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SIMULATING OPERATOR DECISION PROCESSES AT SAVANNAH RIVER (U)

by

H. C. Benhardt
Westinghouse Savannah River Co.
Savannah River Site
Aiken, South Carolina

D. G. Hoecker
Westinghouse Science & Technology Center
Pittsburgh, PA 15235

H. E. Pople, Jr.
Seer Systems, Inc.
Pittsburgh, PA 15213

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Douglas G. Hoecker
Westinghouse Science & Technology Center
Pittsburgh PA 15235

Harry E. Pople, Jr.
Seer Systems, Inc.
Pittsburgh PA 15213

H. Carl Benhardt
Westinghouse Savannah River Laboratory
Aiken SC 29808

INTRODUCTION

Cognitive Environment Simulation (CES) is both a methodology and an AI tool. As a methodology, it denotes a technique that models human operators' cognitive processes to either (a) aid in designing the interface to a complex system (such as nuclear reactor control room), or (b) assess the cognitive causality that affects the likelihood of human error in specific accident scenarios. As an AI tool, CES is an expert system that models human operators' reasoning and decision processes. In this application, both the methodology and the tool were focussed on modeling human intention formation and errors in a problem-solving context.

The CES tool consists of an inference engine and knowledge base that are object-oriented at a level of analysis to facilitate the modeling of human decision-making. While descended from the early AI successes of Internist and Caduceus in the arena of medical diagnosis (Pople, 1985), CES has been restructured and enhanced to deal with additional knowledge requirements encountered in real-time control of complex systems. This version of CES receives its input from a *virtual display*, a file of several hundred plant parameters whose values are sampled every five seconds. Analogously to a crew observing control room displays, CES reads the virtual display file and evaluates what it "sees". CES' evaluation is based on the changes it observes in relation to its prior knowledge of operational goals, plant structure, event history, and operator procedures that are represented in its knowledge base. Its output is an English-like protocol of observations, explanations, and declarations of recommended action (intent) that it would take if it could. These last also represent actions that human operator(s) could take if they so decide. Through manipulation of its knowledge base, CES can also be caused to make mistakes for human-like reasons.

OBJECTIVES

The primary objective of this research has been to develop a new methodology for the study of human reliability, complete with an analytic tool (CES) for learning about context-specific psychological precursors (Wagenaar, Hudson, & Reason, 1991) to operator error in controlling complex processes. The immediate objective of the reported work (Hoecker, Pople, & Benhardt, 1991) was to demonstrate the feasibility of applying CES to a new domain – that of the defense production reactors, whose design and operating philosophy differ in key areas from power reactors, where CES has already demonstrated interesting results (e.g., Woods, Pople & Roth, 1990).

With the recent exercise of CES on a cognitively hard but otherwise easily controllable high-fidelity simulation (combined, moderate-scale primary and secondary cooling system leaks), analysis of the results shows that objective has been met. The purpose of developing a challenging scenario was to generate a plausible yet error-prone context in which to use CES evaluate the performance shaping factors that influence decision-making and error commission. The cognitive difficulty in the scenario arose from a number of sources, but primarily because the first break changed the context in which the second event occurred, so that commonly-used procedures for the second break as an isolated event no longer applied. This meant that the solution to the first break had to be re-worked before action could commence on dealing with the second break. While crews could handle the scenario successfully, it was difficult because of the limited time available for diagnosis and action. Comparing the performance of CES with crews showed that at a top level, CES' responses resembled those of the human operators who responded successfully to the very same event—although operators received their data via the control boards, while CES received its data via the virtual display. CES was also fast, taking less than a minute to process a virtual display representing 45 minutes of human-system interaction. This is encouraging for CES' potential application as a decision-aid although the work reported here was directed toward analytic tools for the design and evaluation of control stations and procedures.

Analysis of crew performance in this scenario showed that operators thought much more broadly and deeply than CES about the issues confronting them. This was expected; the analysis had been performed to provide a rich basis for iteratively growing the knowledge base. It also showed a number of potentially error-likely passages that could become topics for later research into improved performance factors in the control room. While none of these led to the actual commission of error actions, from an error-theoretic view they suggest points at which the combined working knowledge structure (represented here by operators, procedures, and the control room interface) may have higher vulnerability to operator error in the context of this kind of event. The high cost of cognitive task analysis argues for a number of enhancements to CES to make it more productive as a tool to more efficiently uncover and evaluate the large number of intriguing issues that can be generated in just a few simulations that explore this kind of scenario.

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D. G. Hoecker
H. E. Pople
H. C. Benhardt

Westinghouse Computer Symposium
October 21–22, 1991

Human Sciences Dept 401–2B8
Westinghouse Science & Technology Center
Pittsburgh PA 15235

(412) 256–2750 / 1393

internet: hoecker%cognac@unxgtw.wec.com
wems: hoecker.d

OUTLINE

- CES BACKGROUND
- SRS APPROACH
- RESULTS
- CONCLUSIONS

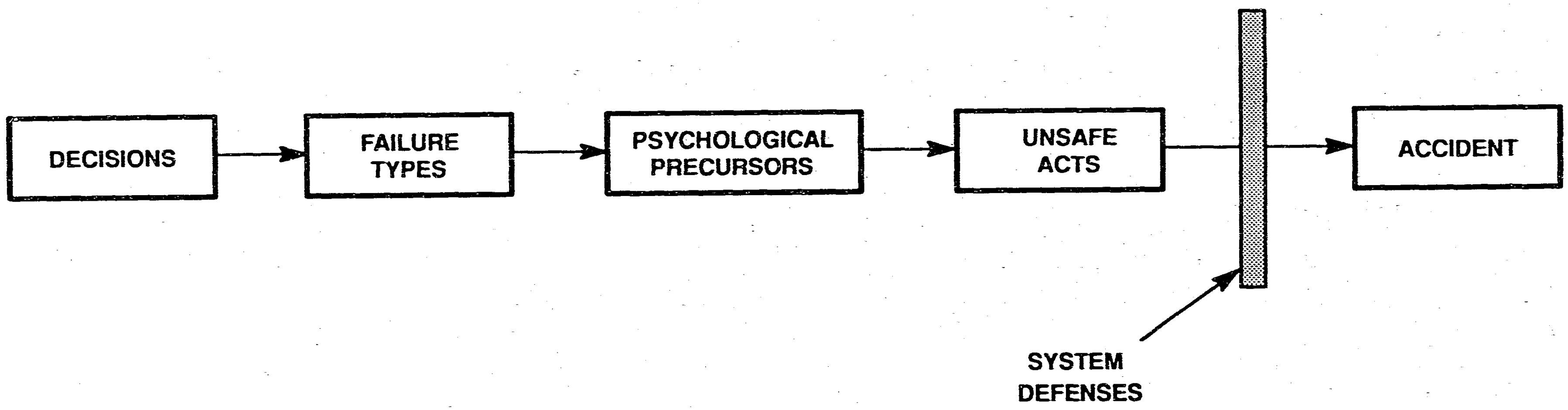
COGNITIVE ENVIRONMENT SIMULATION (CES)

What is it ?

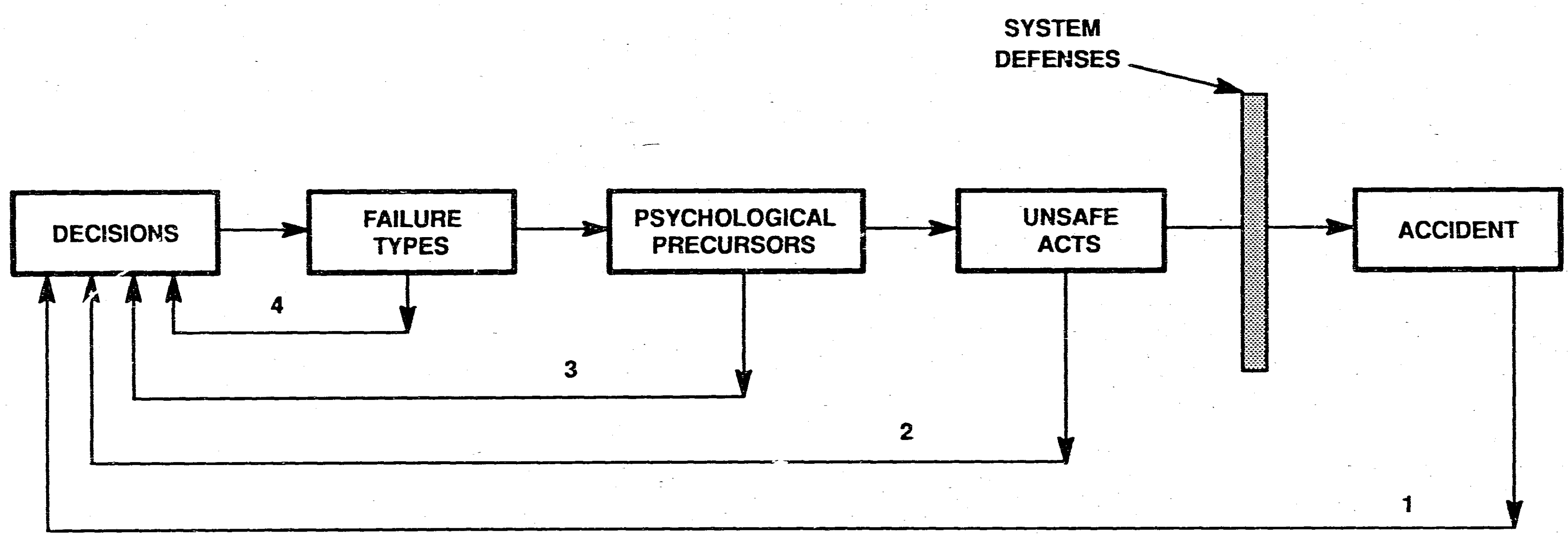
- WHY IS IT?
- A METHODOLOGY
- A SPECIFIC INSTANCE of CODE
- ANALYTIC AID for COMPLEX INTERFACE DESIGN
- DECISION AID for REAL TIME OPERATIONS

CES Background

SCENARIO of an ACCIDENT

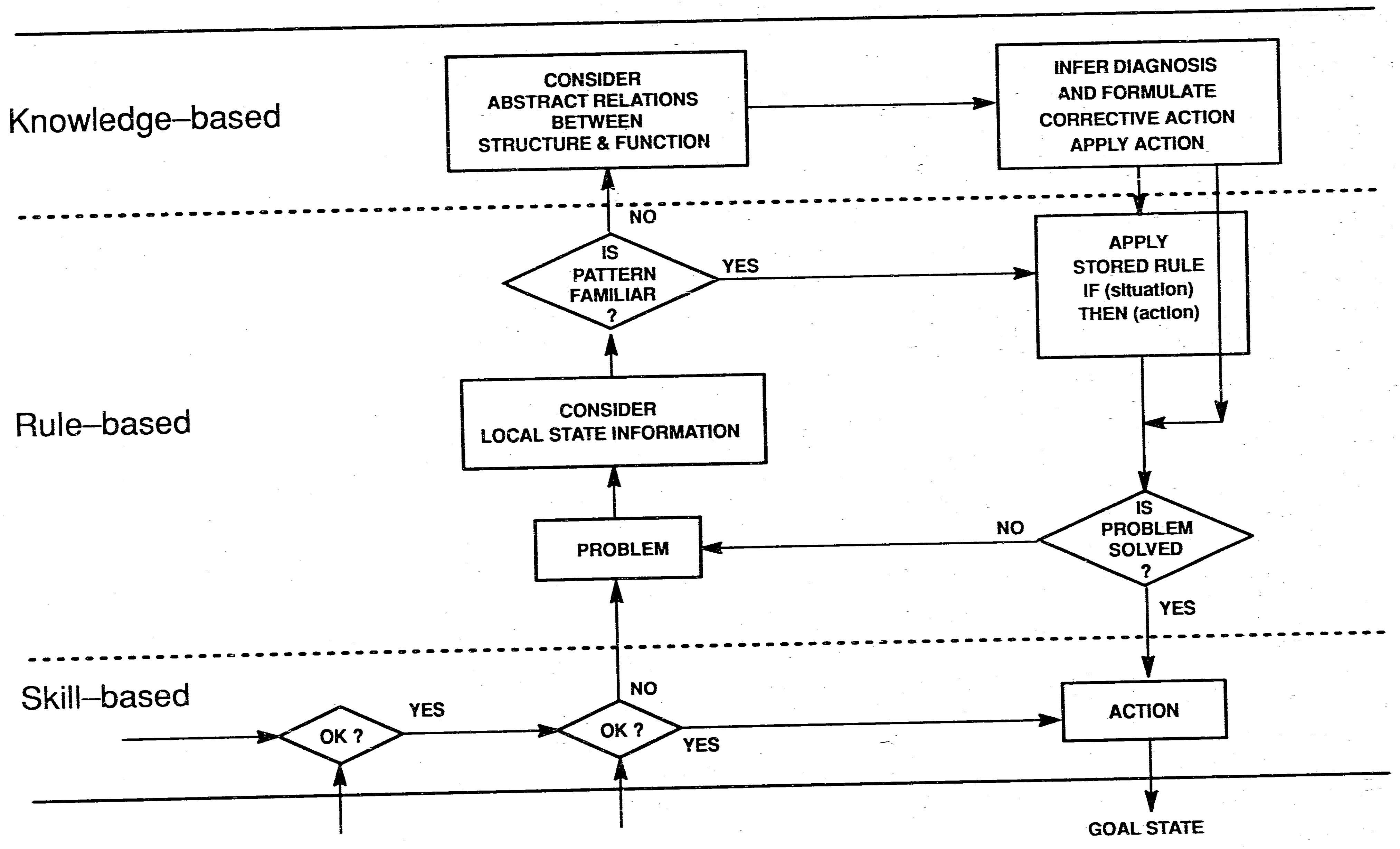


FEEDBACK of SAFETY PERFORMANCE INDICATORS



adapted from Wagenaar, Hudson, & Reason (1990)

GENERIC ERROR MODELING SYSTEM (GEMS)



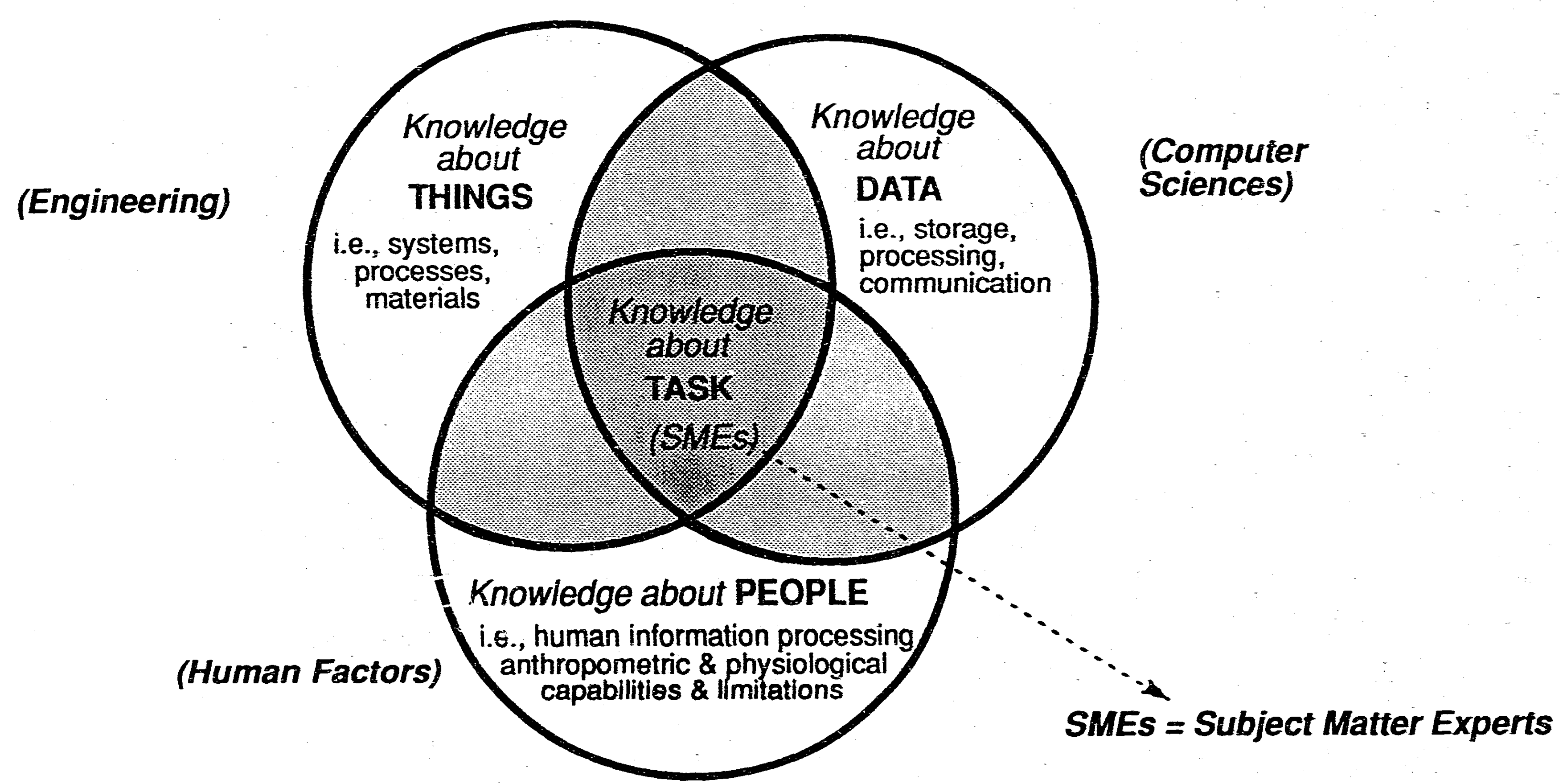
for estimating system reliability

CHALLENGES in CURRENT HRA PRACTICE

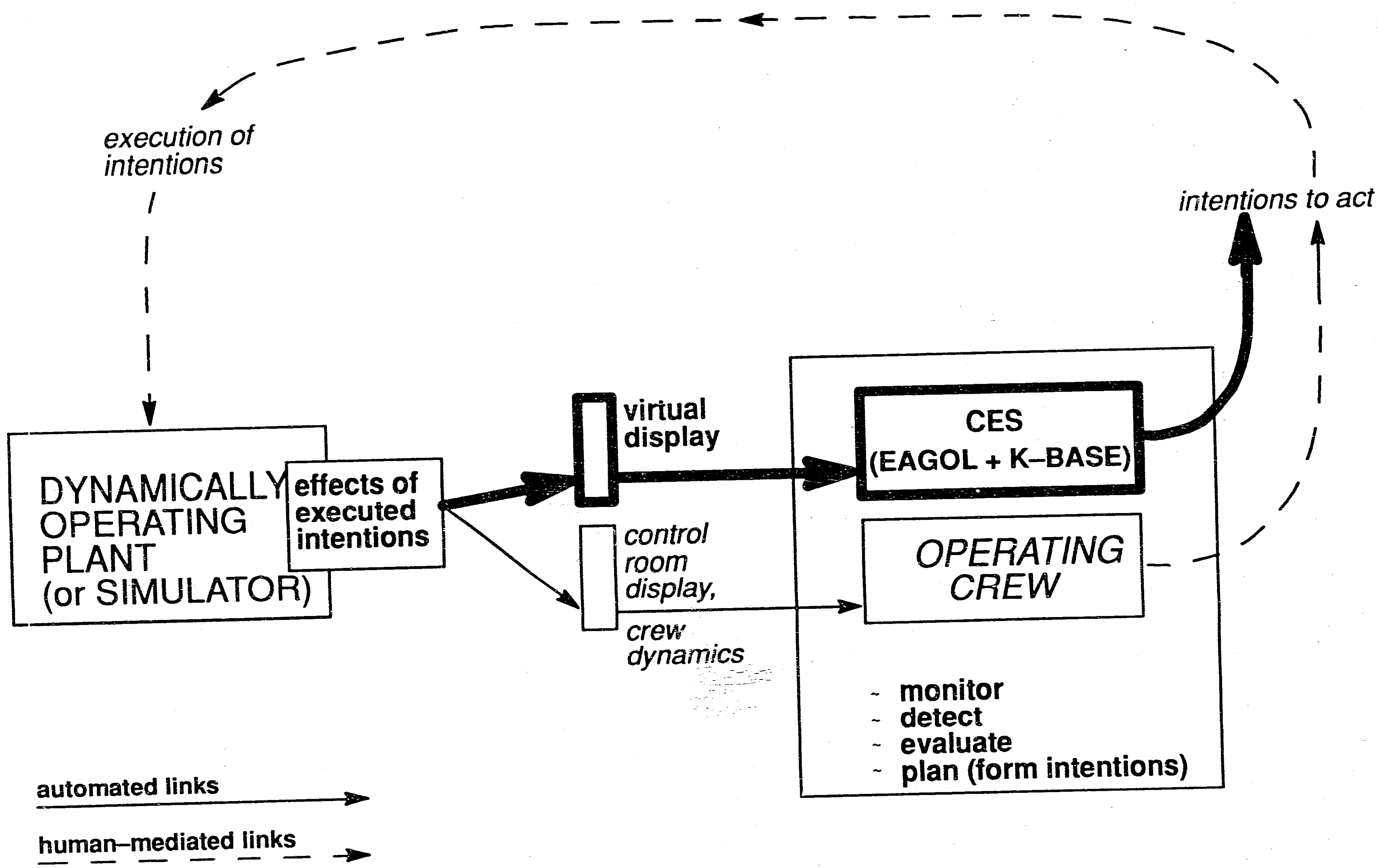
- **usable error performance data are rare**
- **tends to ignore specific cognitive factors that lead to error,**
- **error performance data that do exist have problems**

adapted from Dougherty, 1990

INTEGRATING FOUR CONTEXTS for EFFECTIVE INTERFACE REQUIREMENTS



CES as a Methodology and an Analytic Aid



COGNITIVE ENVIRONMENT SIMULATION (CES)

The Software

- DESCENDANT of INTERNIST, CADEUCEUS MEDICAL RESEARCH
- BASED on *EAGOL* INFERENCE ENGINE
- OBJECT–ORIENTED, SENSITIVE to TIME, INTERVENTION, and INTENT
- 5 YEARS of DEVELOPMENT by NRC
- DESIGNED TO MODEL *INTENTION FORMATION*, & ERRORS of *COMMISSION*

EAGOL

E pistemic

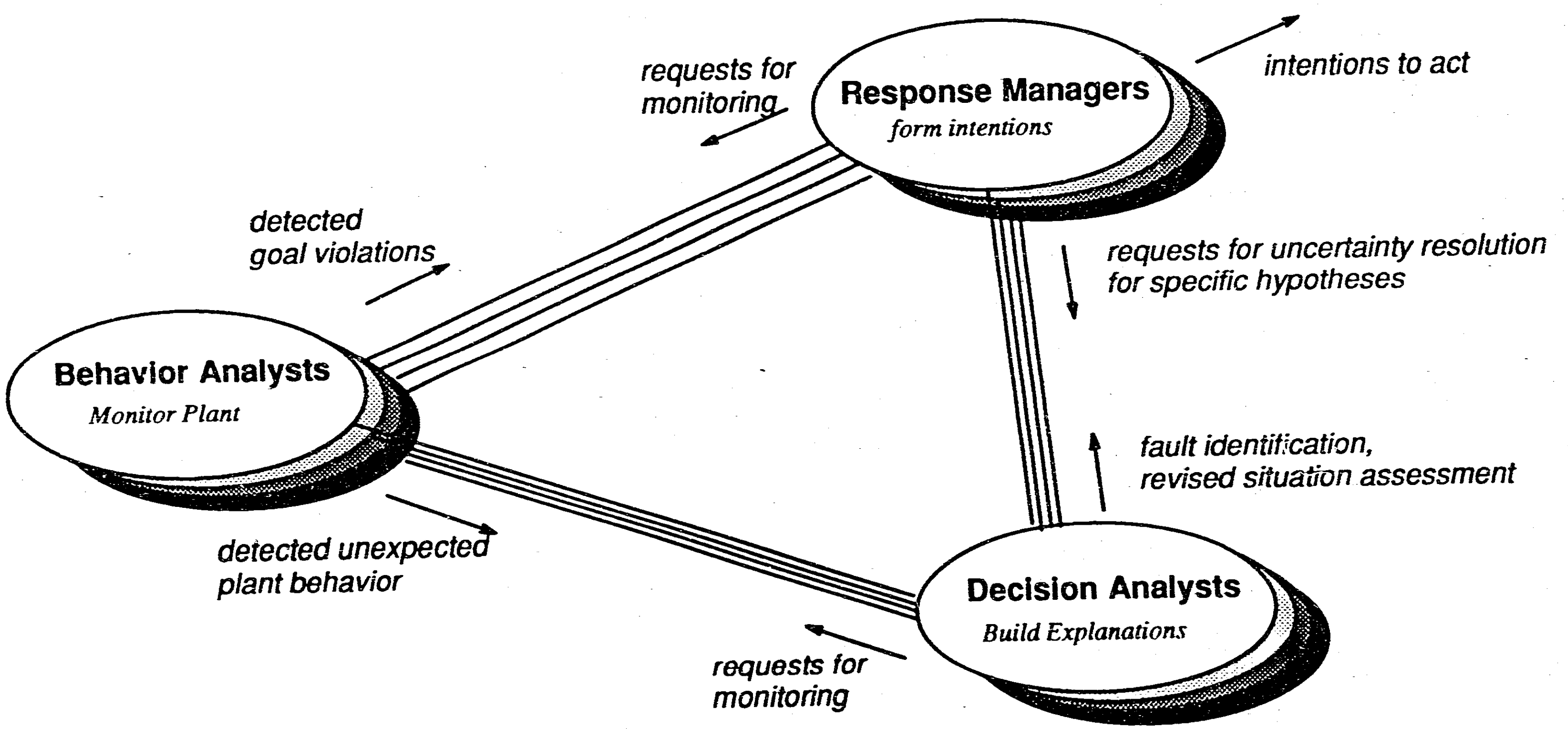
A bductive

G oal–

O riented

L anguage

TYPES of ANALYST "OBJECTS" in the EAGOL ARCHITECTURE

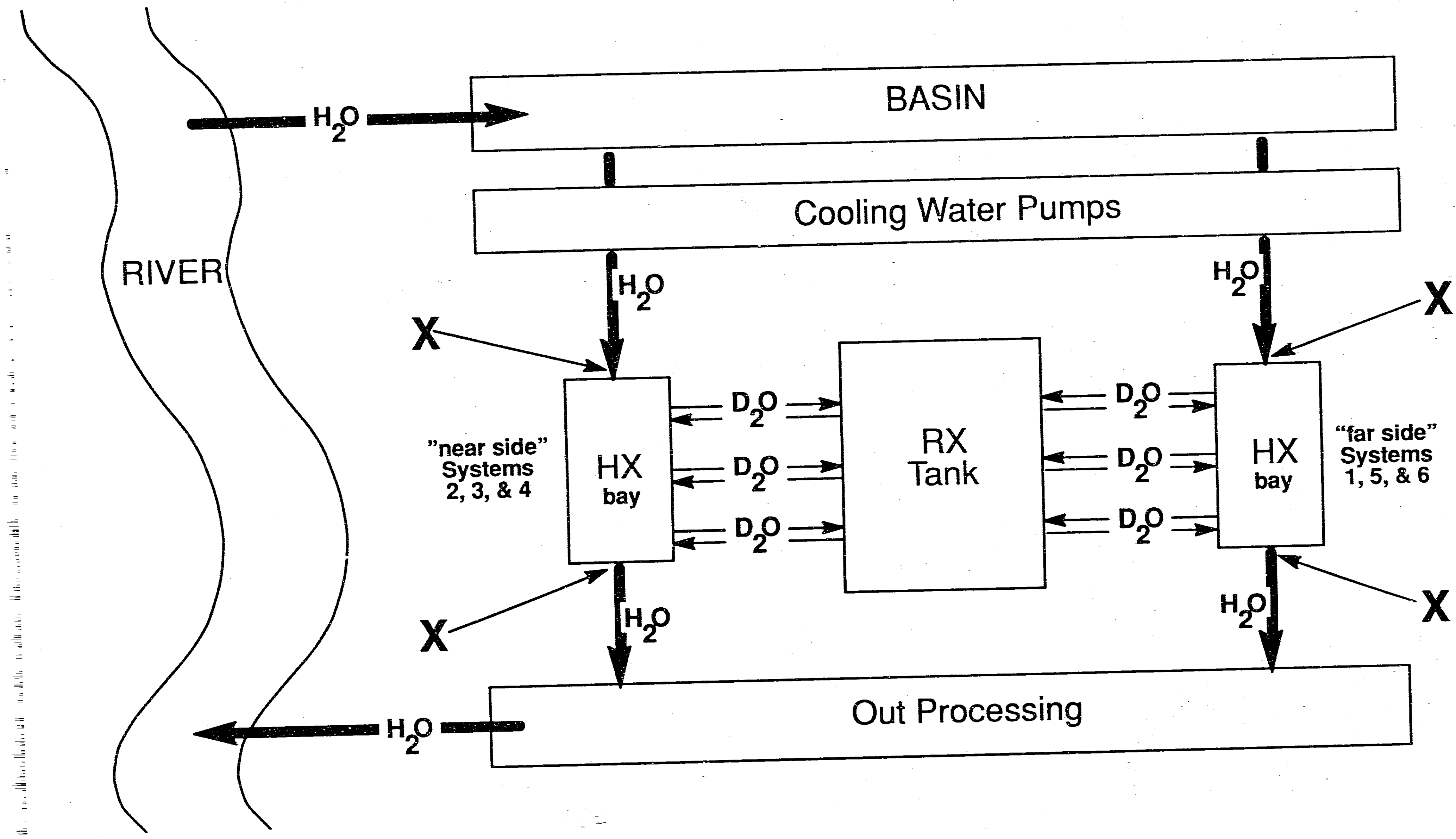


adapted from Woods, Roth, & Pople, 1990

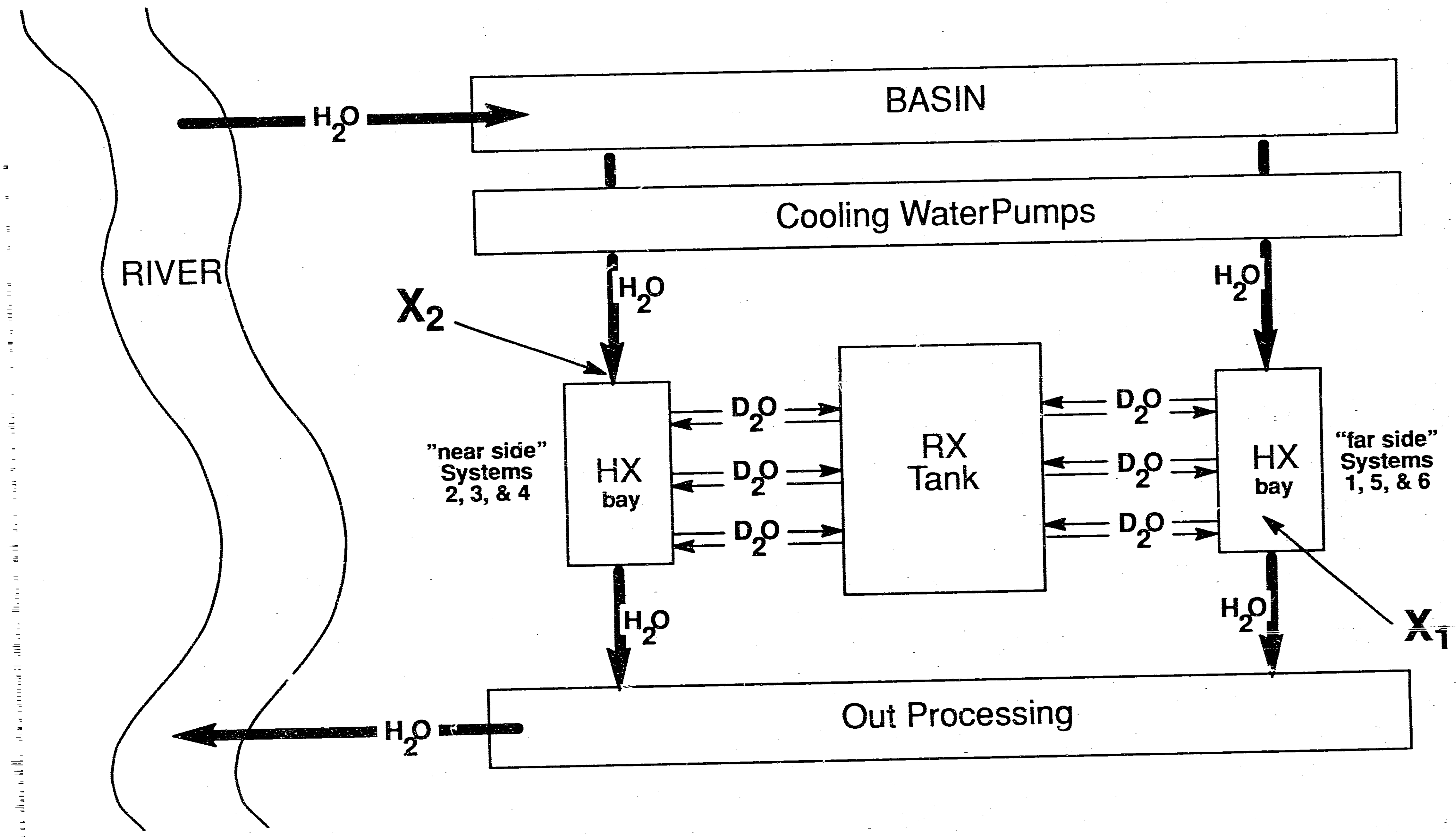
APPROACH to INITIATE CES at Savannah River

- **Familiarization**
- **Specify Scenario**
- **Cognitive Task Analysis**
- **Build Knowledge Base**
- **Run Scenario on Simulator**
- **Compare, Contrast Crew and CES Decision Sequences**

BLOCK DIAGRAM for LOSS of PUMPING ACCIDENT (LOPA)

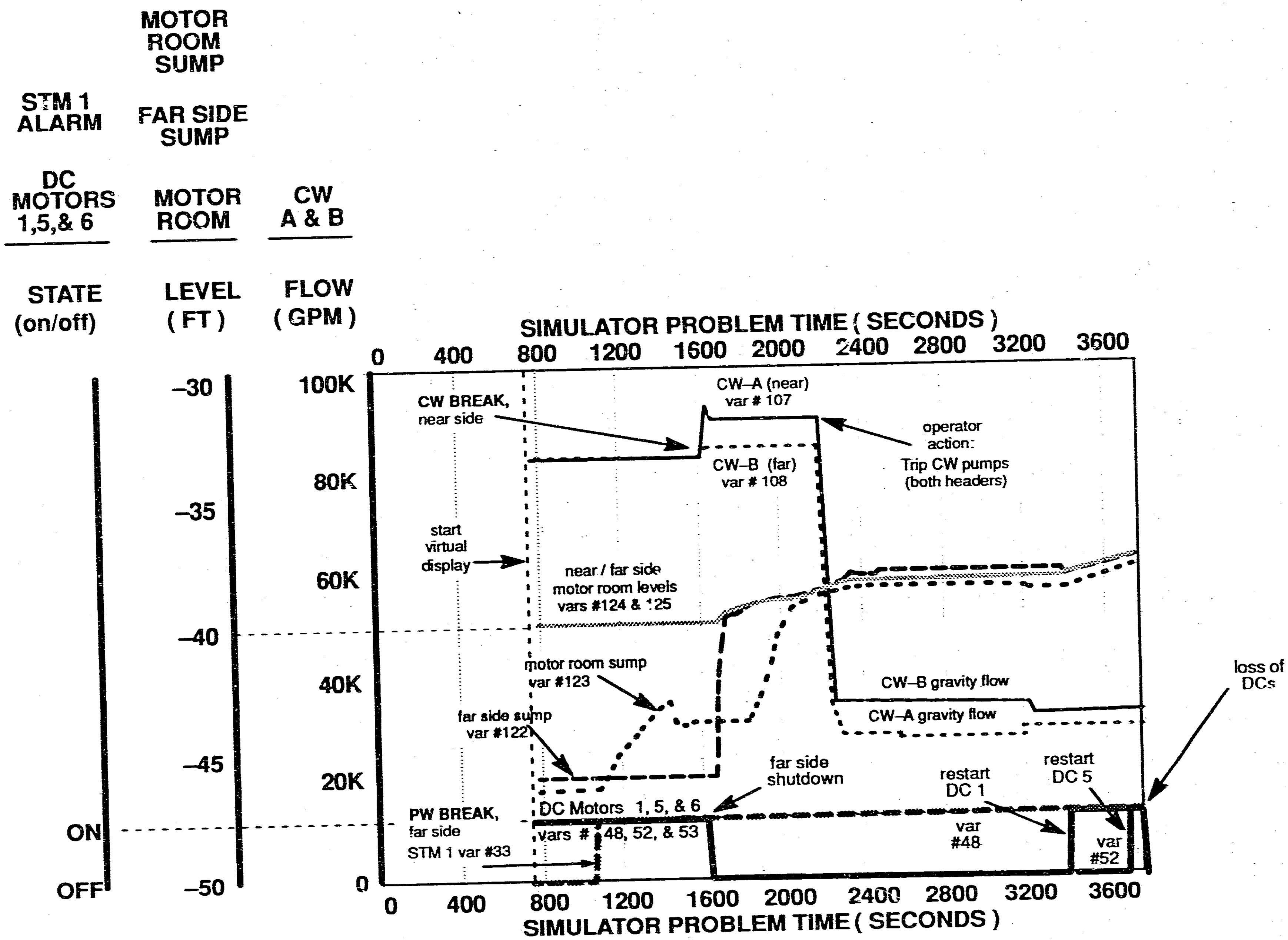


BLOCK DIAGRAM for Combined Process–water and Cooling–water Break (CPCB)



ANATOMY OF A CPCB EVENT

AS SEEN VIA THE VIRTUAL DISPLAY BY EITHER CES OR A HUMAN ANALYST



in the CPCB event

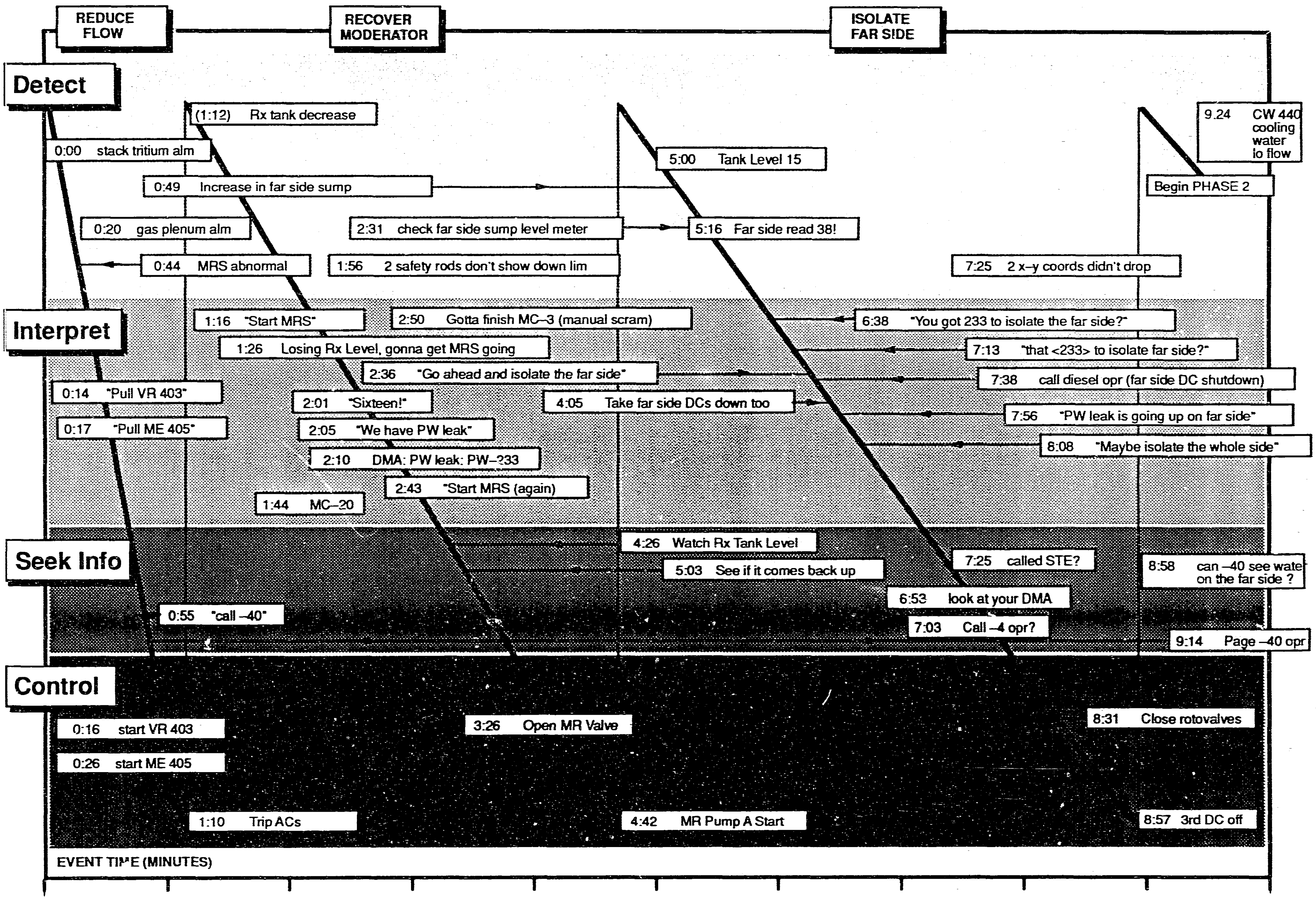
SOURCES of COGNITIVE CHALLENGE

- solution to break #1 –> system in compensated state
- time pressure of impending floodout
- tendency to view break #1 solution as "done"
- conflicting goals
- data requirements for re–solving the first break not well supported
- requirement for proactive situation awareness
- monotonic reasoning from catastrophic anchors

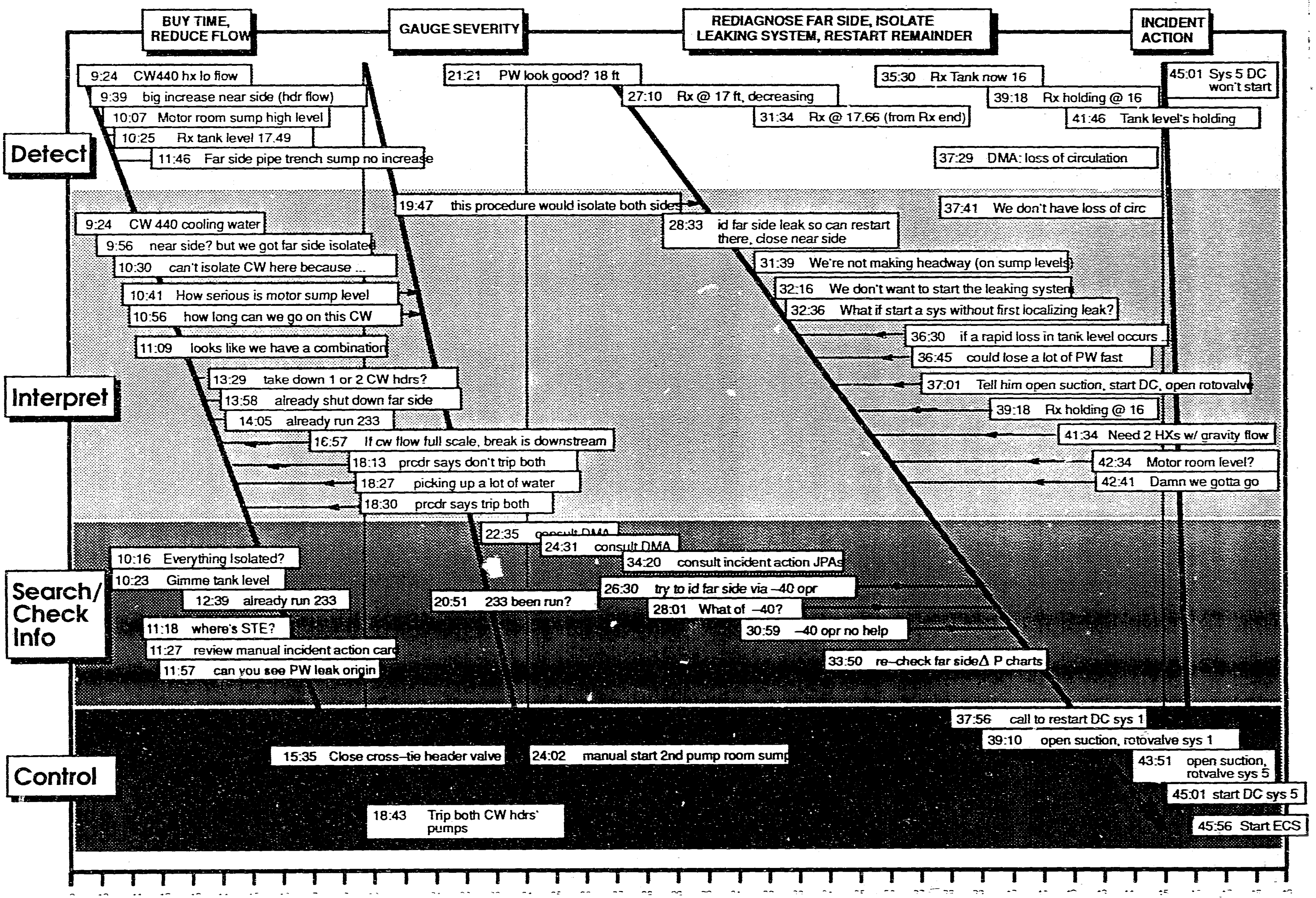
CATEGORIES of CREW and CES DECISION ACTIVITY

CREW	***CES***
DETECT	BEHAVIOR ANALYST
INTERPRET	DECISION ANALYST
SEARCH / CHECK	RESPONSE MANAGER
CONTROL	RESPONSE MANAGER

CREW DECISION SEQUENCE, PHASE 1 of CPCB EVENT



CREW DECISION SEQUENCE, PHASE 2 of CPCB EVENT



CES OUTPUT for Phase 1 of CPCB Event

(opposite–side breaks)

Observations at time 1086 [= 0:00] concerning STM–A–VALUE...A HIGH–VALUE suggests an abnormal INCREASING–PROGRESSION INFLUENCE.

There is only one possible explanation for this:

PW–LEAK is fairly strongly suggested by the observed behavior.

the following expected change has not been observed:

RX–TANK–LEVEL–COARSE DECREASING–PROGRESSION...fairly strongly indicative, strongly indicated

Observations at time 1147 [= 1:01] concerning RX–TANK–LEVEL–COARSE...

There is now unequivocal evidence of an unexplained DECREASING influence on RX–TANK–LEVEL–COARSE.

If we make the assumption that RX–TANK–LEVEL–COARSE and STM–A–VALUE have a common cause there would be only one possible explanation for this: PW–LEAK. With this evidence, the conclusion of PW–LEAK can be made with some confidence. More specifically, we find that the anomalous behavior in RX–TANK–LEVEL–COARSE and STM–A–VALUE is due to one of the following: PW–LEAK–NEAR–SIDE and PW–LEAK–FAR–SIDE

Concerning PW–LEAK–FAR–SIDE:

The following expected change has not been observed:

FAR–SIDE–SUMP–LEVEL INCREASING–PROGRESSION....fairly strongly indicative, strongly indicated

Observations at time 1177 [= 1:31] concerning FAR–SIDE–SUMP–LEVEL...

There is now unequivocal evidence of an unexplained INCREASING influence on FAR–SIDE–SUMP–LEVEL.

If we make the assumption that FAR–SIDE–SUMP–LEVEL and STM–A–VALUE have a common cause, there would be only one possible explanation for this: PW–LEAK–FAR–SIDE.

(continued —>)

CES OUTPUT for Phase 1 of CPCB Event
(same–side breaks)

Observations at time 468 [= 0:00] concerning STM–A–VALUE...A HIGH–VALUE suggests an abnormal INCREASING–PROGRESSION influence.

There is only one possible explanation for this:

PW–LEAK is fairly strongly suggested by the observed behavior.

The following expected change has not been observed:

RX–TANK–LEVEL–COARSE DECREASING–PROGRESSION...fairly strongly indicative, strongly indicated

Observations at time 529 [= 1:01] concerning RX–TANK–LEVEL–COARSE...

There is now unequivocal evidence of an unexplained DECREASING influence on RX–TANK–LEVEL–COARSE.

If we make the assumption that RX–TANK–LEVEL–COARSE and STM–A–VALUE have a common cause, there would be only one possible explanation for this: PW–LEAK. With this evidence, the conclusion of PW–LEAK can be made with some confidence. More specifically, we find that the anomalous behavior in RX–TANK–LEVEL–COARSE and STM–A–VALUE is due to one of the following: PW–LEAK–NEAR–SIDE and PW–LEAK–FAR SIDE

Concerning PW–LEAK–FAR–SIDE:

The following expected change has not been observed:

FAR–SIDE–SUMP–LEVEL INCREASING–PROGRESSION...fairly strongly indicative, strongly indicated

Observations at time 559 [= 1:31] concerning FAR–SIDE–SUMP–LEVEL....

There is now unequivocal evidence of an unexplained INCREASING influence on FAR–SIDE–SUMP–LEVEL.

If we make the assumption that FAR–SIDE–SUMP–LEVEL and STM–A–VALUE have a common cause, there would be only one possible explanation for this: PW–LEAK–FAR–SIDE.

(continued —>)

CES OUTPUT for Phase 2 of CPCB Event
(opposite–side breaks)

Observations at time 1635 [= 9:09] concerning CW–FLOW–LOW...We note that the state of CW–FLOW–LOW is now 1.

There is only one possible explanation for this:

CW–LEAK is strongly suggested by the observed behavior.

This could also explain the following change:

MOTOR–ROOM–SUMP–LEVEL INCREASING–PROGRESSION...fairly strongly suggestive

With this evidence, the conclusion of CW–LEAK can be made with some confidence. More specifically, we find that the anomalous behavior in CW–B–HEADER–FLOW, HX–B1–FLOW, CW–FLOW–LOW, and MOTOR–ROOM–SUMP–LEVEL is due to one of the following: CW–LEAK–NEAR–SIDE and CW–LEAK–FAR–SIDE

Concerning CW–LEAK–NEAR–SIDE: This could also explain the following changes:

CW–B–HEADER–FLOW INCREASING–PROGRESSION...strongly suggestive

HX–B1–FLOW DECREASING–PROGRESSION....fairly strongly suggestive

With this evidence, the conclusion of CW–LEAK–NEAR–SIDE can be made with some confidence.

(Because of CW–LEAK–NEAR–SIDE fault, according to procedures, the following options are to be rendered unavailable: SYSTEM–2–HEAT–SINK, SYSTEM–3–HEAT–SINK, and SYSTEM–4–HEAT–SINK.)

More specifically, we find that the anomalous behavior in CW–B–HEADER–FLOW, HX–B1–FLOW, CW–FLOW–LOW, and MOTOR–ROOM–SUMP–LEVEL is due to one of the following:

CW–LEAK–SYSTEM–4, CW–LEAK–SYSTEM–3, CW–LEAK–SYSTEM–2, OR CW–B–HEADER–LEAK

A note of caution at time 1665 [= 9:39] concerning the means to MAINTAIN CORE–COOLING: The actions leading to deactivation of SYSTEM–4–HEAT–SINK, SYSTEM–3–HEAT–SINK, SYSTEM–2–HEAT–SINK DC–MOTOR–6, DC–MOTOR–5, and DC–MOTOR–1 will leave as the best remaining method for pursuing this goal ECS, which entails some adverse consequences. We must consider the rationale for these changes to see whether they might be reversed. The actions affecting DC–MOTOR–1, DC–MOTOR–5 and DC–MOTOR–6 were apparently taken to PREVENT LOSS–OF–D20–INVENTORY in the event that one of the following abnormal conditions is present: PW–LEAK–SYSTEM–1, PW–LEAK–SYSTEM–5, and PW–LEAK–SYSTEM–6. On checking the decision context, we find that there is an unresolved decision task that includes these possibilities. Efforts should be undertaken to rule these out if possible.

End output

CES OUTPUT for Phase 2 of CPCB Event

(same–side breaks)

Observations at time 1046 [= 9:38] concerning CW–FLOW–LOW...We note that the state of CW–FLOW–LOW is now 1.

There is only one possible explanation for this:

CW–LEAK is strongly suggested by the observed behavior.

This could also explain the following change:

MOTOR–ROOM–SUMP–LEVEL INCREASING–PROGRESSION...fairly strongly suggestive

With this evidence, the conclusion of CW–LEAK can be made with some confidence. More specifically, we find that the anomalous behavior in CW–A–HEADER–FLOW, HX–1A–FLOW, CW–FLOW–LOW, and MOTOR–ROOM–SUMP–LEVEL is due to one of the following: CW–LEAK–NEAR–SIDE and CW–LEAK–FAR–SIDE

Concerning CW–LEAK–NEAR–SIDE:

The following expected changes have not been observed:

CW–B–HEADER–FLOW INCREASING–PROGRESSION...strongly indicative, strongly indicated

HX–B1–FLOW DECREASING–PROGRESSION...fairly strongly indicative, strongly indicated

Concerning CW–LEAK–FAR–SIDE: This could also explain the following changes:

CW–A–HEADER–FLOW INCREASING–PROGRESSION...strongly suggestive

HX–A1–FLOW DECREASING–PROGRESSION...fairly strongly suggestive

With this evidence, the conclusion of CW–LEAK–FAR–SIDE can be made with some confidence. More specifically, we find that the anomalous behavior in CW–A–HEADER–FLOW, HX–A1–FLOW, CW–FLOW–LOW, and MOTOR–ROOM–SUMP–LEVEL is due to one of the following: CW–LEAK–SYSTEM–5, CW–LEAK–SYSTEM–6, CW–LEAK–SYSTEM–1, or CW–A–HEADER–LEAK

End output.

OBSERVED POTENTIAL PRECURSORS of OPERATOR ERROR

- OPERATORS WITH DIFFERENT MENTAL MODELS OF THE PLANT
- PROCEDURES LEADING TO CONFLICTING ACTION, REQUIRING RESOLUTION
- INSUFFICIENT RESOLUTION ON KEY DISPLAY
- SIMULATOR DETAIL INSUFFICIENT TO SUPPORT TASK
- TENDENCY TO FOLLOW PROCEDURES IN EVENT–BASED MODE
- HEAVY COMMUNICATIONS LOAD
- LIMITS OF KNOWLEDGE ABOUT THE PLANT FOR THIS EVENT

CONCLUSIONS

- **EVENT WAS PLAUSIBLE**
- **ABOUT CES and AI:**
  - CES CAN DEAL WITH NEW DOMAIN
  - CES RESPONDED APPROPRIATELY TO DIFFERENT EVENTS
  - CES is SHALLOW
  - CES IS *FAST*
  - CES KB CAN REPRESENT PROCEDURES
  - CES KB CAN INFER OPERATOR INTENT IN PRIOR ACTIONS
  - CES KB CAN REPRESENT DESIGN INTENT
- **IDENTIFIED NUMEROUS INTERFACE ISSUES for POTENTIAL IMPROVEMENT**
- **POTENTIAL PRECURSORS TO OPERATOR ERROR**

END

DATE FILMED

5/06/92