turn SIAS ON (c3) When REA occurs, ESF-CCS waits too long to turn SIAS ON (c4) When Manual SIAS Initiation occurs, ESF-CCS waits too long to turn SIAS ON (c5)	SIAS ON stops before coolant is not provided enough (d1)
SIAS OFF (From ESF-CCS to ESF-AFS)	Not hazardous	Providing SIAS OFF when LOCA occurs (b1) Providing SIAS OFF when 2ndHSL occurs (b2) Providing SIAS OFF S/WP-Ex occurs (b3) Providing SIAS OFF REA occurs (b4) Providing SIAS OFF when Manual SIAS Initiation occurs (b5)	SIAS OFF is provided before the temperature decrease enough (c6)	Not hazardous
Manual SIAS ON (From Operator to MCR/RSR)	Not providing SIAS ON when LOCA occurs (a6) Not providing SIAS ON when 2ndHSL occurs (a7) Not providing SIAS ON when S/WP-Ex occurs (a8) Not providing SIAS ON when REA occurs (a9)	Not hazardous	When LOCA occurs, ESF-CCS waits too long to turn SIAS ON (c7) When 2ndHSL occurs, ESF-CCS waits too long to turn SIAS ON (c8) When S/WP-Ex occurs, ESF-CCS waits too long to turn SIAS ON (c9) When REA occurs, ESF-CCS waits too long to turn SIAS ON (c10)	Not hazardous

Application of STPA (4)

Causal factors (a1) – Initiation

Hazard: Not providing SIAS ON when LOCA occur (a1)



Controller (ESF-CCS)

- 2/4 logic operation not implemented correctly
- Individual component control logic not operates correctly
- OR operation with the Manual SIAS Initiation fails

Application of STPA (4-1)

Causal factors of unsafe control actions (a1-a9)

UCAs	A part of the safety control structure	Causal Factors
(a1-a4)	ESF-CCS	2/4 logic operation not implemented correctly
		Individual component control logic not operates correctly
		OR operation with the Manual SIAS Initiation fails
	SIAS On(ESF-CCS to ESF-AFS)	SIAS ON issued but not received by ESF-AFS
	ESF-AFS	ESF-AFS fails to implement its function
	Release Coolant (ESF-AFS to Reactor)	ESF-AFS delays spraying solution
	Sensing (Reactor to Sensor)	The 4 events is not detected by Sensor
	Sensor	Sensor fails
	Reactor's state (Sensor to PPS)	Sensor provides spurious feedback
	PPS	PPS received the feedback correctly but does not issue SIAS Initiation
	SIAS Initiation (PPS to ESF-CCS)	SIAS Initiation issued but not received by ESF-CCS
(a5)	ESF-CCS	OR operation with the SIAS Initiation of PPS fails
	SIAS On(ESF-CCS to ESF-AFS)	SIAS ON issued but not received by ESF-AFS
	ESF-AFS	ESF-AFS fails to implement its function
	Release Coolant (ESF-AFS to Reactor)	ESF-AFS delays spraying solution
(a6-a9)	Operator	Judgement fails about the 4 events
		Misunderstanding about state of Safety Injection operation
	Manual SIAS (Operator to MCR/RSR)	SIAS Initiation issued but not received by MCR/RSR
	MCR/RSR (Manual Actuation Switch)	Manual Actuation Switch fails
	Manual SIAS Initiation Signal (MCR/RSR to ESF-CCS)	Manual SIAS Initiation Signal issued but not received by ESF-CCS
	ESF-CCS State (ESF-CCS to IPS)	ESF-CCS provides spurious information about Safety Injection
		Information about Safety Injection issued but not received by IPS
	MCR/RSR (Display)	MCR/RSR fails to display information
	Display (MCR/RSR to Operator)	Information of the 4 events issued but not received by Operator
		MCR/RSR displays spurious information about the 4 events and Safety Injection

Conclusion & Future Work

- Analysing 3 of 8 functions and identifying hazardous behaviours and its causal factors using STPA
- An expert involved developing ESF-CCS said “STPA provides analysts with a novel view about causes of hazard”
- Future work
  - Hazard analysis with multiple controllers in progress
  - Objective hazard analysis
    - Need an automatic STPA based on a process model of system
    - STPA based on a formal (NuSCR) model

THANK YOU

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