Current studies on utilization of risk information for Fuel Cycle Facilities in Japan

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Contents

1. Introduction

- Utilization of risk information for the nuclear safety regulation is planed by the Nuclear Safety Commission (NSC) and the Nuclear and Industrial Safety Agency (NISA).

- The presentation outlines current studies in Japan on utilization of risk information for reprocessing facilities and fuel fabrication facilities, especially for the former.

2. Fuel cycle facilities in Japan

Reprocessing and fuel fabrication facilities in Japan

JNFL : Japan Nuclear Fuel Limited

JNC : Japan Nuclear Cycle development institute

MNF : Mitsubishi Nuclear Fuel Co.,Ltd.

NFI : Nuclear Fuel Industries, Ltd.

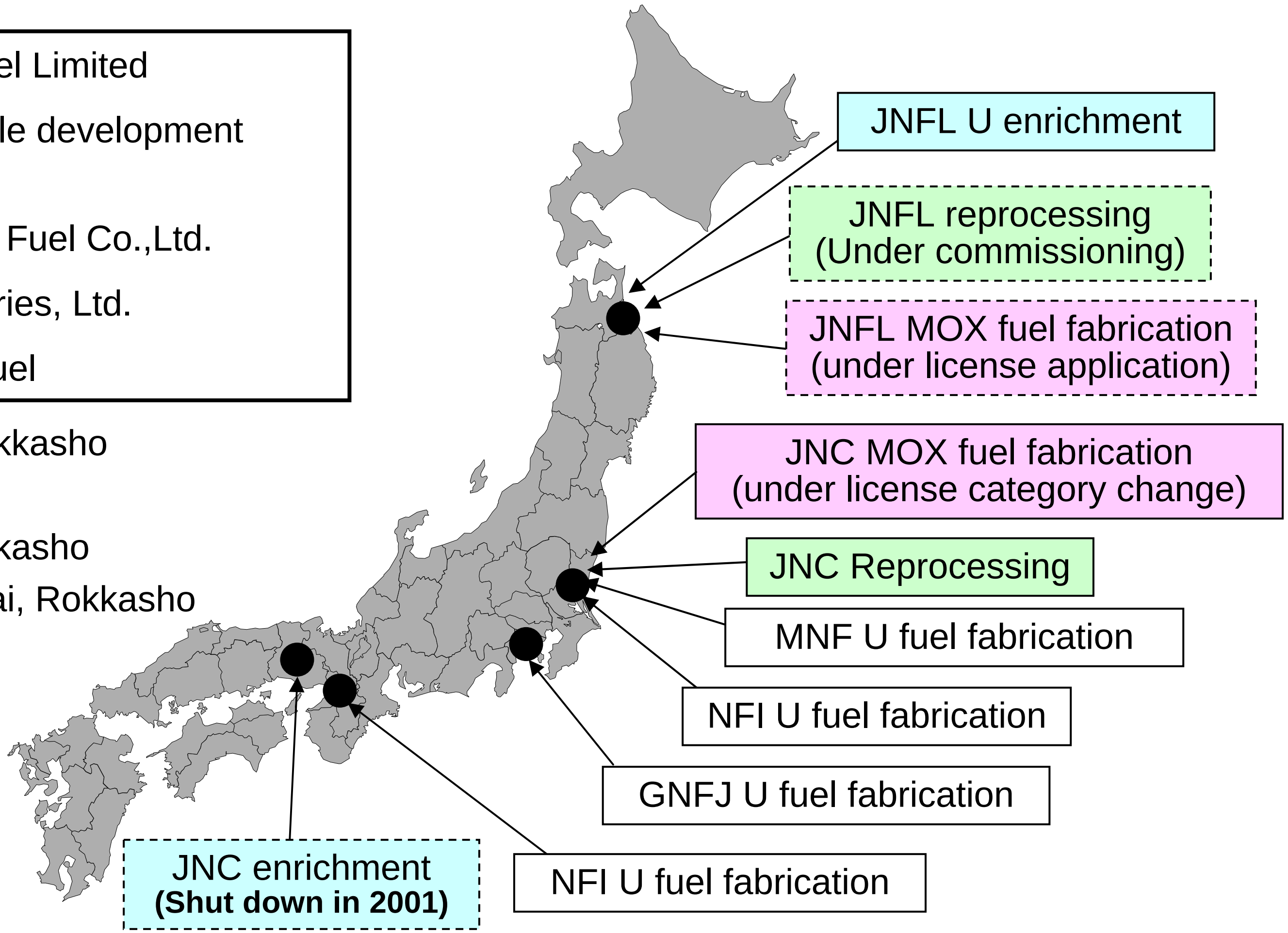
GNFJ : Global Nuclear Fuel

U enrichment: Ningyo, Rokkasho

U fuel fabrication: 4 sites

Reprocessing: Tokai, Rokkasho

MOX fuel fabrication: Tokai, Rokkasho



Status of facilities

- **Uranium fuel fabrication facilities (including uranium enrichment facilities)**
  - long operation experiences (the oldest one in operation since 1970)
- **JNC reprocessing facility in Tokai-mura (Tokai Reprocessing Plant (TRP))**
  - in operation since 1977
- **JNFL reprocessing facility in Rokkasho-mura (Rokkasho Reprocessing Plant)**
  - now under the commissioning stage (uranium test)
  - to be operated in 2007
- **JNC MOX fuel fabrication facilities in Tokai-mura[1)]**
  - in operation since 1972 (PFFF)[2)] and 1988 (PFPF)[3)]
- **JNFL MOX fuel fabrication facility in Rokkasho-mura**
  - submitted the license application of the "nuclear fuel fabrication business" in April 2005
  - to be operated in 2012

1) Facility of the research type is excepted.
2) Plutonium Fuel Fabrication Facility, 3) Plutonium Fuel Production Facility

3. Status of studies

(1) Studies on reprocessing facilities

(2) Other studies

(3) Key issues

(1) Studies on reprocessing facilities

Outline of studies

- Studies on risk assessment methodology and related researches have been conducted by JNC, JAERI, JNFL and JNES based on methodologies such as the probabilistic safety assessment (PSA) used for nuclear reactors and the methods of hazard analysis and risk evaluation for chemical plants.

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- Recently, on the basis of these experiences, studies to apply the PSA methodology to the existing reprocessing facilities and a generic facility with realistic specifications have been conducted by JNC, JNFL and JNES.

Background

- The "Safety examination guideline for reprocessing facility" (established by NSC) for the safety assessment

- According to the guideline, events of BAT (Beyond anticipated transient) and AT (anticipated transient) have to be selected in consideration of their possibility of occurrences as DBEs (design basis events).

- Identifications of potential hazards and postulated accidents were performed by HAZOP and/or FMEA. (by deterministic approach)

Recent studies

JNC	・To obtain useful insights from PSA into maintenance of TRP, and to identify weaknesses in design and operation of TRP ・Evaluation of relative importance measures of safety functions that prevent the accidents, which are assumed to occur at TRP
JNFL	・To aim to use insights from PSA for inspection and maintenance of Rokkasho Reprocessing Plant ・Evaluation of frequency, and that of importance measures on safety components and operations for the design basis and non-design basis events with large inventory of radioactivity
JNES	・To aim to establish standard PSA procedure for reprocessing facilities ・Evaluation of frequency, consequence and risk for various events that are taken into consideration in safety designs (the risk is given as the product of frequency and consequence)

Common procedures in the studies of PSA

Item	Procedure
Identification of Hazard	HAZOP [1)], FMEA [2)]
Development and description of event progression scenario	Event Tree, Fault Tree
Evaluation of frequency	Event Tree and Fault Tree
Reliability data of components and units	Most of the data are prepared from those of nuclear reactors, general industries, etc. in published literatures. [3, 4, 5)]
Human error rate	THERP [6)] method (in NUREG/CR-1278)
Evaluation of importance measure	Fussel-Vesely importance Risk Achievement Worth

1) HAZOP (Hazard and Operability Study) is well accepted in a chemical plant safety.
2) FMEA (Failure Mode and Effect Analysis)
3) Data are prepared based on the data in literatures whose operating environment and condition are similar to those in the studies.
4) Available data on equipment failure rate of reprocessing facilities are extremely limited.
5) In frequency evaluation in the study by JNC, some of data on equipment failure rates are given by analyzing the operation and maintenance data at TRP.
6) Technique for Human Error Rate Prediction

Characteristics of reprocessing facility

Radioactive and nuclear materials are processed throughout a facility with a variety of chemical and physical forms.

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- Wide distribution of potential hazardous sources, e.g. radioactivity, heating source, and flammable and explosive materials, in many part of a facility
- Wide variety of postulated events in many part of a facility

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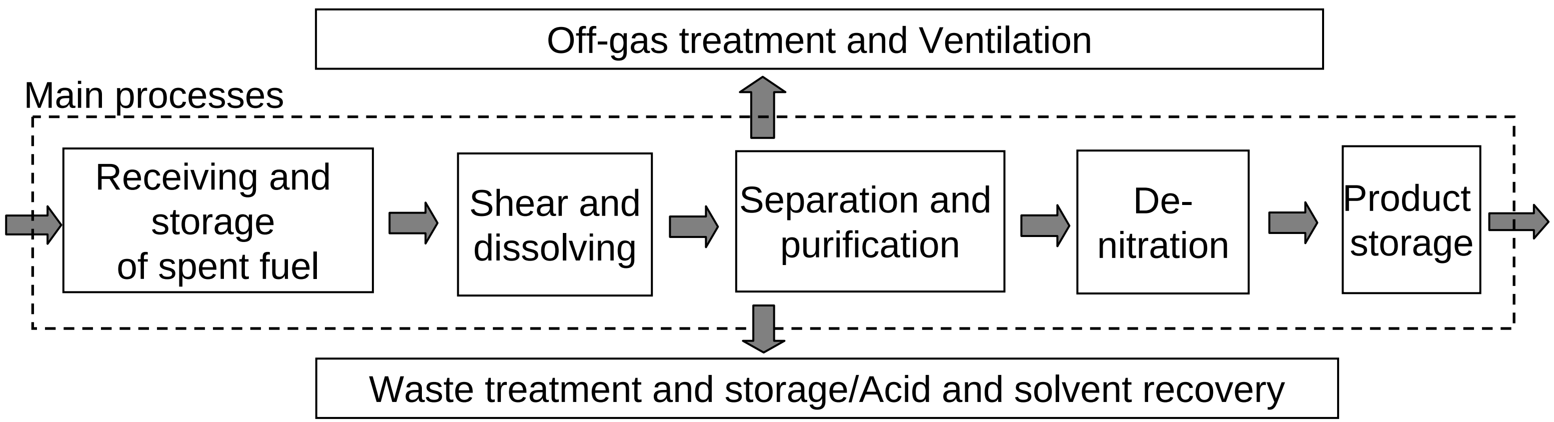
A greater number and variety of events to be studied in PSA than those of nuclear reactors as possible major risk contributors



Outline of reprocessing facility

Events in frequency evaluations [1)]

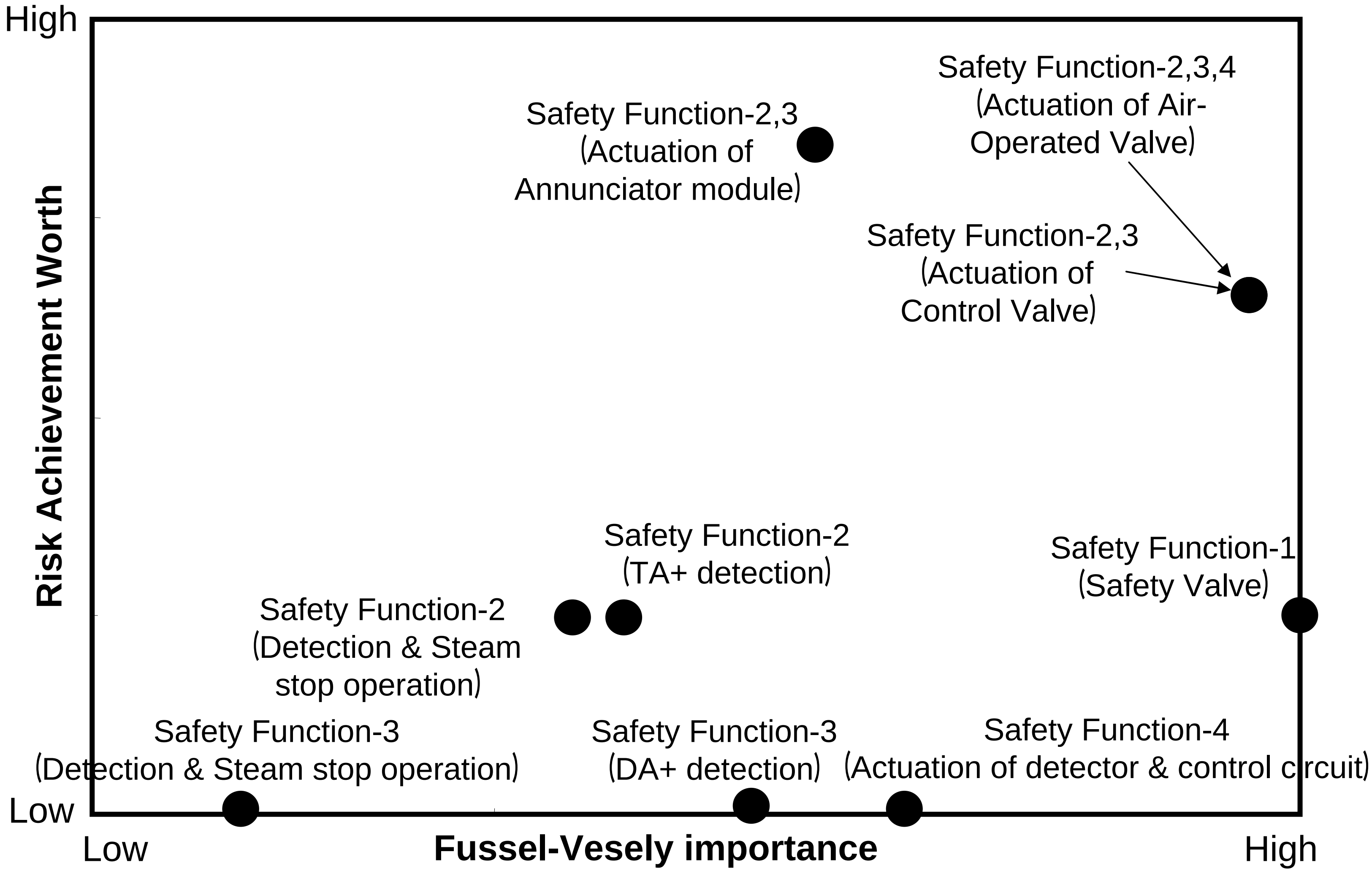
Event	JNC	JNFL	JNES
Boiling of solution (including loss of liquid cooling function)		○	○
Hydrogen gas explosion (including loss of H_2 scavenging function)	○	○	○
Solvent Fire (including excess of ignition point of n-dodecane)	○	○	○
Rapid decomposition of TBP complex [2)]	○	○	○
Criticality (in many part of a facility with various causes, in dis-solver, in extraction process, by miss-transfer of liquid, etc.)	○	○	○
Loss of electricity	○	○[3)]	○[3)]
Fire of the waste solvent decomposition equipment		○	
Increase of H_2 concentration in Roasting-Reduction process	○		
Holmarin/HNO_3 chemical reaction (in HALW concentrator)	○		
Leakage of HALW			○

1) Events reported in the references on the abstract
2) Occurs in conditions such as over a certain concentration of TBP and at elevated temperatures ranging from 130 to 150 degrees centigrade (So called "Red-oil Reaction")
3) Evaluated as an initiating event

Examples of results

Example (1)

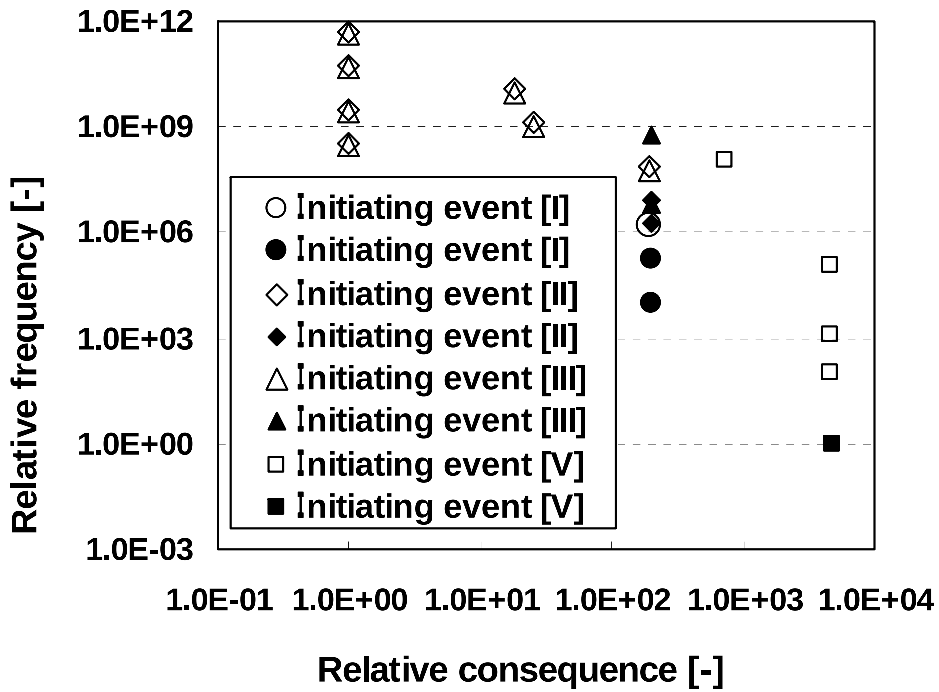
Importance measure for the rapid decomposition of TBP complex in Pu concentrator [1)]



1) PSA Application on the Tokai Reprocessing Plant, JNC TN8410 2003-017 (2004)

Example (2)

Identification of independent sequences and evaluation of their frequency and consequence for the hydrogen explosions in Pu purification process [1)]



1) “Outline of, and a topic about, risk assessment study for fuel cycle facilities at JNES ,” OECD/NEA Workshop for PSA for Non Reactor Facilities, October 2004

(2) Other studies

Studies on fuel fabrication facilities

Facility	Description
MOX fuel fabrication facility	• Study to develop a PSA methodology applicable to MOX fuel fabrication facilities by JAERI - Started in 2000 under the sponsorship of NISA - Including trial PSA for a generic model plant and documentation of proposed procedure - Developed procedure is shown in the next viewgraph.
	• Collaboration between JAERI and JNC in 2003 and 2004 - Independent hazard analyses by HAZOP at JNC and FMEA at JAERI for the same process unit - Comparison of the results given by both methods

PSA Procedure for MOX Fuel Fabrication Facility [1)]

Hazard Analysis

Identifying potential abnormal events with functional FMEA method

Screening of potential abnormal events
- Order estimation of max. RMR without prevention and mitigation
- Estimation of likelihood of events

Identification without missing important events

Efficient screening

Top-Down Analysis

Identifying potential leak path for RMR by the MLD method
- Simple FT analysis of event cause
- Estimation of confinement integrity in energetic event

Rough PSA

Detailed PSA

Accident Scenario Analysis

Identifying accident scenarios
- FT analysis of accident cause
- ET analysis of accident sequence

RMR	**:Radioactive Material Release**
FMEA	**:Failure Mode and Effect Analysis**
MLD	**:Master Logic Diagram**
FT	**:Fault Tree**
ET	**:Event Tree**

Evaluation of RMR

With Five Factor Formula in NUREG/CR-6410

Evaluation of Frequency

Quantifying FT and ET with substitutable NPP reliability data

Efficient estimation

Preparation of reliability data

1) "Methodology Development and Application of PSA for MOX Fuel Fabrication Facilities," OECD/NEA Workshop for PSA for Non Reactor Facilities, October 2004

Studies on fuel fabrication facilities (continued)

Facility	Description
Uranium fuel fabrication facility (including uranium enrichment facility)	• Study to apply ISA procedure [1, 2] by JNES - Started in 2004 - To identify the "Items relied on for safety" (IROFS) and their priority for rational maintenance of facilities - Modification of procedure, for example, on first screening process of postulated events, etc. • ISA is tried because of - relatively lower complexity and risk than those of other types of fuel cycle facilities, - few available data of equipment failure rate - expectation to identify significant accidents and IROFS with adequate details in a relatively quick manner

1) ISA (Integrated Safety Analysis) is the procedure for assessing risks for fuel cycle facilities applied by U.S. NRC (Nuclear Regulatory Commission).

2) The procedure is referring to the Standard Review Plan NUREG-1520, ISA Guidance NUREG-1513 and other documents based on 10CFR Part 70 by NRC.

Working groups

Working group [1)]	Description
JNES Working Group	・Formed in 2004 by JNES ・A review of domestic and foreign information related to risk assessment of fuel cycle facilities to identify issues to be studied ・Study of "Performance Goal" for fuel cycle facilities according to the concept proposed by NSC [2)]
Special Committee of Atomic Energy Society of Japan	・Formed in 2004 (JAERI works as secretariat) ・ A review of state-of-the-art on consequence evaluation aiming at providing efficient methods for determining maximum (bounding) source terms for various accident types such as fire, explosion and criticality events

1) Both consists of experts from relevant organizations in Japan, including industries, researchers and academia.

2) In the NSC published "Interim Report on the Investigation of Safety Goals" (in December 2003), "a probability of release of significant amount of radioactive materials and emission of radiation in a specific time period by accident during operation" is proposed for fuel cycle facilities.

(3) Key issues

- Identification of dominant events contributing a total risk of a facility
- Consequence evaluation
- Study of potential uses of risk information
- Acceptance criteria of PSA/ISA

- Quality of reliability data
- Appropriate accuracy of PSA/ISA results
- Graded approach in accordance with a risk level of facilities

Background

- A risk of fuel cycle facilities may be smaller than that of reactors because of the smaller inventory of radioactivity and relatively milder operational conditions than those of reactors.

- Therefore, when we utilize risk information for fuel cycle facilities, the same degree of accuracy of risk evaluation as that of reactors may not be necessary.

(3) Key issues

- Identification of dominant events contributing a total risk of a facility
- Consequence evaluation
- Study of potential uses of risk information
- Acceptance criteria of PSA/ISA

- Quality of reliability data
- Appropriate accuracy of PSA/ISA results
- Graded approach in accordance with a risk level of facilities

4 Summary

- The current studies on utilization of risk information for fuel cycle facilities in Japan were outlined, especially for reprocessing facilities.

- Although the studies of risk assessment methodology for fuel cycle facilities started later than those for nuclear reactors, studies are ongoing actively and are gaining progress.

- It is necessary not only to continue to conduct studies as a basis for utilization of risk information, but also to make clear what methodology and data should be prepared.

Effective dose	Total predicted frequency
<a	f1
b～c	f2
- - - -	- - - -
- - - -	- - - -
>n	fn

Total risk of each section satisfies the safety goal.

Overview of Fuel Fabrication and Enrichment Facilities in Japan

Name	Japan Nuclear Cycle Development Institute (JNC) Ningyo-Toge Environmental Engineering Center	Japan Nuclear Fuel Limited	Global Nuclear Fuel Japan Co., Ltd.	Mitsubishi Nuclear Fuel Co., Ltd.	Nuclear Fuel Industries, Ltd. Kumatori Works	Nuclear Fuel Industries, Ltd. Tokai Works
Licensed Date	Oct 18, 1985	First phase: Aug 10, 1988 Second phase: Jul 12, 1993	Aug 30, 1968	Jan 11, 1972	Sep 1, 1972	Sep 29, 1978
Facility	Enrichment (centrifugal separation method)	Enrichment (centrifugal separation method)	Fuel fabrication (for BWR)	Conversion Fuel fabrication (for PWR)	Fuel fabrication (for PWR)	Fuel fabrication (for BWR)
Date of Operation start	Mar 10, 1988 Shutdown in 2001	Sep 30, 1991	Aug 29, 1970	July 28, 1972	Sep 1, 1972	Jan 4, 1980
Max. enrichment	5% UO_2	5% UF_6	5% UO_2	5% UO_2	5% UO_2	5% UO_2
Max. capacity	200t-SWU/y	1,050t-SWU/y	750t-U/y	Conversion: 450t-U/y Fuel fabrication: 440t-U/y	284t-U/y	200t-U/y
No. of employees	Approx. 150	Approx. 200	Approx. 430	Approx. 380	Approx. 370	Approx. 270

Hazard Analysis Step

(1) Identification of potential abnormal event
by function level FMEA

- to analyze functional hierarchical structure of fabrication process
- to identify failure mode causing loss of function
- to predict effect of failure and/or malfunction and to predict appearing abnormal event
- to categorize potential abnormal events into fire, explosion, criticality and confinement failure by other cause
- to summarize results of analysis in tabular form such as location, failure mode, consequence and type of potential abnormal event

(2) Screening of potential abnormal events

- Order estimation of Likelihood of event -

Likelihood = [Frequency of Cause Event]
×[Failure Prob. of Preventive Measures]
×[Failure Prob. of Mitigative Measures]

Character index is used instead of numerical index for keeping information of reliability of each factors which is masked by summing up of numerical indexes.

Failure Frequency Index (NUREG-1718)

Index		Based on Evidence	Based on Type of Control
Cha	Num		
A	-3	No failure in 30 years for tens of similar controls in industry	A single control with redundant parts, each a PEC or AEC
B	-2	No failure of this type in this facility in 30 years	A single PEC
C	-1	A few failures may occur during facility lifetime	A single AEC, an enhanced AC, an AC with large margin, or a redundant AC
D	0	Failures occure every 1-3 years	A single AC
E	1	Several occurrence per year	A frequent event

Failure Probability Index (NUREG-1718)

Index		Based on Type of Control
Cha	Num	
a	-3 or -4	A singlle PEC or and AEC with high availablity
b	-2 or -3	A single AEC, an enhanced AC, an AC with large margin, or a redundant AC
c	-1 or -2	An AC that must be performed in response to a rare, unplanned demand

PEC :Passive Engineered Control
AEC :Active Engineered Control
AC :Administrative Control

JNES

Categorization of Likelihood based on the Combination of Frequency and/or Probability Character Index

Category 1
$F < 10^{-6}$ /yr

- A
  - a+
  - b+
- B
  - a+
  - bb
  - bb+
- C
  - aa
  - aa+
  - ab+
- D
  - aa
  - aa+

Category 2
$10^{-6} \leq F < 10^{-4}$ /yr

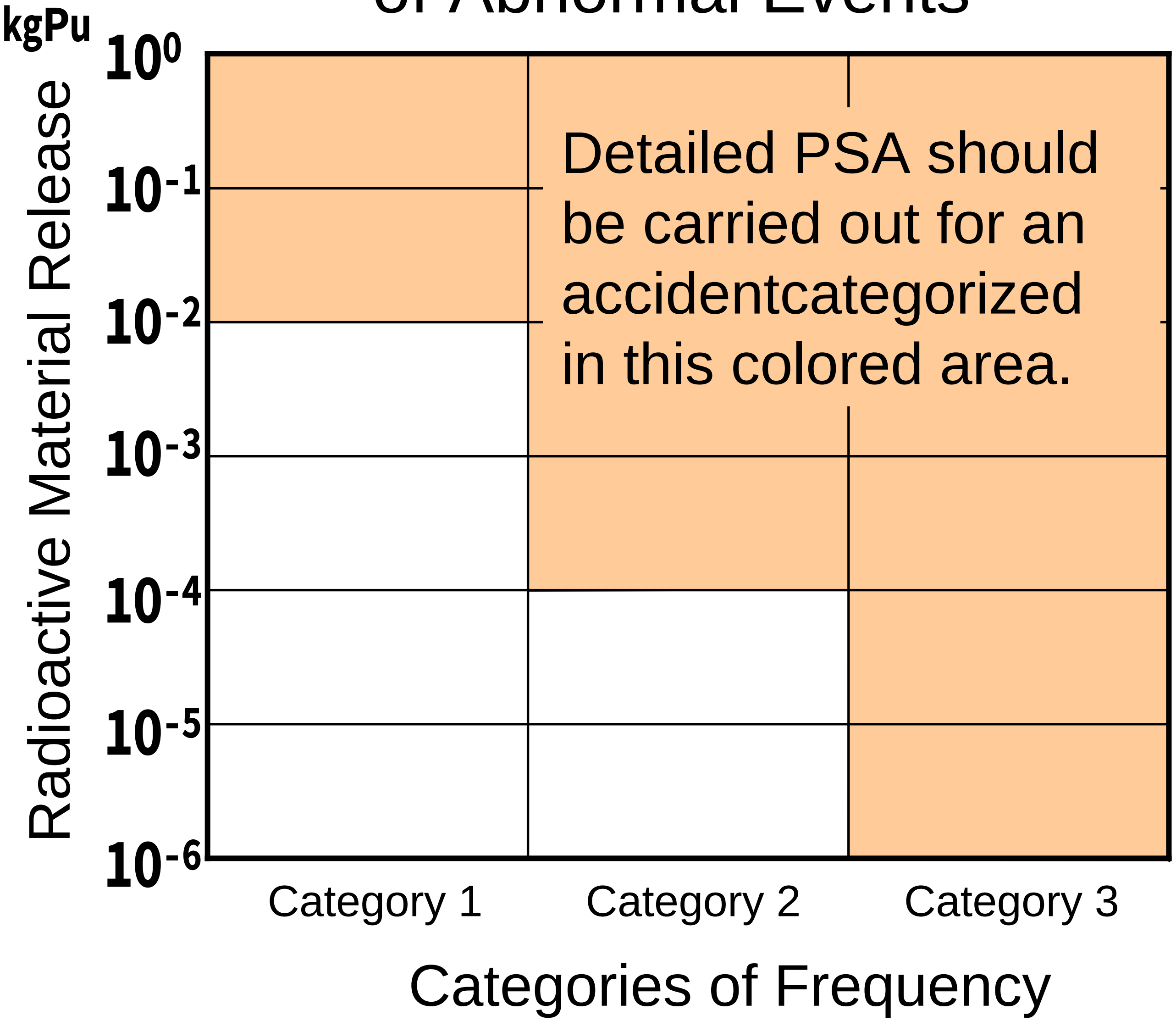
- A
  - a
  - b
  - c+
- B
  - bc
  - bc+
  - a
  - b
  - c+
- C
  - ab
  - ac
  - ac+
  - b+
- D
  - ab
  - ab+
  - ac
  - ac+
  - bb+
- E
  - aa
  - aa+
  - ab
  - ab+

Category 3
10^{-4} /yr $\leq F$

- A
  - c
- B
  - c
- C
  - a
  - b
  - c
  - c+
- D
  - bb
  - bc
  - bc+
  - a
  - b
  - c
  - c+
- E
  - any

A, B,….: Frequency of accident cause
a, b, ….: Unavailability of preventive or mitigative measures
a+, b+ : Other measure(s) less or equally reliable

Framework of Risk Matrix for Screening of Abnormal Events



Trial application with a model MOX plant (2)

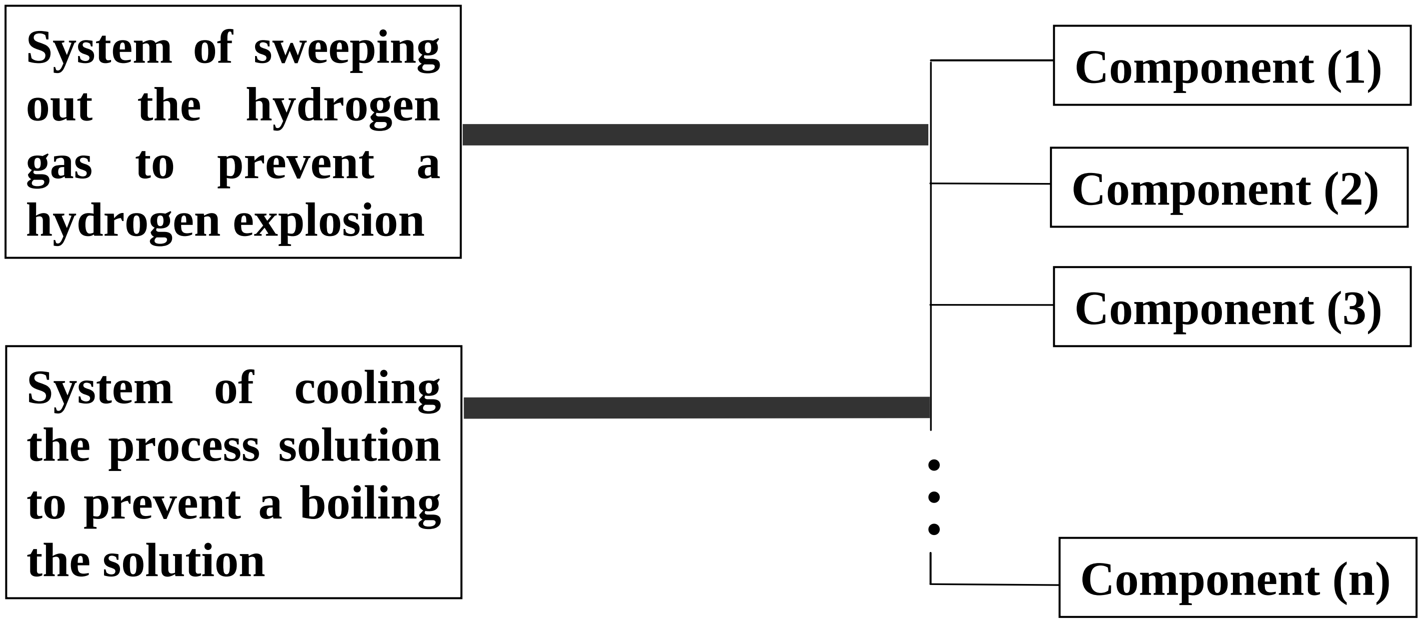
- Selected candidate abnormal events -

- Fire in the GB of ball mill blending unit
- Explosion of organic solvent in MOX powder handling GB
- Falling of MOX powder container in storage area
- Spill of MOX powder from the joint of outlet of final homogenizer
- Falling of pellet tray
- Hydrogen explosion in sintering furnace
- Hydrogen explosion in GB of inlet and outlet of sintering furnace
- Over-pressure of sintering furnace by vaporization of water

Background of the study (1)

Specific characteristics of a reprocessing facility

A loss of certain safety functions affects many components (e.g. vessels and solvent extractors) simultaneously.

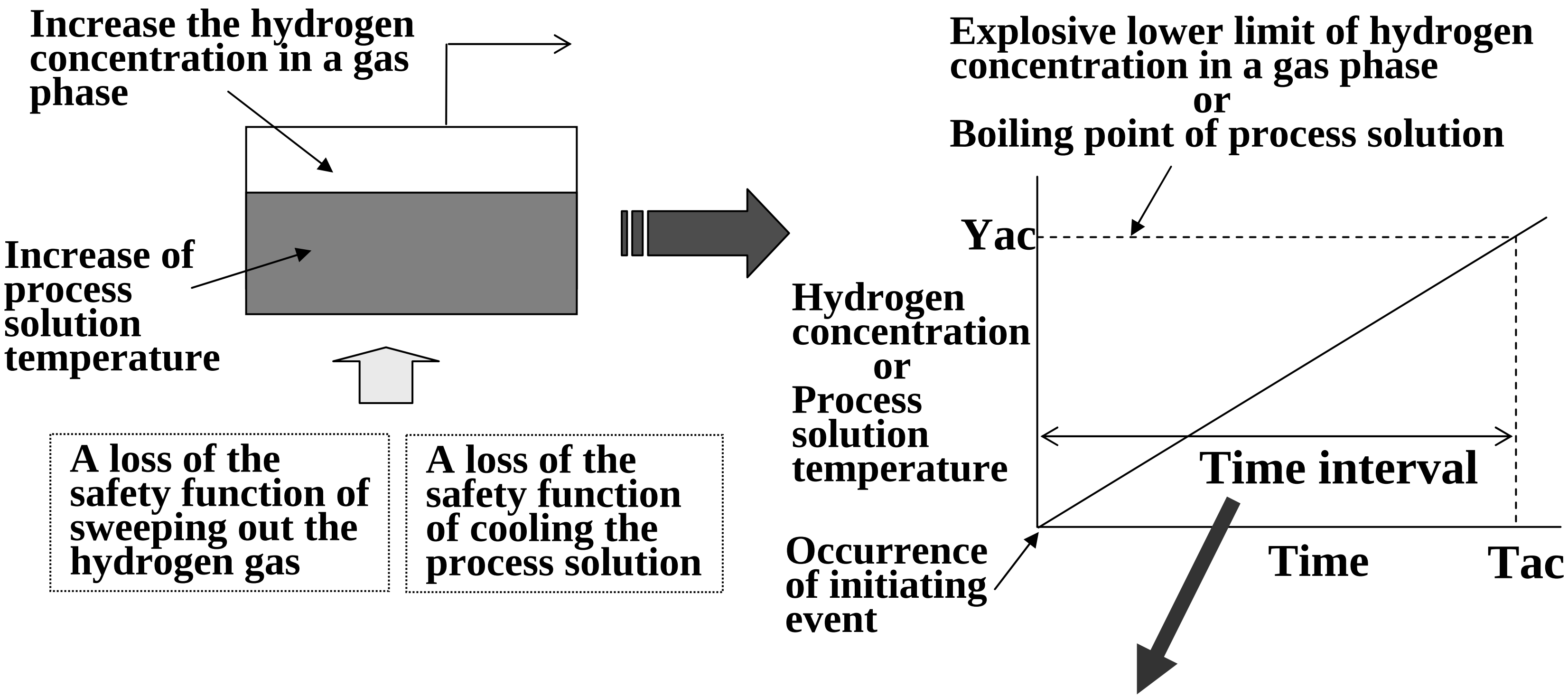


Example of the number of the components connected the system
ca. 70 (function of sweeping out the hydrogen gas)
ca. 45 (function of cooling the process solution)

Background of the study (2)

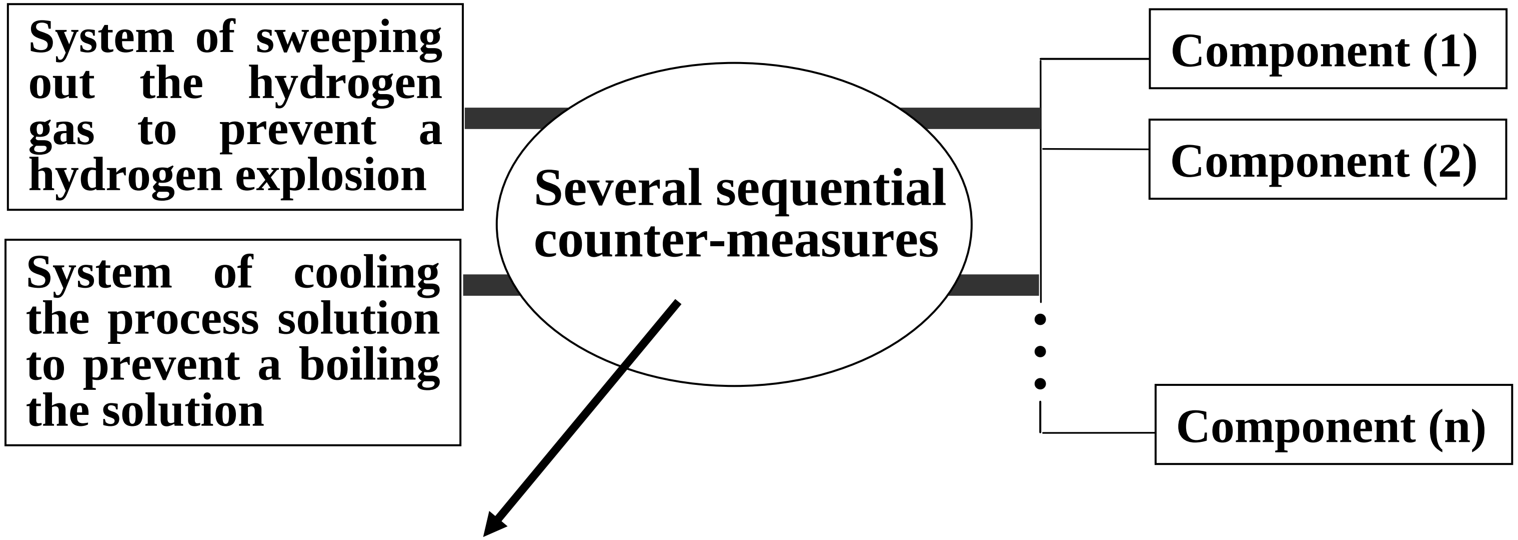
Specific characteristics of a reprocessing facility

Each component has a different "time interval" between the occurrence of an initiating event and the point when the condition leading a resultant accident is given.



The "time interval" depends on the process conditions of each component, e.g. the concentration of the radioactive materials and nitric acid, and the liquid hold-up.

Background of the study (3)



Each event progression scenario has a different timing of accomplishment of a counter-measure after occurrence of a initiating event (due to a difference of a combination of failure and success of counter-measures).

Example of time interval

ca. 30 min. to 12 hr (hydrogen explosion)
ca. 8 to 90 hr (boiling of process solution)

The components with the resultant accident and those without the resultant accident may coexist in one event progression scenario.

Background of the study (4)

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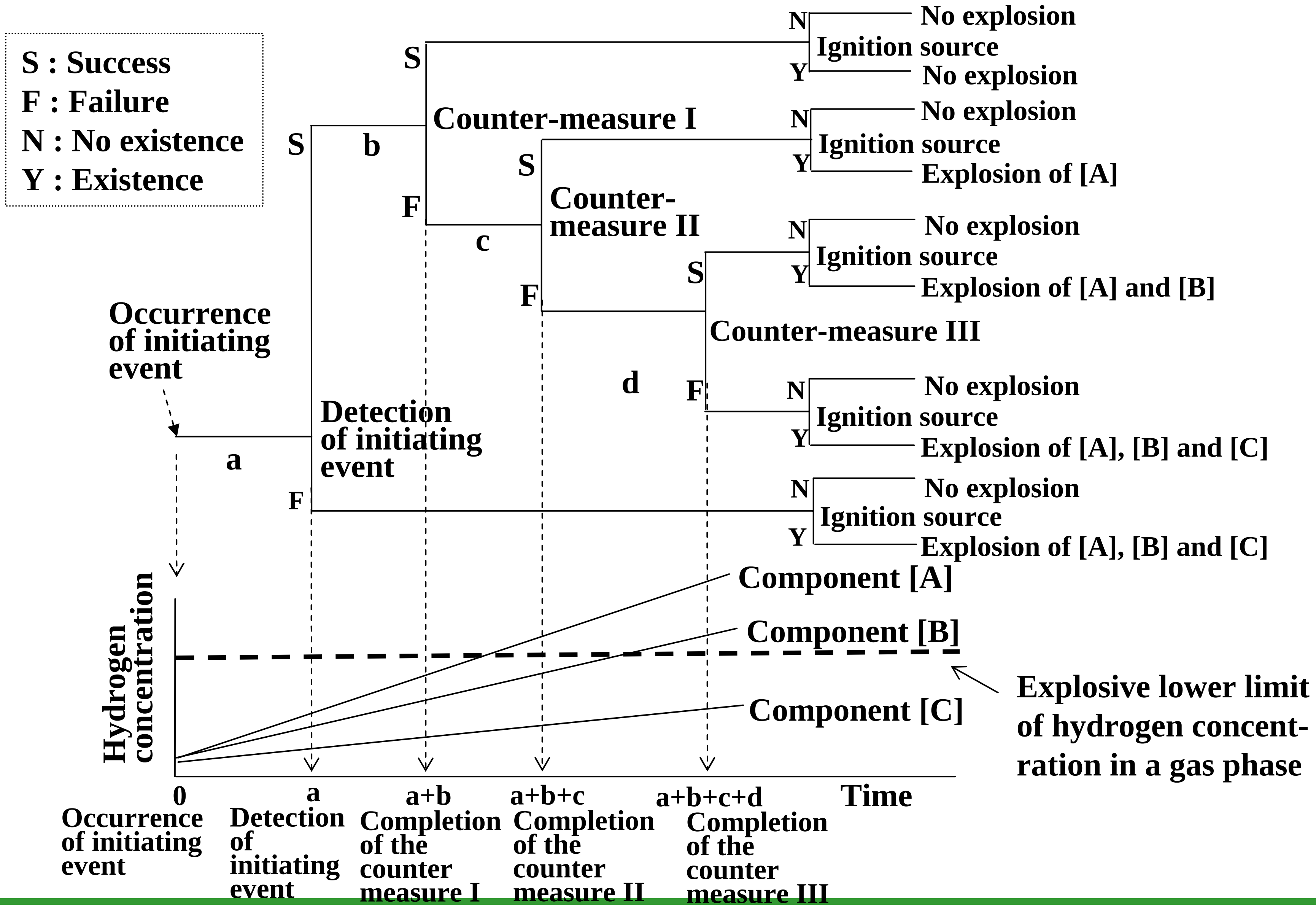
■The difference of such combination affects:

- ➢the consequence and the risk of an accident scenario,
- ➢the total risk of a facility,

■The combination of components with and without a resulting accident should be carefully considered in the analysis to identify all independent accident scenarios.

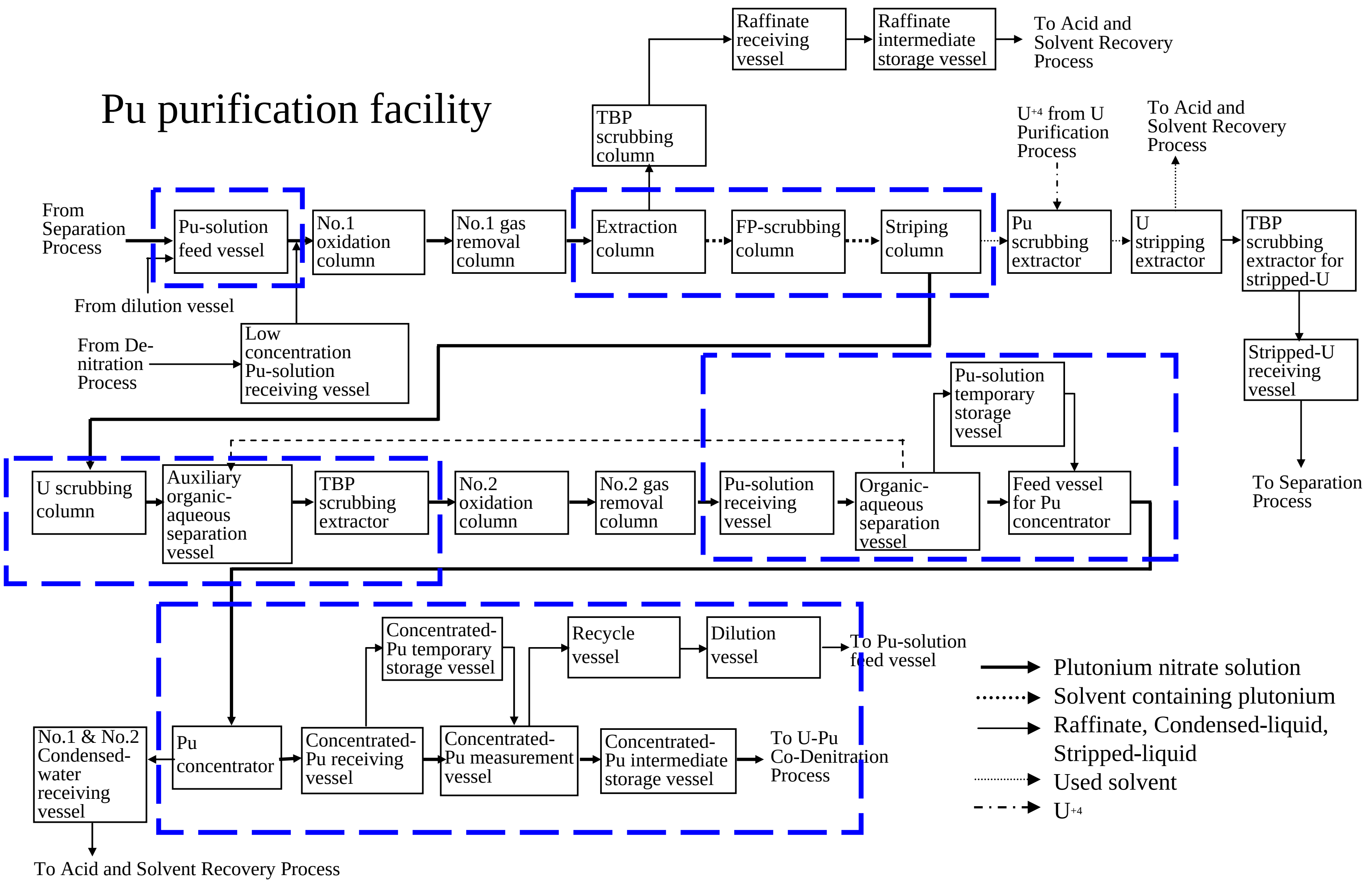
■The basic procedure to identify the independent accident scenarios for such a case was studied.

Basic procedure to identify independent scenarios

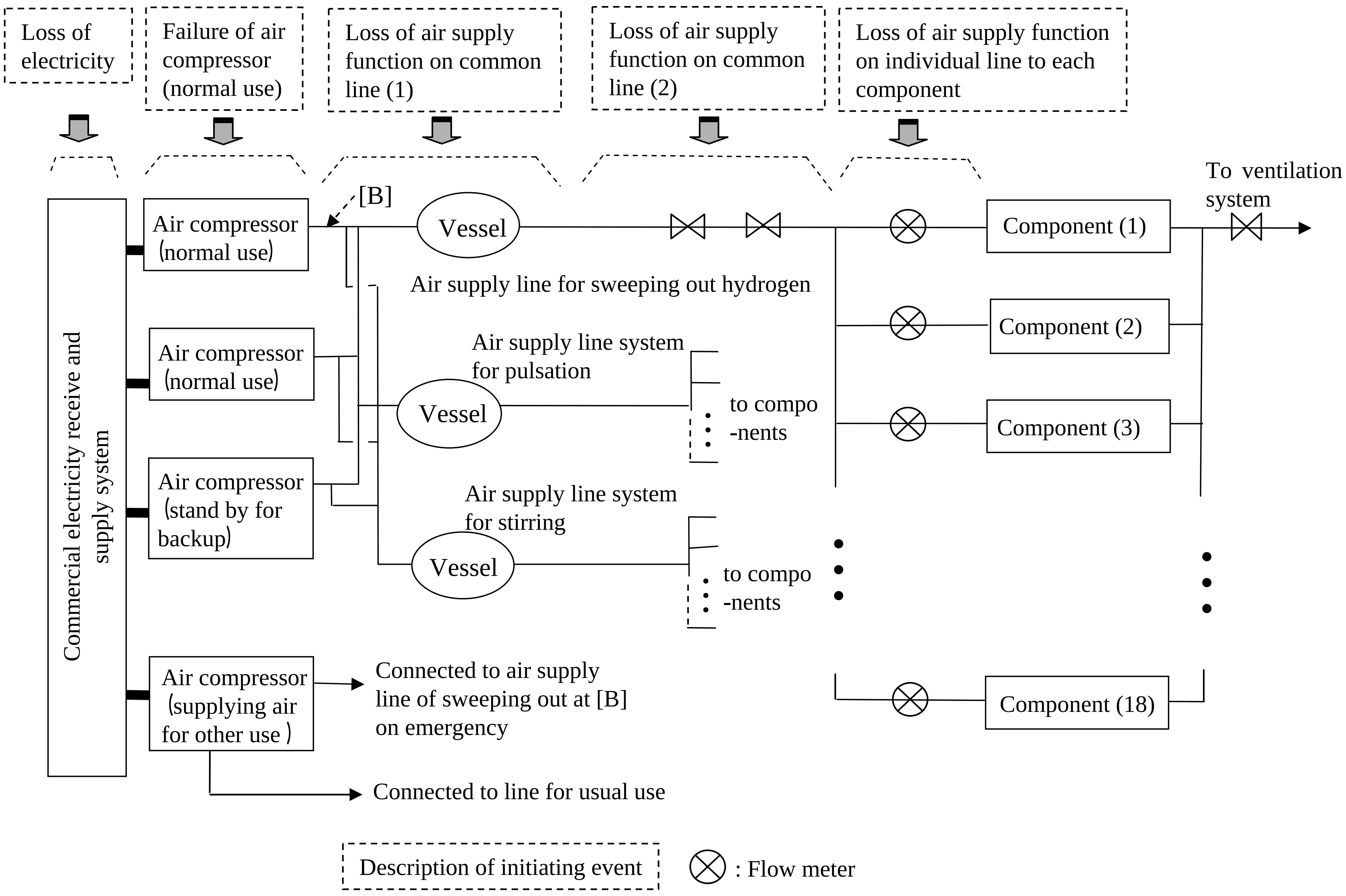


JNES

Model process for example study



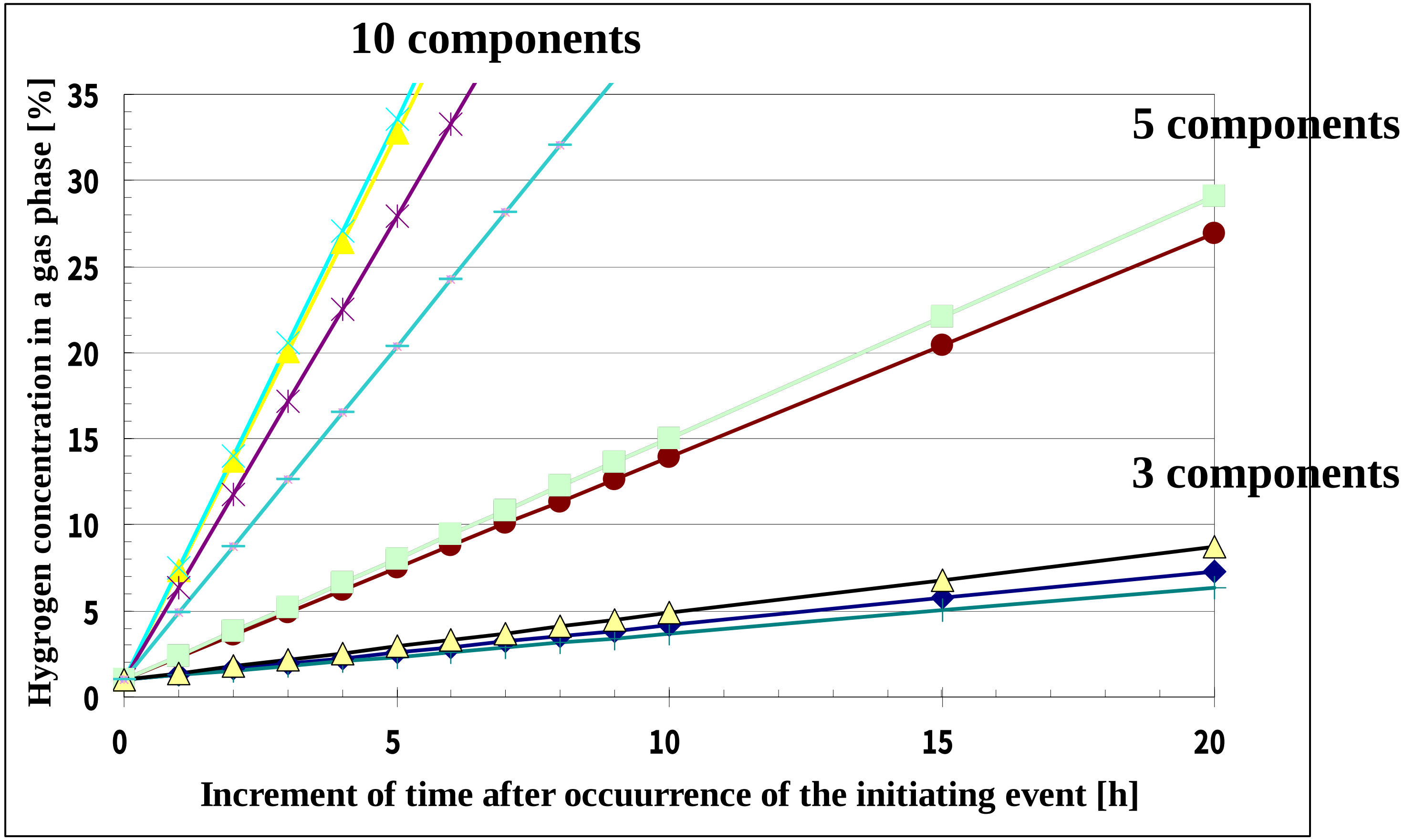
System related to hydrogen explosion



Initiating events and counter-measures

Initiating event		Counter-measure (1st)	Counter-measure (2nd)	Counter-measure (3rd)
Description	Sym-bol			
Failure of air compressor (for normal use)	I	Startup of backup air compressor	Connect air compress-or for other use to line for sweeping out hydrogen	Open up the line around flow meter
Loss of air supply function on common line (1)	II	Use line for pulsation	Use line for stirring	Open up the line around flow meter
Loss of air supply function on common line (2)	III	Use line for pulsation	Use line for stirring	Open up the line around flow meter
Loss of air supply function on individual line to each component	IV	Use line for pulsation	Use line for stirring	Open up the line around flow meter
Loss of commercial electricity	V	Recover of commercial electricity	Start up emergency electricity	

Transient behavior of the hydrogen concentration in a gas phase



Identified sequences

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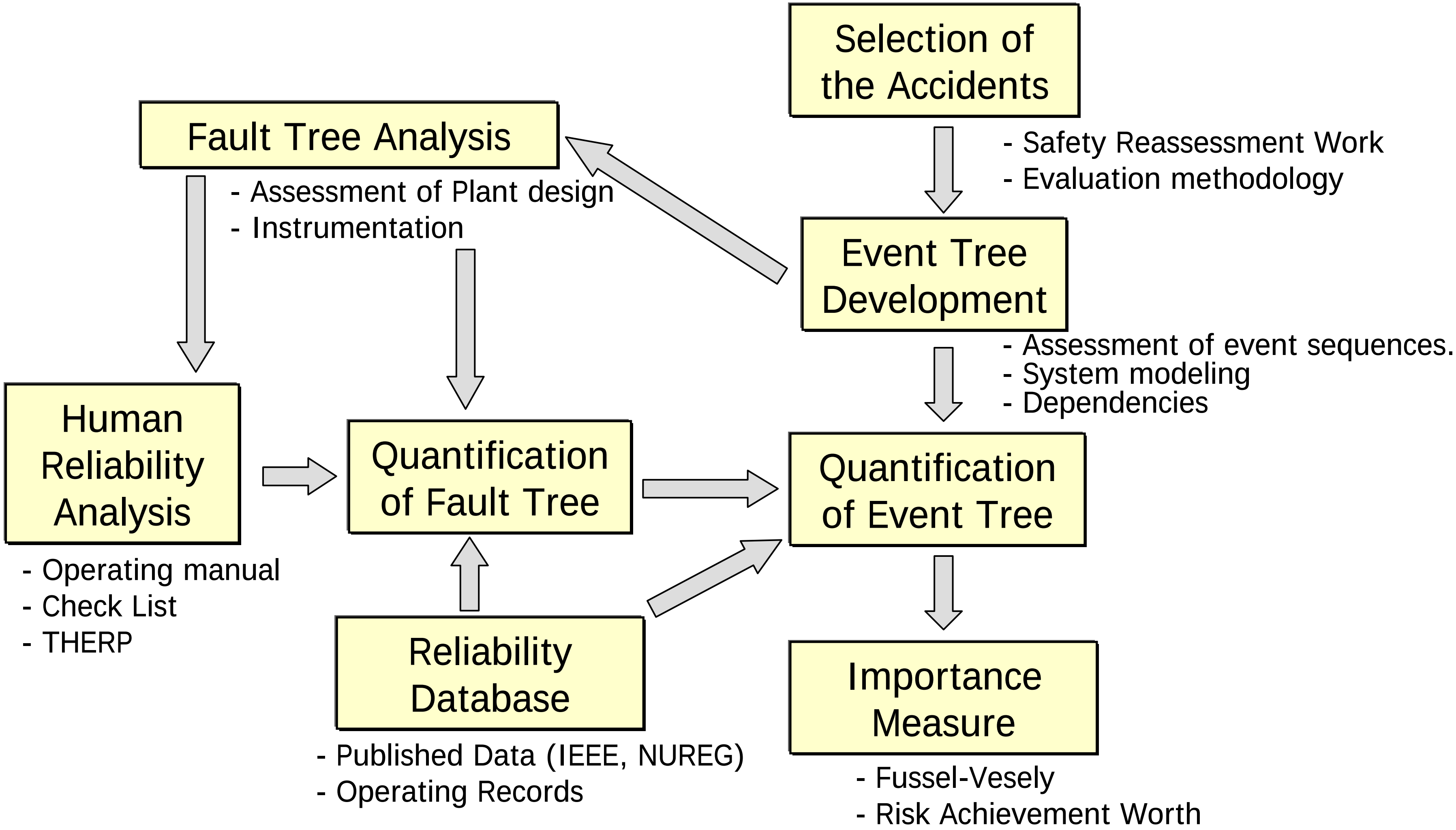
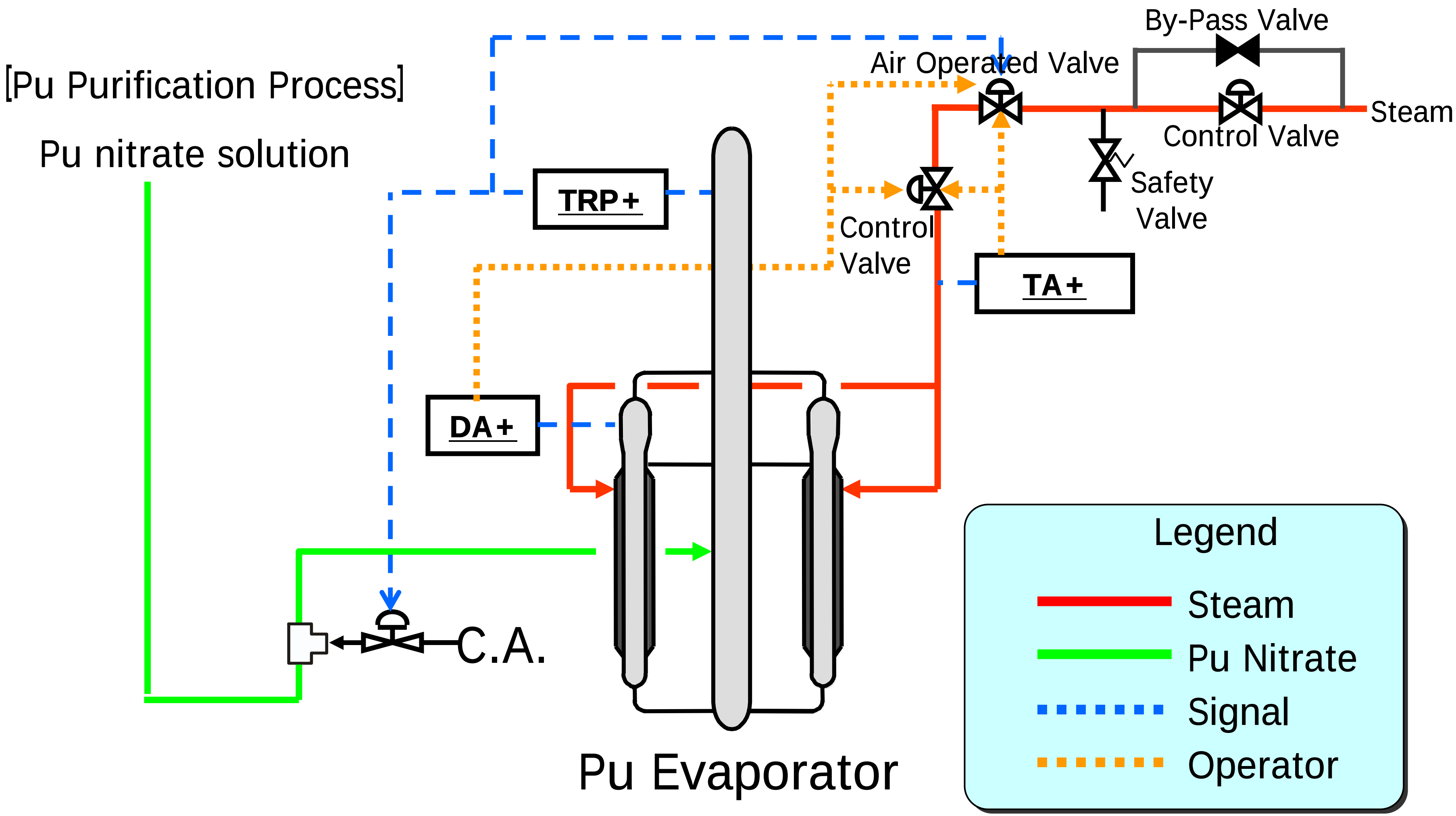
Initiating Event	Symbol of sequence	Sequence: Combination of failure and success of counter-measures	Components with occurrence: Gr. 1 – Gr. 1'	Gr. 1"	Gr. 2	Gr. 3 – Gr. 3'	Gr. 3"
I	I -1	A, B (failure) , C (success)	*	*	*	—	—
	I -2	A, B, C (failure)	*	*	*	*	*
	I -3	Failure to identify initiating event	*	*	*	*	*
II	II -1		*	*	*	*	*
	II -2		*	*	*	—	—
	II -3		*	—	*	*	*
	II -4		*	—	—	—	*
	II -5		*	—	—	—	—
	II -6		*	—	*	—	—
	II -7		*	—	—	—	*
	II -8		*	—	—	—	—
	II -9		*	*	*	*	*
III	III-1		*	*	*	*	*
	III-2		*	*	*	—	—
	III-3		*	—	*	*	*
	III-4		*	—	—	—	*
	III-5		*	—	—	—	—
	III-6		*	—	*	—	—
	III-7		*	—	—	—	*
	III-8		*	—	—	—	—
	III-9		*	*	*	*	*
IV	IV-G1'-1		*	—	—	—	—
	IV-G1'-2		*	—	—	—	—
	IV-G1"-1		—	*	—	—	—
	IV-G1"-2		—	*	—	—	—
	IV-G2-1		—	—	*	—	—
	IV-G2-2		—	—	*	—	—
	IV-G3'-1		—	—	—	*	—
	IV-G3'-2		—	—	—	*	—
	IV-G3"-1		—	—	—	—	*
	IV-G3"-2		—	—	—	—	*
SL- V	V -1		*	*	—	—	—
	V-2		*	*	*	—	—
	V-3		*	*	*	—	—
	V -3		*	*	*	—	—
	V -4		*	*	*	*	*
	Total number of Sequence						
	62						

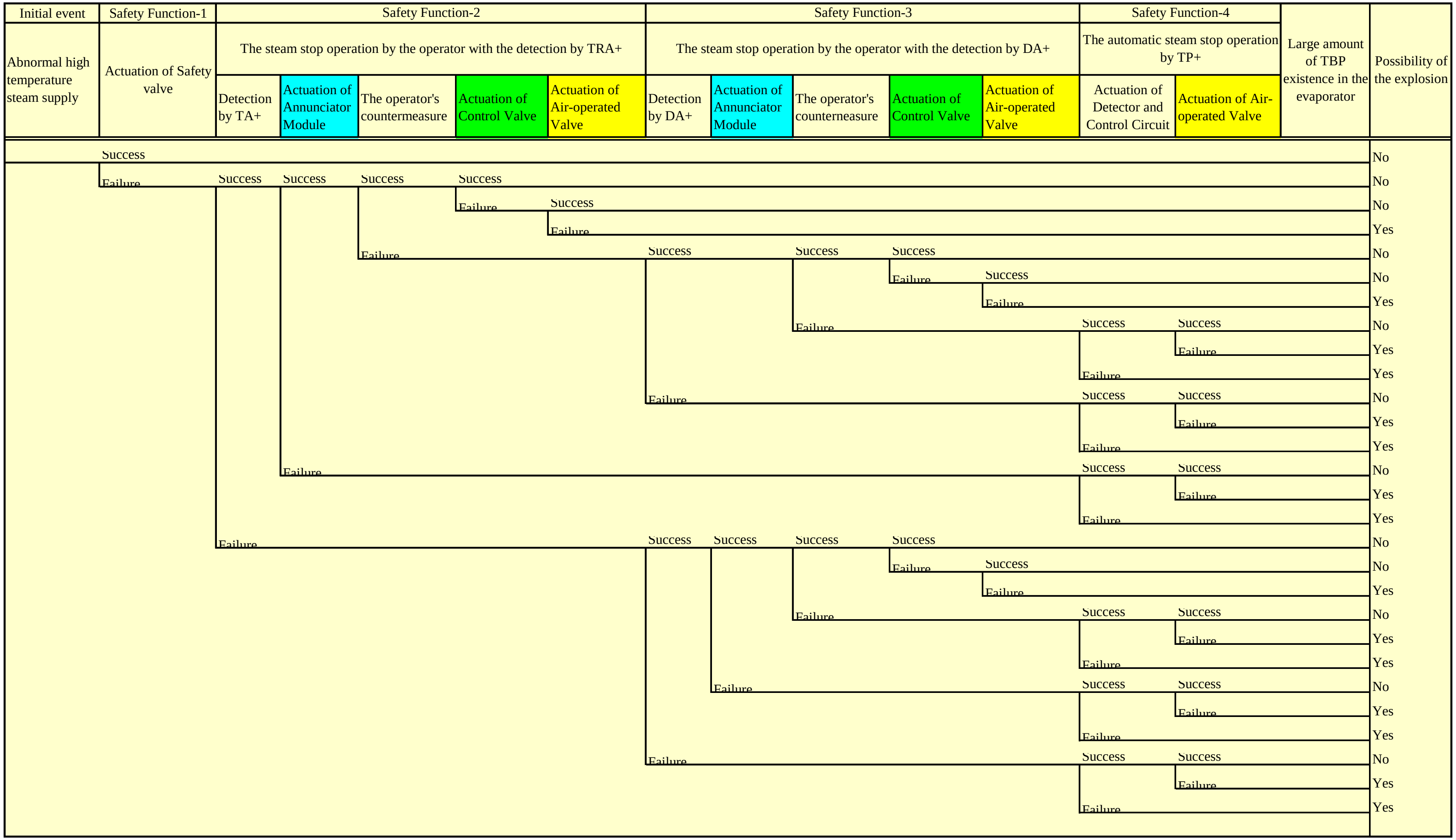
Evaluation Procedures



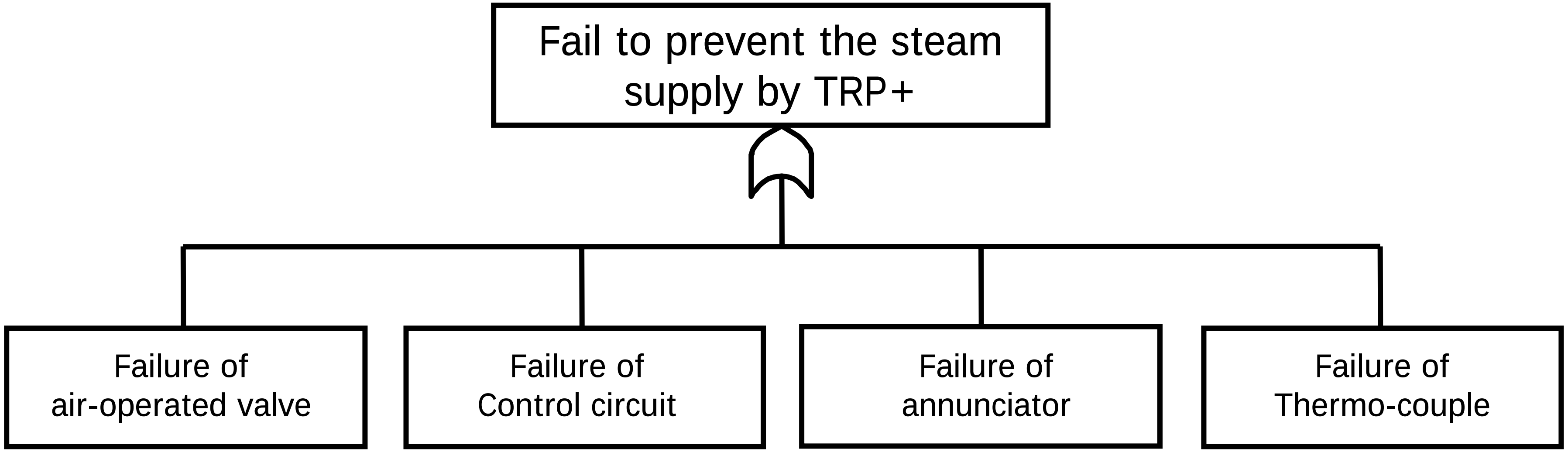
System Modeling



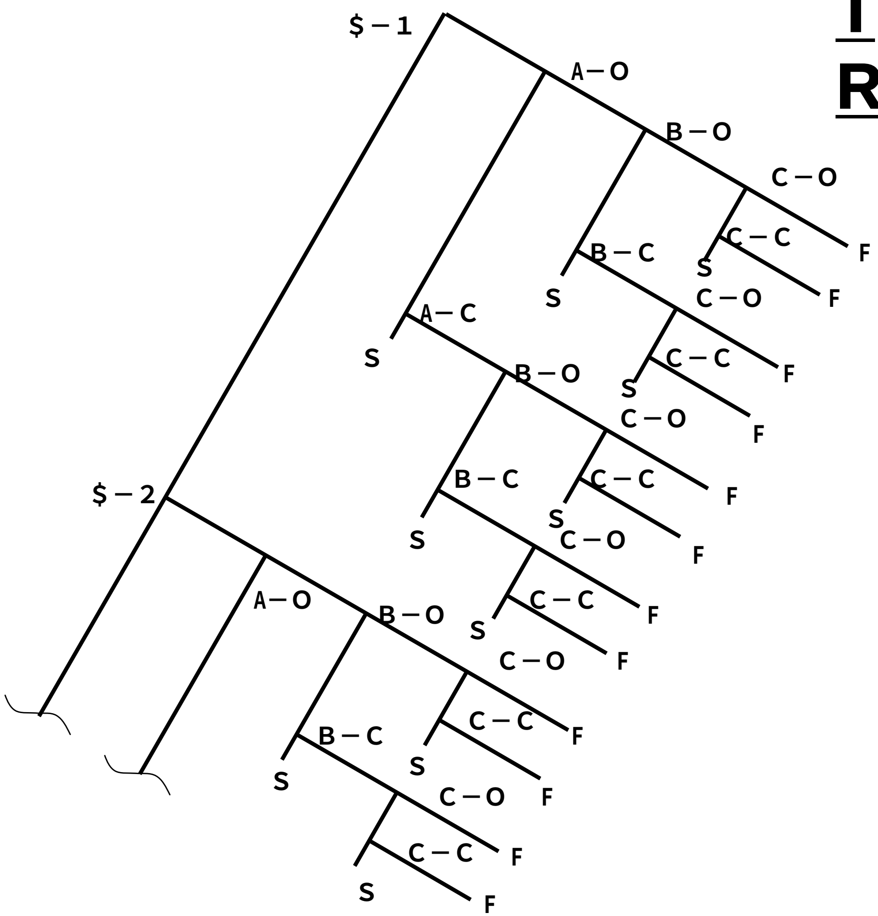
Event Tree Development



Fault Tree Analysis



Human Reliability Analysis



HRA Event Tree

Technique for Human Error Rate Prediction (THERP)

Operation Procedure

1. Operator closes PRC20.4 control valve

↓

2. Operator closes W100 air-operated valve

↓

3. Operator sets PRC20.4 to 0kPa

Reliability Database

Disorder Mode		Failure Rate [/h]	Source
Category	Failure Mode		
Air-Operated Valve	Fail to Operate	1.00E-05	NUREG/CR-2815
Solenoid Valve	All modes	2.00E-06	
Control Circuit	All modes	1.00E-06	IEEE std-500 (1984)
Safety Valve	Fail to Open	2.27E-06	
Annunciator Module	All modes	1.02E-06	
Thermo-couple	All modes	1.79E-06	
Converter		2.39E-06	
Compresser	Fail to start	5.05E-04	TRP Operation Data
Pressure Detect Nozzle	Blockage	1.29E-05	

Importance Measure