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Advanced Chemistry Management System to Optimize BWR Chemistry Control

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Introduction

BWR plant chemistry control has close relationships among nuclear safety, component reliability, radiation field management and fuel integrity. Advanced technology is required to improve chemistry control [1,3,6,7,10,11]. Toshiba has developed TACMAN (Toshiba Advanced Chemistry Management System) to support BWR chemistry control. The TACMAN has been developed as response to utilities' years of requirements to keep plant operation safety, reliability and cost benefit. The advanced technology built into the TACMAN allows utilities to make efficient chemistry control and to keep cost benefit.

TACMAN is currently being used in response to the needs for tools those plant chemists and engineers could use to optimize and identify plant chemistry conditions continuously. If an incipient condition or anomaly is detected at early stage, root causes evaluation and immediate countermeasures can be provided. Especially, the expert system brings numerous and competitive advantages not only to improve plant chemistry reliability but also to standardize and systematize know-how, empirical knowledge and technologies in BWR chemistry This paper shows detail functions of TACMAN and practical results to evaluate actual plant.

Outline of TACMAN

As shown in Figure 1, the TACMAN is made up by two systems, one is a chemistry data management and the other is expert system. Those systems have a sharing of common database. The chemical data management system has two functions, data acquisition and data treatment functions. All data are stored into the database. The database can be used to make chemistry trend graphs, tables and reports easily by friendly user interfaces.

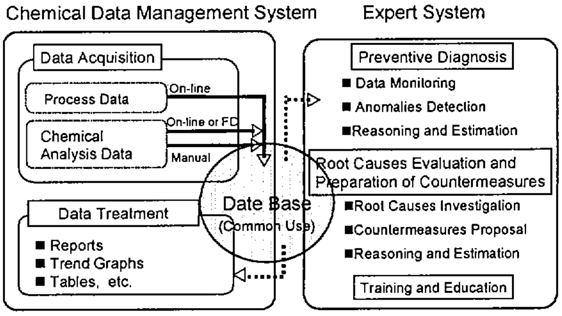


Figure 1 Relationship between Chemical Data Management and Expert Systems in TACMAN

On the other hand, plant chemistry condition can be monitored by the expert system using the database [5,9]. There are two major functions in expert system, one is preventive diagnosis and the other is root causes evaluation and preparation of countermeasures against chemistry malfunctions or anomalies.

The preventive diagnosis expert function is designed to identify anomalous indications at as early stage as possible. This means the plant chemistry situation can be followed-up more quickly, reliably and easily at any time. The root cause evaluation function shows the detail causes and countermeasures against chemistry malfunctions and anomalies.

Preventive Diagnosis Function

The chemistry and plant operating data are monitored continuously. Threshold values and limits can be set in advance or automatically by using individual plant data (Figure 2). Usually, threshold values and limits will be fixed by moving average, cumulative probability or correlation of data. There are prepared many scenarios, composed diagnostic matrix to make root cause evaluation. Each scenario is prepared to each cause of anomalies or malfunctions.

For example, the reactor water conductivity will increase, there may be many possibilities of root cause such as resin intrusion, TOC intrusion, RWCU (F/D) performance degradation, interruption of HWC, conductivity monitor error and so on.

At the present, the predictive diagnosis expert system in the TACMAN can evaluate eight chemical changes as shown in Figure 3. There consists many root causes in each chemistry change. New scenarios will be added easily if there will occur chemistry anomalies or malfunctions induced by other causes. The system will be improved satisfactorily and continuously by adding new scenarios. The each scenario has been constituted by detail matrix table depend on each root cause. The preventive diagnosis matrix is settled beforehand by empirical and theoretical knowledge bases.

There should be close relationships among chemistry anomalies or malfunctions and changes of operation and chemistry data. Plant operation parameters and chemistry data should change depend on chemistry anomalies or malfunctions. The affirmative, positive parameter should change and negative parameters should not change against chemistry anomalies or malfunctions. Each parameter should be given some kind of weight by considering magnitude of influence depending on chemical anomalies or malfunctions.

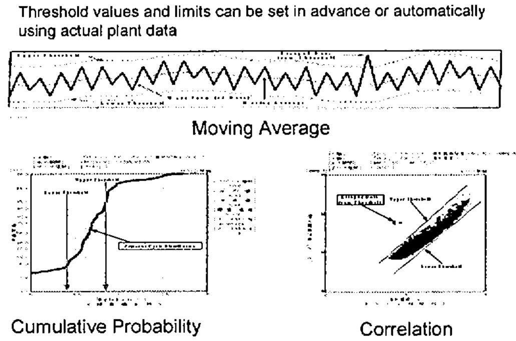
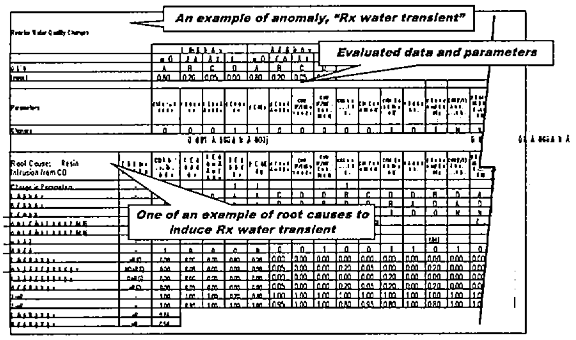


Figure 2 Example of Chemical Data Monitoring

The weight for each parameter is decided by actual experiences, heuristic intelligence, theoretical calculation results. An example of decision table to evaluate root cause is shown in Table 1.
As mentioned above, the predictive diagnosis expert system can detect an indication of plant operation and chemistry data change and decide possibility of causes in early stage. After detecting chemistry anomalies by using the predictive diagnosis expert system, detail causes will be estimated by root causes investigation expert system [7,9].

Table-1 An Example of Diagnostic Matrix
(Decision Table of Root Cause Evaluation)



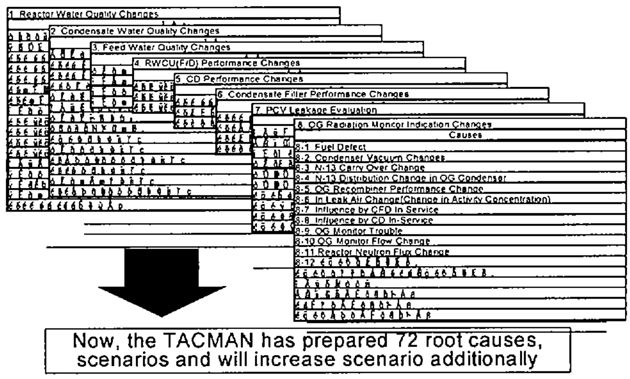


Figure 3 Diagnostic Matrix in the TACMAN

Root Causes Investigation and Preparation of Countermeasures

When chemistry anomaly or malfunction will be detected by preventive diagnosis expert function, root cause investigation or proper countermeasure should be required. It is required empirical knowledge, technologies and experiences to investigate root causes and provide adequate countermeasures.
Now, the TACMAN has root cause investigation and countermeasure functions as following items.

(1) Investigation of reactor water quality changes
(2) Countermeasures against sea water leakage in the main condenser
(3) Evaluation of reactor water cleanup system performance
(4) Leakage evaluation in the primary containment vessel

Detail Investigation of Reactor Water Quality Changes

The reactor water quality should be kept in high purity and stability. It is important to maintain reliability of the reactor internal materials, mitigating corrosive environments, reducing radiation exposure and radioactive waste generation. The purpose of this expert system is to provide adequate root causes quickly when the reactor water quality will change. The inference rules are made up with actual experiences and stipulated simulation results of reactor water quality changes [1].

Countermeasure against Main Condenser Cooling Water

Usually, the main condenser cooling water contains many impurities in high concentration. For example, Japanese BWR plants are constructing near the seashore. The seawater is used as cooling water in Japan. The seawater contains large quantities of chloride, sulfate, sodium ions and so on. Those ion impurities will accelerate corrosion of the reactor component materials. It is important to maintain the adequate performance and operation condition of the condensate purification systems to prevent impurities intrusion into the reactor under the main condenser cooling water leakage.

The expert system provides quick and adequate countermeasures for condensate purification systems operation under the main condenser cooling water leakage. The system can calculate seawater leak rate and simulate the reactor water quality changes. Especially, the system can provide countermeasures, calculation and simulation quickly according to leak rate changes [2].

Reactor Water Clean-up Filter Demineralizer Performance Evaluation

To keep good reactor water quality, it is important to maintain adequate performance of reactor water clean-up filter demineralizer (RWCU (F/D)). The RWCU (F/D) removes impurities, such as ions, crud, activated corrosion products and fission products. Usually, powdered ion change resins are used as precoat material for RWCU (F/D) to remove impurities. When the RWCU (F/D) performance deteriorates, powdered resins will be disposed by backwash operation and new powdered resins will be precoated. The RWCU (F/D) performance will have close influences on the reactor water quality and radioactive waste generation.

The purpose of this system is evaluation of RWCU (F/D) performance, provision of adequate operation measures and seeking for root causes of performance deterioration [4].

Leak Detection and Leakage Source Investigation in Primary Contain Vessel

The primly coolant leakage in primary contain vessel (PCV) is strictly restricted by the technical specification requirement to keep the reliability of plant. It is very important to investigate the source of leakage to provide recovery actions. Usually the indication of leakage will be detected increasing discharge drain flow rate from the PCV. There are many possibilities of leakage sources in the PCV, such as reactor water, main steam, feedwater, and closed cooling water etc. In any case of leakage, cooler drain flow rate of the PCV cooling system will increase similarly. This means that leakage indication can be detected by monitoring the cooler drain flow rate.

But it is difficult to detect leakage source by cooler drain flow rate, itself. The leakage sources contain different chemical and radiochemical species. The expert system can infer the leakage source into the PCV used by chemical and radiochemical data in the PCV atmosphere and cooler drain water [8].

Data Acquisition Requirements for Expert Systems

The plant operation and chemistry data should be collected on-line as many as possible. These data can be collected quickly and easily used by a local area network environment. These data are evaluated by the TACMAN to detect indications of chemistry anomalies or malfunctions.

Usually, the plant operation and chemistry data are collected into a server computer of the chemistry management system via an information collection computer. The information collection computer is used commonly and set up to avoid a direct connection between the process computer and other computer systems such as the chemistry management system. Chemistry analysis data are collected directly into the server computer of the chemistry management system. Figure 4 shows an example of system configuration and network environment of the chemistry management system [6].

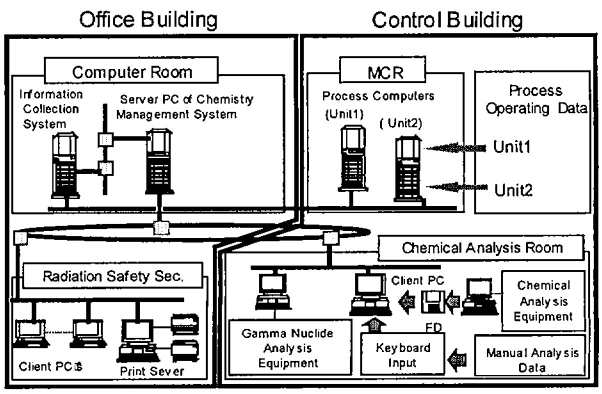


Figure 4 An Example of System Configuration of Advanced Chemistry Management System

An Example of Actual Plant Data Evaluation by Preventive Diagnosis Function

The reactor water conductivity had increased by resin intrusion from condensate demineralizer (CD) in an actual BWR. Chemistry and plant operation data have evaluated by preventive diagnosis function of the TACMAN. Figure 5 shows the reactor water conductivity changes. Figure 6 shows trends of the reactor water and feedwater conductivities and differential pressure of condensate demineralizer effluent strainer.

The plant operator had confirmed the reactor water conductivity change at "D", there might occur large amount of resin intrusion. There have been shown small conductivity spikes as shown at "A", "B" and "C" before large conductivity spike. It might be very difficult to identify the small spikes clearly by plant operators or chemists.

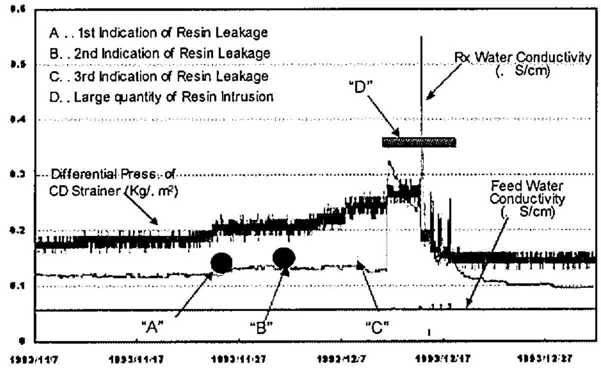


Figure 6 Indication of Resin Intrusion estimated by TACMAN

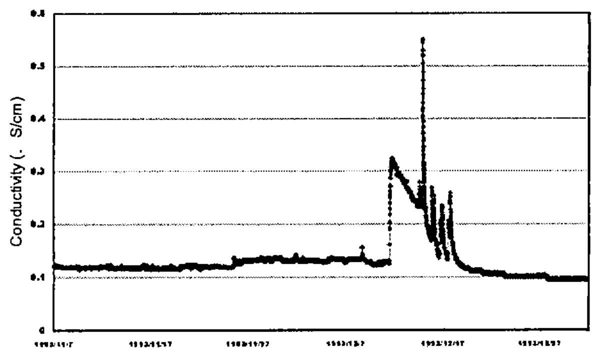


Figure 5 Reactor Water Conductivity Change

The plant data have evaluated by the preventive diagnosis function of the TACMAN. Figures 7,8 and 9 show results of plant data evaluations by the TACMAN. As shown in Figure 7, there had occurred small spikes and exceeded moving average and the cumulative probability before the large reactor water conductivity spike has occurred, The small changes of the reactor water conductivity could be detected clearly by exceed upper limits of the moving average and cumulative probability. Before the reactor water conductivity had increased suddenly, there had detected small changes of the differential pressure of condensate demineralizer effluent strainer and the feedwater conductivity as exceed upper limits of the moving average and the cumulative probability.

Table 2 shows summary results of the reactor water conductivity changes evaluated by the TACMAN. The TACMAN shows a little possibility of the resin intrusion from the condensate demineralizer at point "A" and shows high possibility at "B" and "C" points. In this case it had been very difficult to identify or predict an indication of the resin intrusion before there had occurred the large increase in the reactor water conductivity.

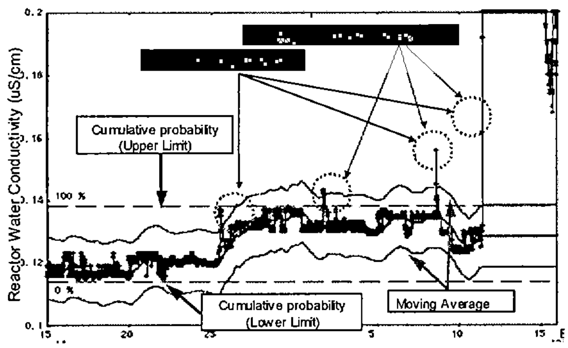


Figure 7 Detection of Reactor Water Conductivity Anomalies by TACMAN

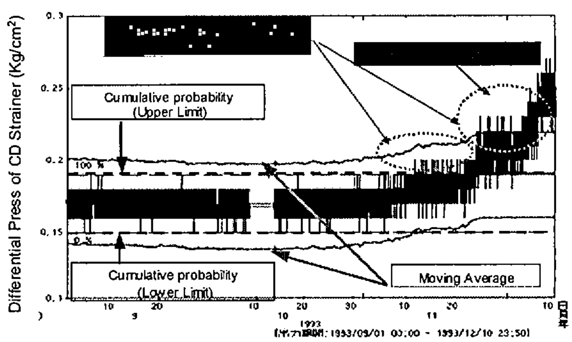


Figure 8 Detection of CD Strainer dP Changes by TACMAN

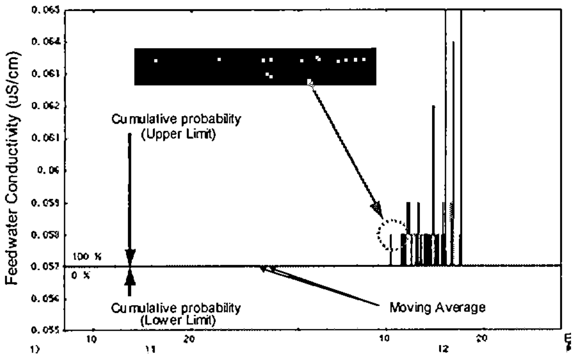


Figure 9 Detection of Feedwater Conductivity Changes by TACMAN

Table 2 An Example of Evaluation by Preventive Diagnoses Function of TACMAN

Time and Period	Category Anomalies	Root Causes	Probability (%)
Before "A"	Normal Condition	–	0
"A"	CD Performance Degradation	Resin Intrusion	37
"B"	Reactor Water Quality Changes	Resin Intrusion	77
	CD Performance Degradation		52
"C"	Reactor Water Quality Changes	Resin Intrusion	81
	CD Performance Degradation		55

Table 3 shows the comparison of data judgments or confirmation among by plant operators or chemists and the TACMAN when condensate demineralizer resin leakage will occur. It is clear that the TACMAN can detect small changes of plant operation data used by the moving average and cumulative probability methods. Table 4 shows calculating results of amount of resin intrusion. The calculation can be done automatically on the assumption that the reactor water conductivity is dominated by sulfate ion. of plant operation data used by the moving average and cumulative probability methods. Table 4 shows calculating results of amount of resin intrusion. These calculations can be done automatically.

Table 3 An Example of Rx Water Transient

Process Parameter	Changes	Evaluation	
		Operators and/or Chemists	TACMAN
Rx Water Conductivity	Small spike	−	++
	Jump up	++	++
CD Outlet Strainer dP	Small spike	−	++
	Increase	+/−	++
CD Header dP	Small spike	−	++
	Increase	+/−	++
Feedwater Conductivity	Small spike	−	++
	Increase	+/−	++

++ . Easy to identify or detect ←→ − . Hard to identify or detect

Table 4 Calculating Evaluation of CD Resin Intrusion

(Period of Evaluation: Dec. 11 to Dec.14)

	Evaluation items	Results
1	Sulfate Ion Generation in Reactor	176 g-SO4
2	Cation Resin Intrusion into Reactor	338-g-CER
3	Total Resin Intrusion (CER+AER)	652-g-Resin
4	Average Feedwater Resin Concentration	0.3ppb-Resin

Conclusions

The BWR plant chemistry control should be contributed to keep plant integrity and reliability. To keep these purposes, the empirical knowledge and technologies on plant chemical control should be systematized and utilized effectively. The TACMAN has been developed to provide the effective and reliable BWR chemistry control. It provides two kinds of expert system functions, one is the predictive diagnosis, and another is the root cause evaluation and preparation of countermeasures against chemistry malfunctions or anomalies. The preventive diagnosis expert function is designed to identify anomalous indications at as early stage as possible. This means the plant chemistry situation can be followed-up more quickly, reliably and easily at any time. The root cause evaluation function shows the detail causes and appropriate countermeasures against chemistry malfunctions and anomalies.

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