HOW TO APPLY DID RISK ANALYSIS FRAMEWORK FOR INTELLIGENT SUPPORT TO MANAGE EMERGENCY SITUATION OF NUCLEAR POWER STATION

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FOREWORD

The author of this presentation is a member of Prof. Yang Jun's research project on Research on the key technologies for intelligent risk-informed decision support system for nuclear safety and emergency response management and his responsibility is Sub-topic IV :Development of an integrated decision support system for risk-oriented intelligent applications.

In this presentation, the author would like to report on his recent output along the direction towards sub-topic IV.

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PART A

HOW TO MONITOR DYNAMICALLY CHANGING RISK STATE FOR ACCIDENT MANAGEMENT

Design principles of NPP safety

Defense in depth; Multiple barriers against radiological releases to the environment.

Four barriers:

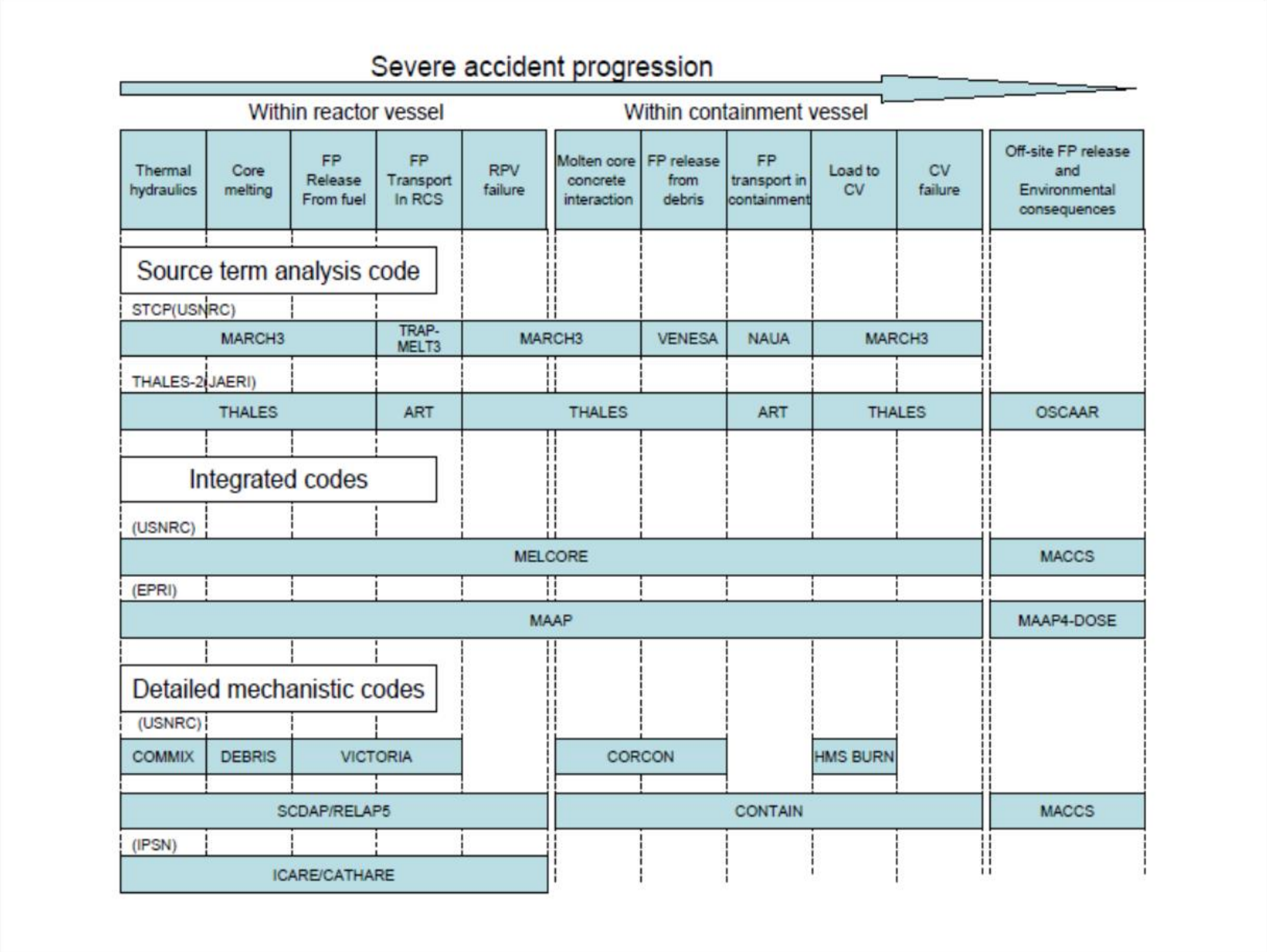
- Nuclear fuel
- Cladding
- Pressure boundary of reactor coolant including reactor vessel
- Containment

Barrier intactness is assured by three safety functions:

- STOP nuclear reaction
- COOL reactor
- CONTAIN radiological release

Reliability of safety functions is enhanced by principles of diversity, redundancy and physical separation

Severe accident sequence and the related severe accident codes



The author's past idea of risk ranking by the combination of two state stop, cool and contain has to be reconsidered!

Risk ranking (principle)

Fukushima Daiichi Accident

Risk level	Stop	Cool	Contain	Possibility of severe accident
0	1	1	1	No risk Safely shutdown, cooled and no release
1	1	1	0	No severe accident phenomena but some problem in containment
2	1	0	1	Loss of not so serious cooling function Safely shutdown, but cooling failed but no release
3	1	0	0	Serious severe accident possible Safely shutdown, but both cooling and contain function failed
3	0	1	1	Severe accident may be suppressed by ESF function Shutdown failed but cooling and no release
3	0	1	0	Some contain function failed Shutdown failed , cooled but released
4	0	0	1	Serious though severe accident phenomena occurr because containment function succeeded Shutdown failed , cooling failed but no release
5	0	0	0	Worst severe accident because all safety functions failed

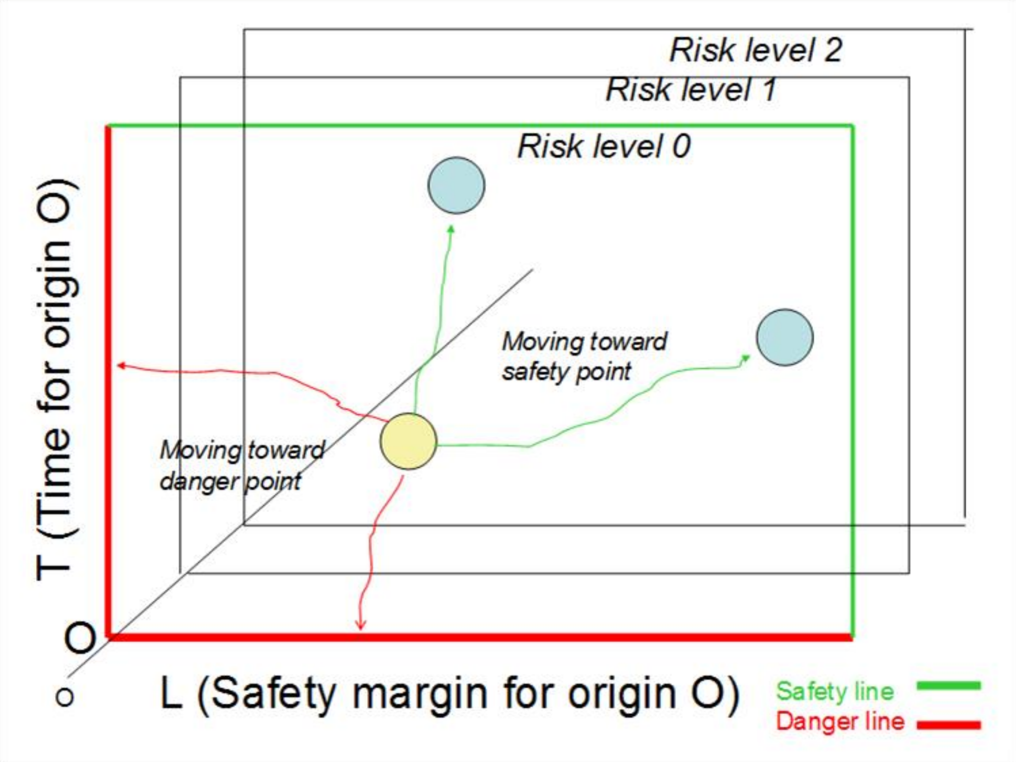
Before tsunami

After tsunami
SBO+ H2 explosion

Chernobyl accident

First, Risk levels should be decided by (i) seeing the intactness of three safety functions, and then Degree of risk by (ii) evaluating by what degree the plant would be damaged based on accident phenomena and their consequences.

Two stage visualization of dynamically changing risk

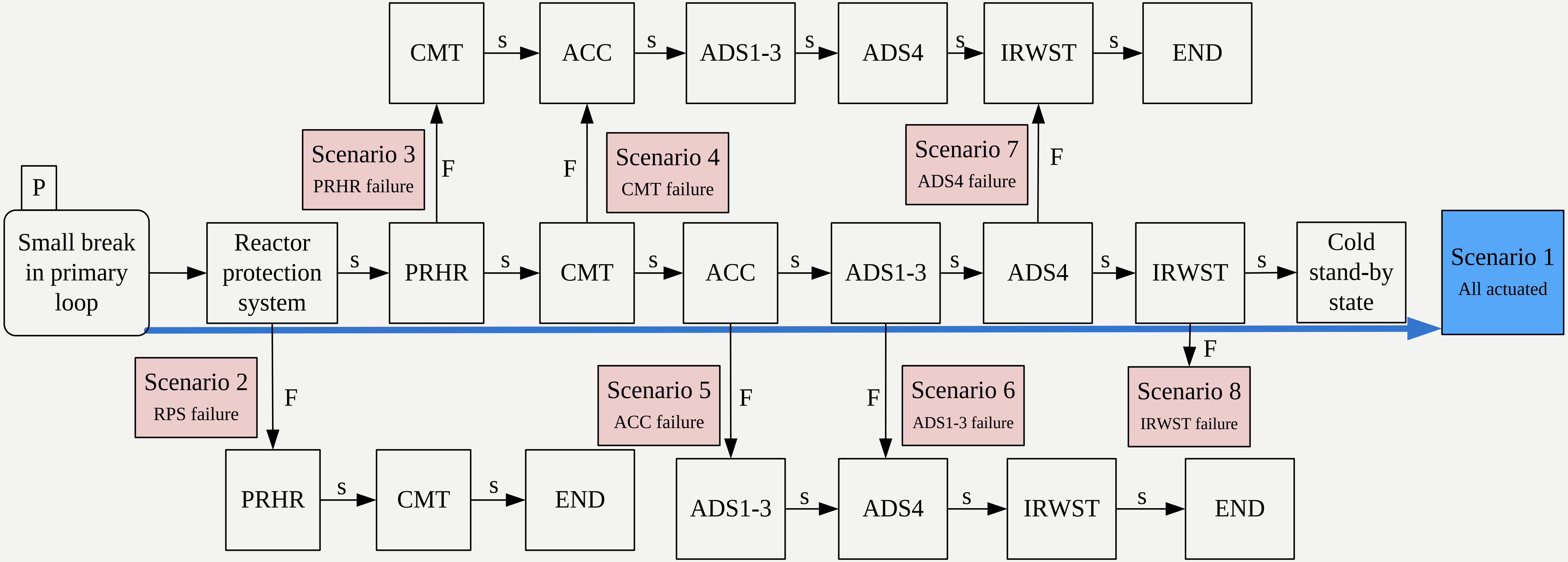


Difference of risk level by different plane
Quantification of risk by two factors in the same risk level;
- Time margin to reach the point of no return
- Degree of physical damage no more to be recovered

AT ISSUE IN THE PAST IDEA

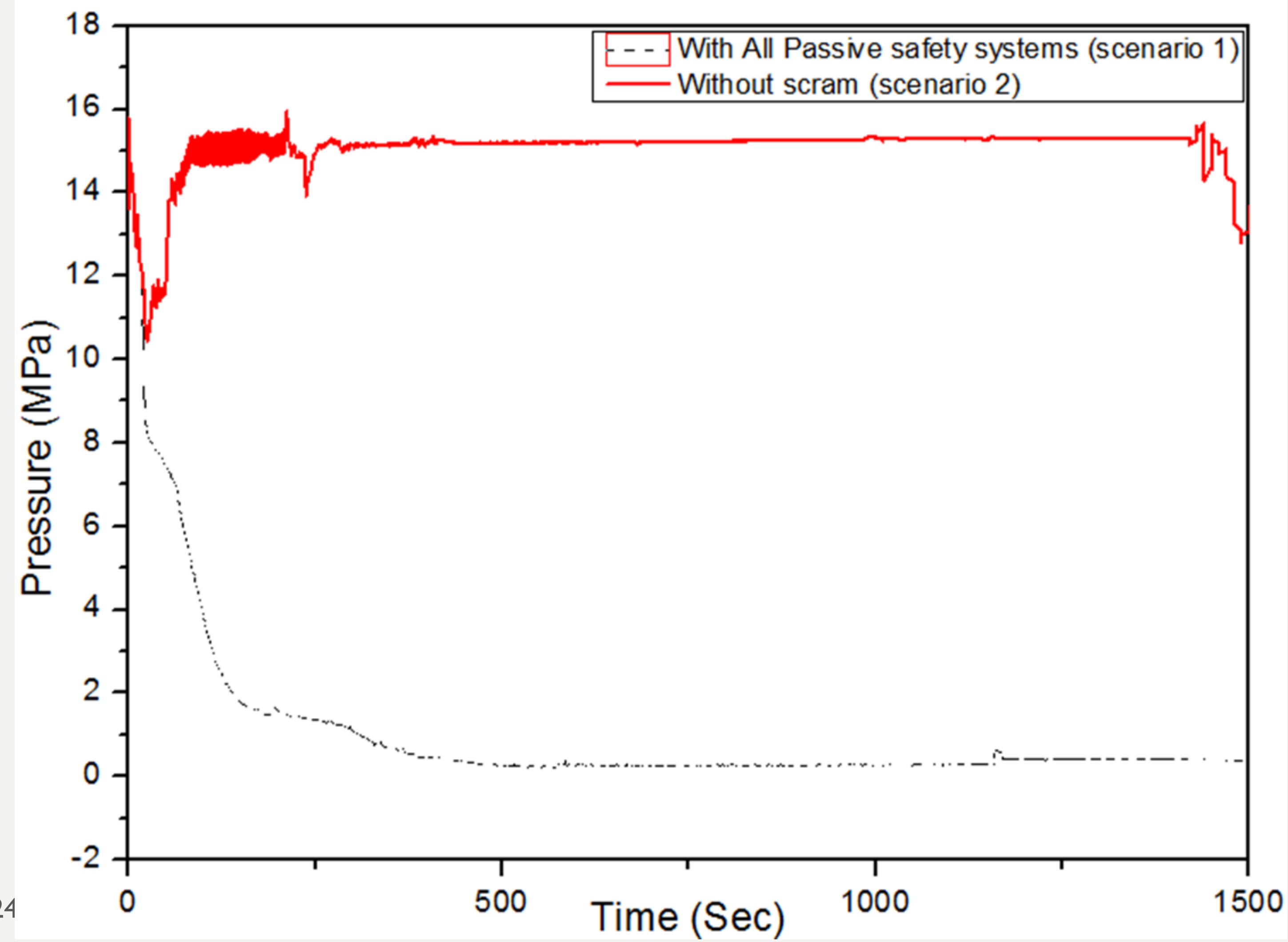
- How to assign different risk plane
- Different risk plane might be IAEA's five Defense-in Depth concept
- For Dr. Yang Jun's project, risk planes may be for DBA and Severe Accident (level 2, 3, and 4)
- And then How to monitor the dangerousness of plant safety
- Here we consider by the case of AP1000 SBLOCA

CASE STUDY : SBLOCA OF AP1000
-RELAP5 CALCULATIONS FOR SBLOCA-



Two scenarios (Scenarios 1 and 2) from 8 possible scenarios were calculated by RELAP5 code

TIME CHANGES OF REACTOR PRESSURE CALCULATED BY RELAP5 CODE (SCENARIO 1 VS 2)



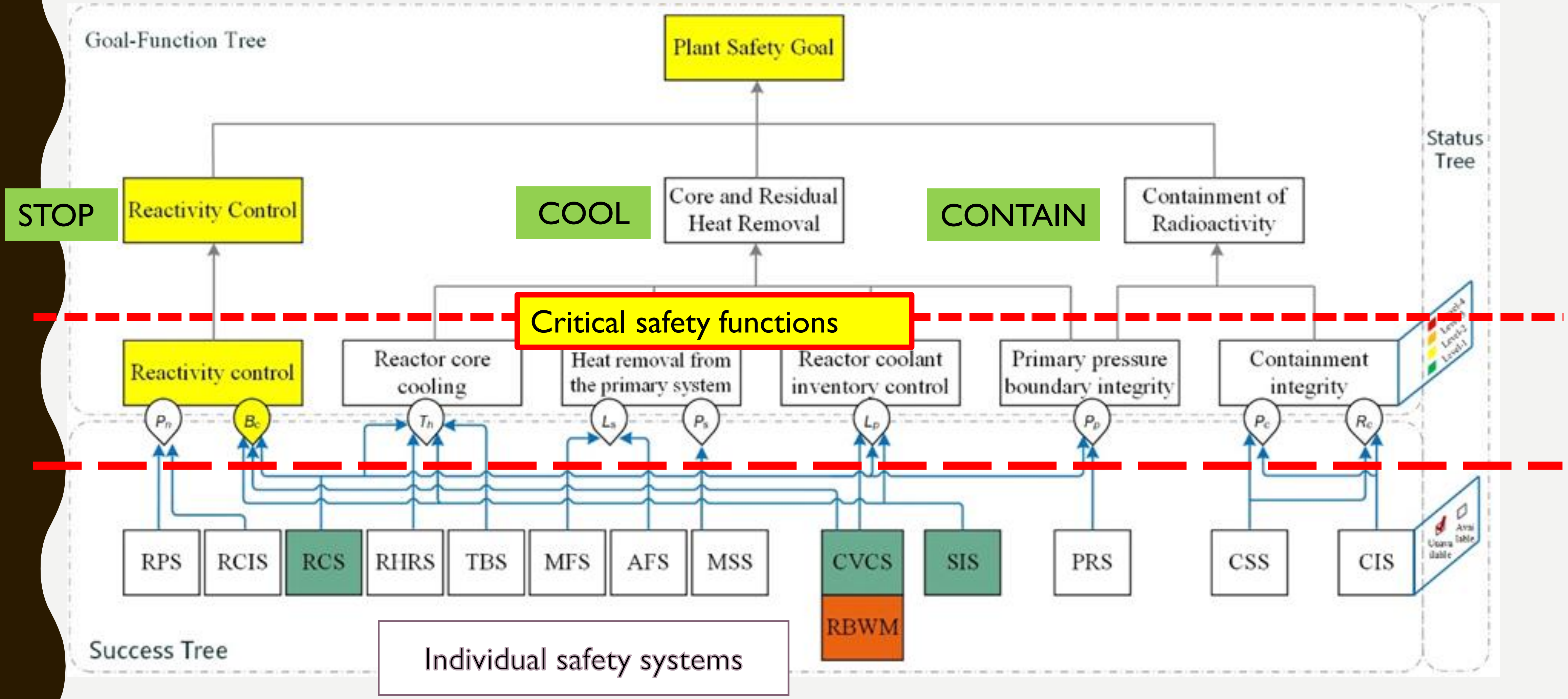
FINDINGS FROM THE AP1000-SBLOCA SIMULATION

- There are more scenarios than depicted by 8 scenarios.
- It is not known whether or not the plant ultimately succeeds in "cold standby state" except for Scenario 1.
- Then what to do?
- We should know (a)whether every safety system (RPS, PRHR, CMT, etc.) works successfully or not at all times, and (b)whether or not every barrier (fuel pellet, cladding, pressure boundaries, containment) maintain its intactness.

How to represent (a)

- Degree of how the intactness of the individual critical safety functions are damaged can be evaluated by monitoring the state of relevant sub-systems as Dr. Yang Jun's reducing knowledge representation by Coupling tree model for critical safety functions with their rating of the seriousness of critical safety functions. (See the next two slides)

Coupling tree model for knowledge representation



State definition of critical safety functions

State	Description	Alarm Priority/Severity Level
Negligible	The critical safety function is operational.	1
Moderate	The critical safety function is partially degraded.	2
Critical	The integrity of a critical safety function is severely damaged.	3
Catastrophic	The integrity of a critical safety function is completely lost.	4

REALIZING CRITICAL SAFETY PARAMETERS MONITORING SYSTEM BY THE AUTHOR'S PROPOSED DID RISK ANALYSIS FRAMEWORK

Offline RELAP5 Calculation (for all possible scenarios)

Time series data of obtained process parameters

The calculated values of plant parameters by RELAP5/MOD4 are used as appropriate sensor signal values (considering time delay, sensor noise, and drift with the continuation of operation).

They are converted to "real time scale" for feeding into the related state chart diagrams.

Plant DiD risk monitor system

Socket interface

State chart diagram

State chart diagram

State chart diagram

HIS Display

Whole plant system should be described by basic plant system, control & safety system, and HIS system, in addition to human organization in the control room.

Procedures for monitoring and state judgement are included in appropriate state chart diagrams of plant DiD risk monitor system.

Various threshold values for state judgement should be adjusted by plant operation mode.

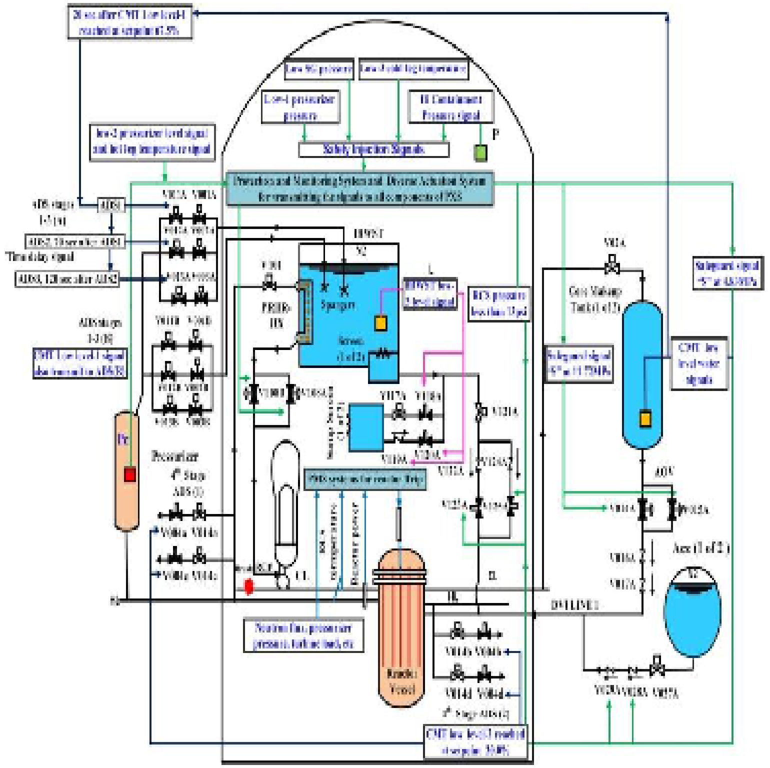
Incoming plant parameters from sensors and messages to HIS display will be mediated by socket interface.

DISPLAY IMAGE FOR OPERATOR

Critical Safety Function Display

T and L Estimation Display

YEAR:MONTH:DAY HR:MIN: SEC POWER XXX MWTH



AUTOMATIC MESSAGE OF DIAGNOSIS & OPERATION GUIDE

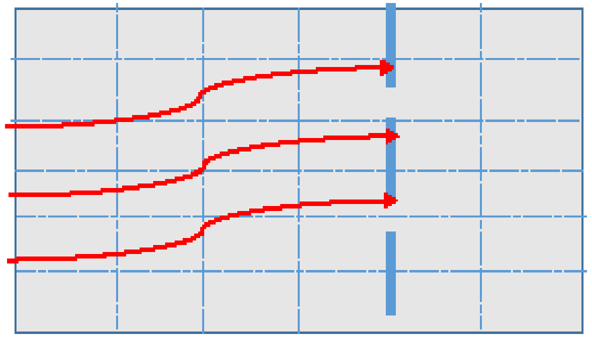
HH:MM:SS REACTOR SCRAM CAUSED BY XXX HIGH & ZZZ ON
CONFIRM XXX & ZZZ

ALARM MESSAGE

HR:MM:SEC MESSAGE

HH:MM:SS PUMP A START
HH:MM:SS VALVE B CLOSE
HH:MM:SS REACTOR SCRAM

SELECTED TREND GRAPGH



THEN WHAT TO DO FOR ESTIMATING BOTH T AND L IN RISK PLANE?

- To know how the plant is in dangerous state at present and to predict future is another thing.
- You can display the present dangerousness as by adding Dr. Yang Jun's knowledge presentation to the DiD risk monitor system.
- Estimating both T and L in individual risk plane is important information for the proper accident management to take appropriate countermeasures by timely fashion. So we need any proper means to estimate the both parameters in real time.

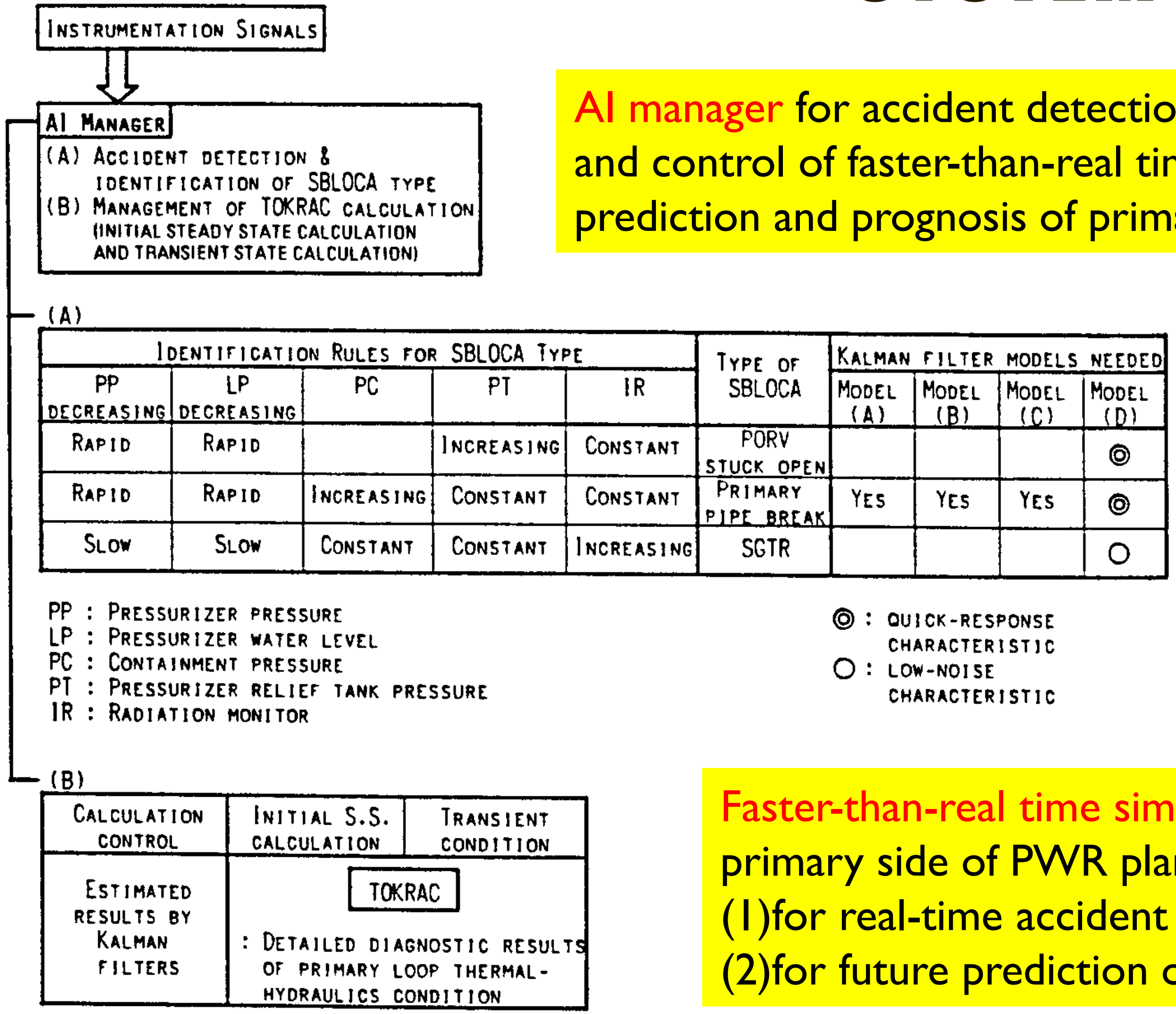
Problems here from the aspect of emergency management

- To know all the state of individual safety functions is vital for the health monitoring of the plant state, but it is further necessary to diagnose dynamically changing risk state by those health monitoring data in accident situation.
- It is also necessary to consider on how to recover from the monitored risk state to more safety state in a timely fashion which can be made either by human operator or by automatic function.

PART B
REVIVAL OF THE AUTHORS' PAST STUDY ON "FAST ACCIDENT TRACKING SYSTEM" AS INTELLIGENT DECISION SUPPORT FOR NPP EMERGENCY MANAGEMENT

J.WAKABAYASHI, H.YOSHIKAWA, A.GOFUKU: DIAGNOSTIC PLANT ANALYSIS FOR NUCLEAR POWER PLANT EMERGENCIES, PROC. INTERNATIONAL CONFERENCE ON MAN-MACHINE INTERFACE IN THE NUCLEAR INDUSTRY (CONTROL AND INSTRUMENTATION, ROBOTICS AND ARTIFICIAL INTELLIGENCE),15-19, FEB.1988, TOKYO, JAPAN. (IAEA)

THREE ELEMENTS OF "FAST ACCIDENT TRACKING SYSTEM"



INSTRUMENTATION SIGNALS

AI MANAGER
(A) ACCIDENT DETECTION & IDENTIFICATION OF SBLOCA TYPE
(B) MANAGEMENT OF TOKRAC CALCULATION (INITIAL STEADY STATE CALCULATION AND TRANSIENT STATE CALCULATION)

(A)

IDENTIFICATION RULES FOR SBLOCA TYPE					TYPE OF SBLOCA	KALMAN FILTER MODELS NEEDED			
PP DECREASING	LP DECREASING	PC	PT	IR		MODEL (A)	MODEL (B)	MODEL (C)	MODEL (D)
RAPID	RAPID		INCREASING	CONSTANT	PORV STUCK OPEN				◎
RAPID	RAPID	INCREASING	CONSTANT	CONSTANT	PRIMARY PIPE BREAK	YES	YES	YES	◎
SLOW	SLOW	CONSTANT	CONSTANT	INCREASING	SGTR				○

PP : PRESSURIZER PRESSURE
LP : PRESSURIZER WATER LEVEL
PC : CONTAINMENT PRESSURE
PT : PRESSURIZER RELIEF TANK PRESSURE
IR : RADIATION MONITOR

◎ : QUICK-RESPONSE CHARACTERISTIC
○ : LOW-NOISE CHARACTERISTIC

(B)

CALCULATION CONTROL	INITIAL S.S. CALCULATION	TRANSIENT CONDITION
ESTIMATED RESULTS BY KALMAN FILTERS	TOKRAC : DETAILED DIAGNOSTIC RESULTS OF PRIMARY LOOP THERMAL-HYDRAULICS CONDITION	

FIG. 5. Roles and functions of AI manager as required for effective computerized diagnostic plant analysis.

AI manager for accident detection, diagnosis of accident type, and control of faster-than-real time lant simulator for detailed prediction and prognosis of primary side of PWR reactor

Diagnostic plant analyzer by a set of Kalman filters give the types of SBLOCA as well as real time estimation of unmeasurable safety parameters by plant sensors. The estimated parameters then gives the input to the faster-than-real time plant simulator.

Faster-than-real time simulator to simulate only the primary side of PWR plant
(1)for real-time accident tracking
(2)for future prediction of accident trend

SIMPLIFIED PLANT MODEL TO REDUCE KALMAN FILTER MODELS

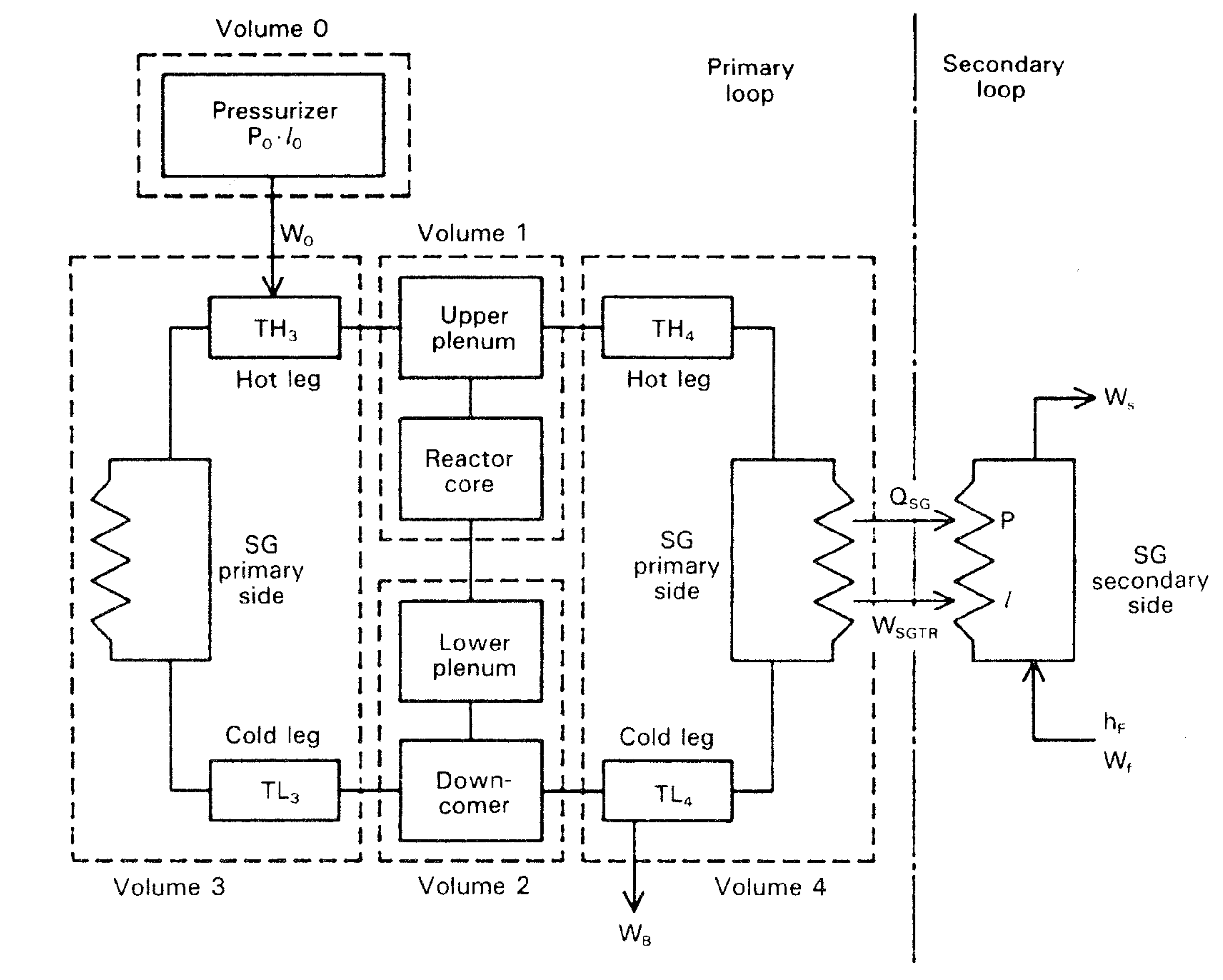


Fig. 1. Simplified primary system model.

Input plant signals

Four kinds of Kalman filter

Estimated unmeasurable
Plant parameters
By Kalman filters

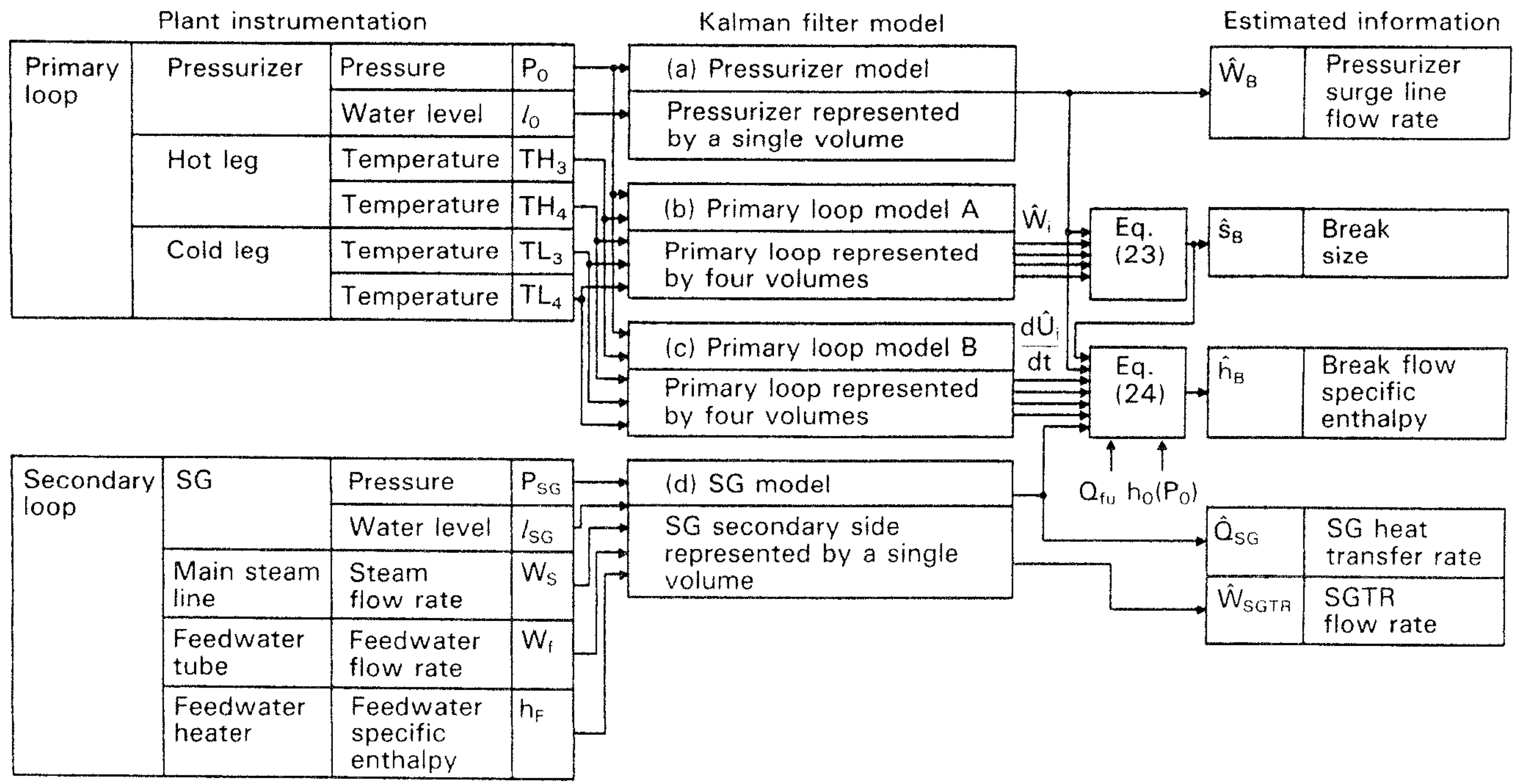


Fig. 2. Relationship between the observed signals by plant instrumentation, Kalman filters, and the resultant estimated parameters.

Intercomparison of SGTR leak rate prediction between Kalman filter and RELAP5/MOD

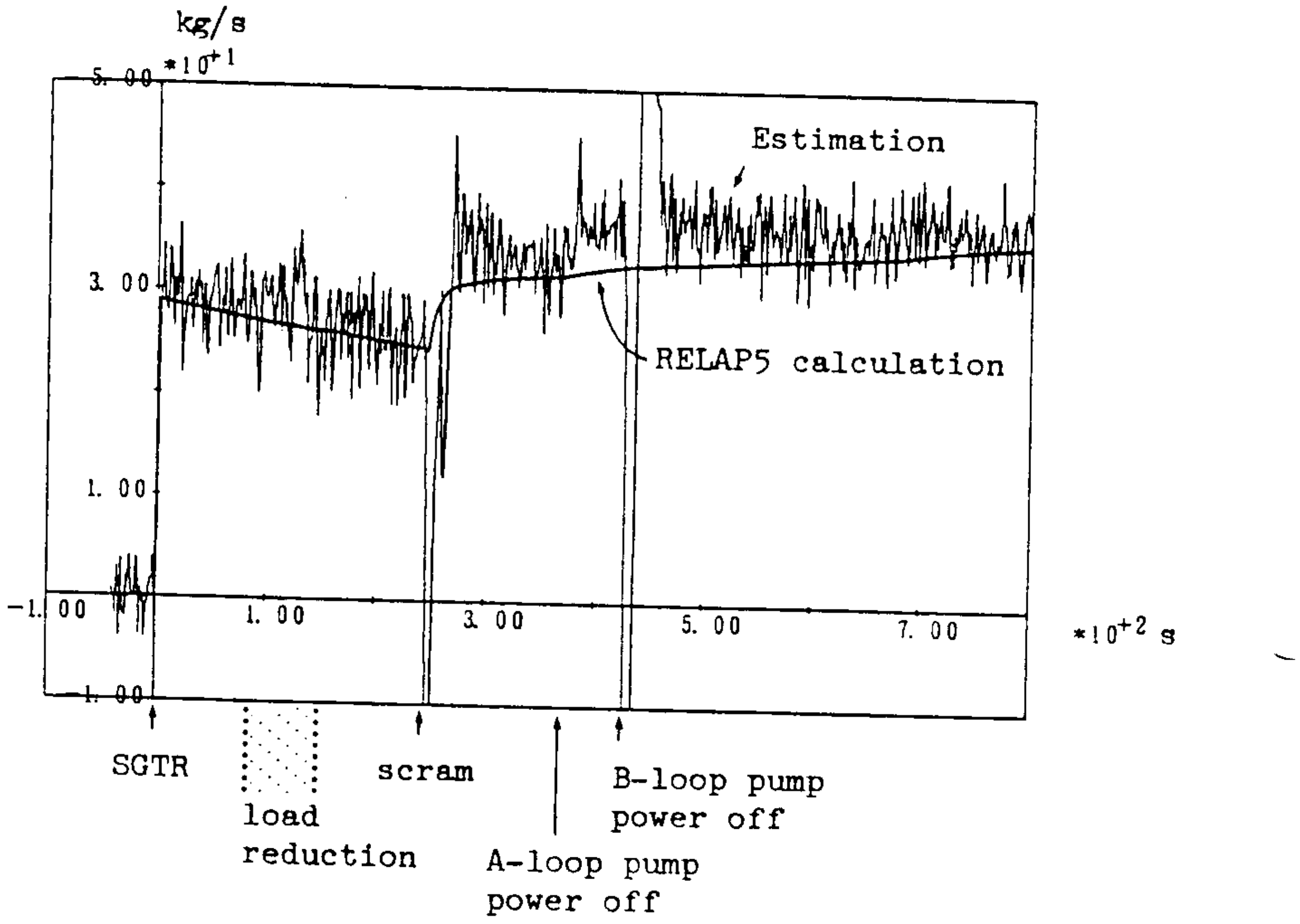


FIG. 3. Intercomparison of time trajectories of leak flow rate in Prairie Island Unit 1 SGTR accident (RELAP5/MOD1 calculation versus Kalman filter estimation).

FASTER-THAN-REAL-TIME SIMULATOR TOKRAC FOR PWR SBLOCA ACCIDENT

- Simulate major components of PWR primary plant system only with Homogenous Flow model by Node and Junction scheme
- Various boundary conditions for TOKRAC are given as external input as follows;

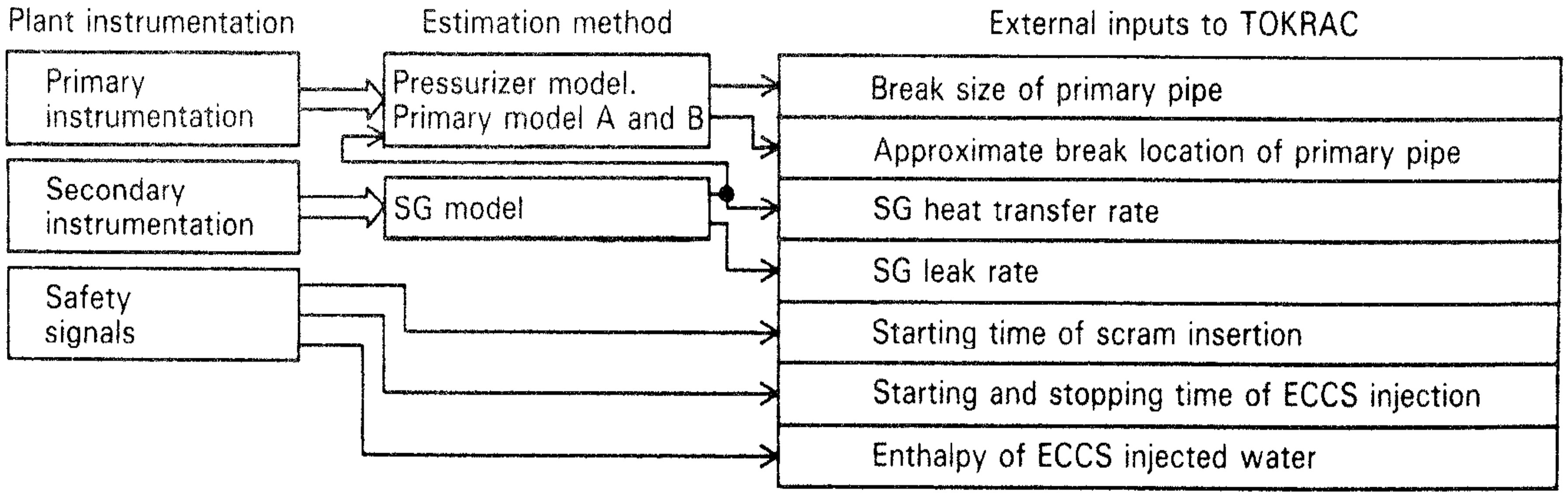


Fig. 3. Relationship between external input to TOKRAC and observed signals from plant instrumentation.

NODE AND JUNCTION SCHEME EMPLOYED IN TOKRAC

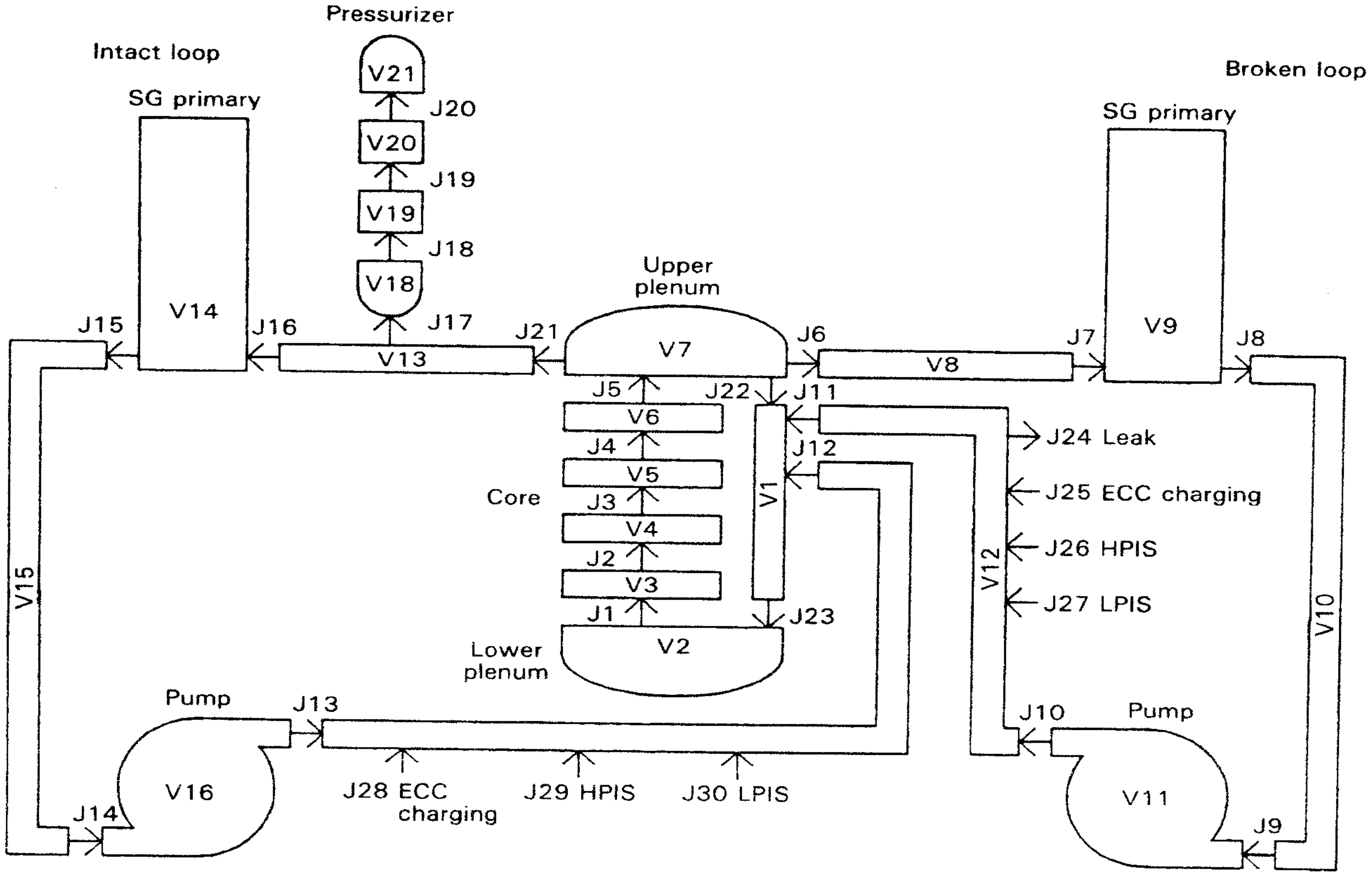


Fig. 11. Nodalization scheme of a Westinghouse-type PWR plant for a 1.5% cold-leg SBLOCA simulation by TOKRAC.

INTERCOMPARISON BETWEEN TOKRAC AND RELAP4/MOD6

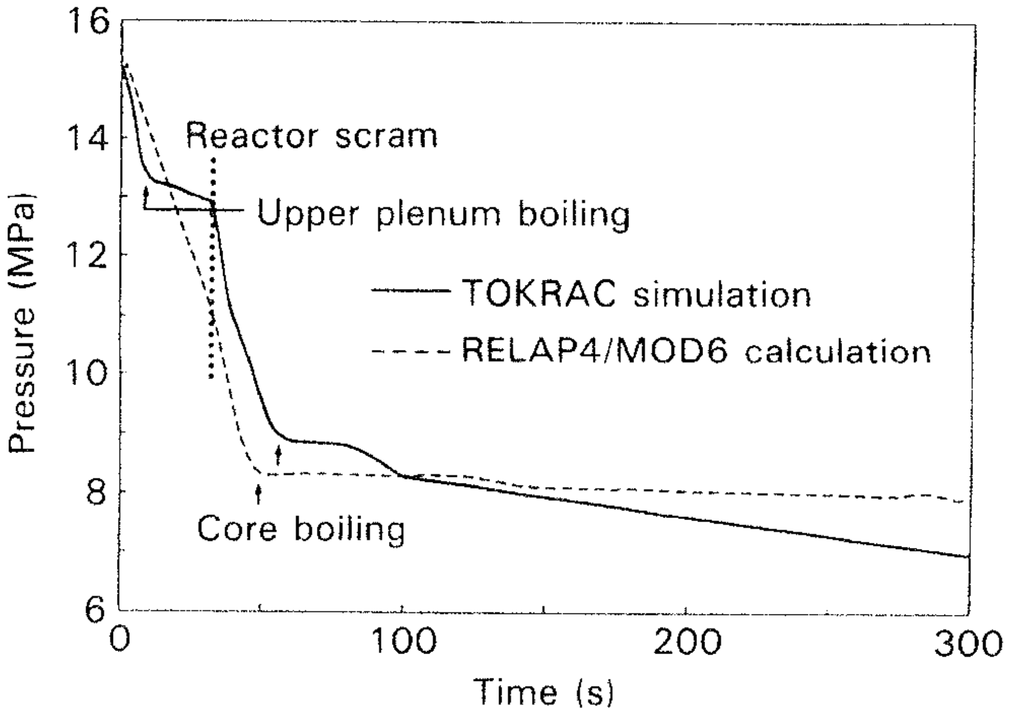


Fig. 12. Time histories of upper plenum pressure calculated by TOKRAC and RELAP4/MOD6 in the case of a 1.5% cold-leg SBLOCA.

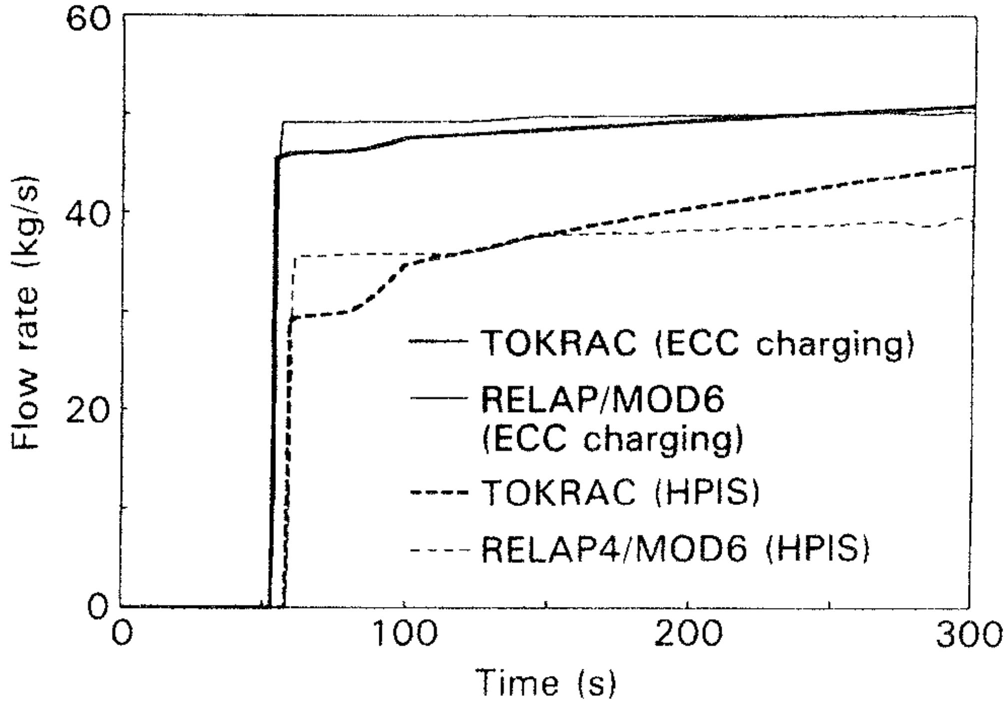


Fig. 15. Time histories of injection flow rate by ECC charging and HPIS calculated by TOKRAC and RELAP4/MOD6 in the case of a 1.5% cold-leg SBLOCA.

CONCLUDING REMARKS

- In this presentation, the author reviewed his past studies on DiD Risk Analysis Framework for NPP in order to realize intelligent support to emergency situation management.
- The author would like to point out promising capability of his past study on "fast accident tracking system " as intelligent decision support for NPP emergency management.
- This is realized by AI techniques as a sort of Data Assimilation: More accurate predictive analysis can be made by blending simulation and data science.

CONCLUDING REMARKS

- Faster-than-real time simulator for real-time accident tracking not only gives the detail estimation of the safety barriers of NPP. But also the future prediction of accident trend gives the time margin until the disruption of the barrier.
- The crucial feature is the construction of Kalman filters to estimate unmeasurable safety-related physical parameters from the plant signals and use them as data assimilation for detailed and prompt estimation of risk-related parameters such as time margin until critical stage.
- For realizing further capability other than just monitoring, you have to implement various countermeasures to recover the reactor from those risky state that can be made by operator intervention or automatic measures.
- Those functions should be implemented into the DiD risk monitor system as a whole in order to realize an integrated decision support system for risk-oriented intelligent applications.

THIS IS THE END OF MY PRESENTATION.

THANK YOU VERY MUCH FOR YOUR KIND ATTENTION.