DEVELOPMENT OF RISK-INFORMED APPROACH FOR ASSET MANAGEMENT- A CASE STUDY ON NUCLEAR PLANT

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ABSTRACT

The traditional approach to engineering asset management, which primarily includes management and operation and maintenance activities, in a nuclear plant is based on engineering judgment. Here, the defence-in-depth and conservative criteria form the basis of decisions. Ideally, it is expected that the decisions should be based on performance of systems, structures and components (SSC), which should also take plant safety margin into consideration.

A risk-based operations and maintenance management system (RBOMMS) has been developed for a research reactor. The results of a level-1 PSA study in terms of minimal cut-set equations along with other engineering plant information forms major input for this system. The system is envisaged to be operational in plant control room conditions in support of routine decisions.

This paper presents the development details of RBOMMS. The future regulatory requirements for this system along with verification and validation procedure has also been discussed. It is expected that the use of this system in real-time scenario will provide improved understanding of safety on one hand while enabling enhancement of plant economics on the other.

INTRODUCTION

Asset management approach for any complex system like nuclear plant is based on the qualitative criterion and guidelines. For the purpose of this paper the term Asset management exclusively refer to operational & maintenance activities of the plant. The operational actions are governed by the plant technical specifications and other approved documents which are prescriptive in nature. Whereas the test & maintenance schedules are formulated based on experience in design, operation and maintenance of the systems and components. In few cases, manufacturer's recommendations also form the basis for planning and scheduling of maintenance.
Even though safety forms the prime driver for operations & maintenance management in complex systems like nuclear plants in particular, emphasize is also based on plant economics which is essential to plant availability and cost of operation. Whereas safety limits are stipulated by the regulatory bodies while economic factor is given importance due to market competition. Since maintenance is directly associated with safety and cost of operation of the plant, it needs to be optimized in such a way that even though safety takes priority, the cost factor should be optimized to address complex issues. The amount of inspections carried out on the systems directly influences the failure probability or unavailability of the system, hence, the overall risk of the system need to be optimized with number of test or maintenance.

The state of art in "PSA-an analytical approach" enables to represent performance parameters of the component, safety and human action in the form of reliability and safety [1]. The PSA insight couples with design and operation activities a framework called risk-inform approach. This approach provides probabilistic, systematic, and logical framework for optimization of parameters in decision making also gives integrated plant performance view for safety performance. The outcome of this approach is used for several applications in decision making.

RBOMMS – DEVELOPMENT OBJECTIVE AND THE APPROACH

The development objective of RBOMMS is to estimate, apart from risk-based plant configuration management are: a) Technical specification evaluation and optimization which means assessment of surveillance test interval and allowable outage time and comparing the same with the existing deterministic rules, b) Identification and prioritization of technical issues, c) Decisions based on comparisons between operational risk and shutdown risk d)

Uncertainty characterization and sensitivity analysis, e) shutdown scheduling and f) Implementation of a mechanism to compare with international criteria in support of decision making [3-7].
The major features of the approach are; a) development of level 1 PSA for the research reactor for full power as well as shutdown state of the plant, b) Preparation of core software specifications that takes into account GUI (Graphic User Interface) requirements and plant operational requirements, c) Development of software with sample cut-set equations, d) Updating and modifying the output of PSA studies keeping in view on-line RBOMMS applications, e) Finalization and incorporation of unavailability equation at system level and accident sequence list at plant level in the core module of the software, f) Development of the RBOMMS GUI, g) Incorporation of plant reliability data for quantification of parameters and h) Test run as part of validation and verification of the system.

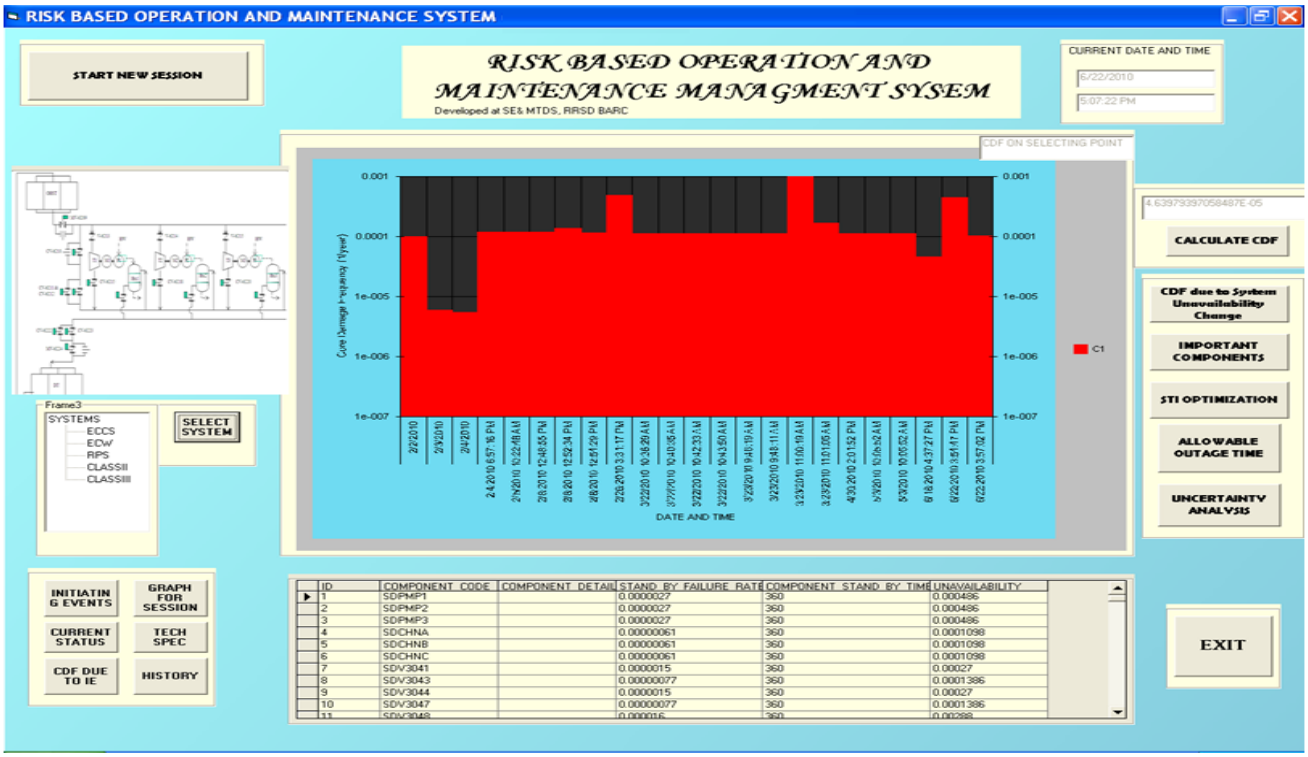

Fig. 1: Main screen of RBOMMS

ACCEPTANCE GUIDELINES

Basic quantified criteria and guidelines form the backbone of risk-informed decisions. Even though national criteria stipulated by the regulatory authority is requisite. However, in the absence of national stipulations international criteria can be adopted as guidelines with adequate interpretation and margins [2]
The guidelines for CDF are:

- When the calculated increase in CDF is very small, (less than 1E-6 per reactor year), the change will be considered regardless of whether there is a calculation of the total CDF (Region III). While there is no requirement to calculate the total CDF, should there be an indication that the CDF may be considerably higher than 1E-4 per reactor year, the focus should be on finding ways to decrease rather than increase it. Such an indication would result, for example, if: (1) the contribution to CDF calculated from a limited scope analysis, such as the IPE, and, if appropriate the IPEEE, significantly exceeds 1E-4; (2) there has been an identification of a potential vulnerability from a margins type analysis; or (3) historical experience at the plant in question has indicated a potential safety concern.
- When the calculated increase in CDF is in the range of 1E-6 per reactor year to 1E-5 per reactor year, applications will be considered only if it can be reasonably shown that the total CDF is less than 1E-4 per reactor year (Region II).
- Applications which result in increases to CDF above 1E-5 per reactor year (Region I) would not normally be considered.

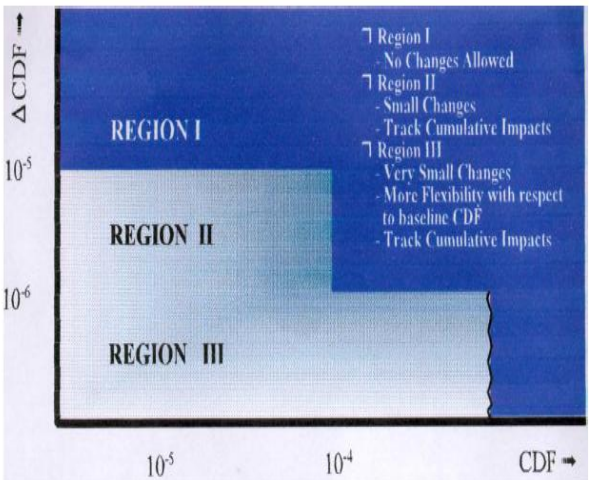

Fig. 2: Acceptance guidelines for CDF [2]

METHODOLOGY FOR RISK-INFORMED ASSET MANAGEMENT FOR NUCLEAR PLANTS

1. Firstly, a level 1 PSA model of the Nuclear Plant needs to be developed. This provides holistic and logical view of the plant. For the same component database needs to be developed.
2. Using PSA model's fault tree results i.e. minimal cut-set eqation, calculate system unavailability. Calculate Core damage frequency (CDF) using system unavailability and initiating events.
3. Perform Uncertainty analysis and Sensitivity analysis, uncertainty analysis is important for any plant PSA. The main objective of this to obtain measure of uncertainty in PSA results. The sources of uncertainty in the PSA results are uncertainties in modeling parameter, data input, lack of knowledge, etc. where as sensitivity analysis is to performed to determine the sensitivity of a component at system level and effect of system unavailability and initiating event at plant level.
4. After uncertainty and sensitivity analysis compare the obtained PSA results with NUREC acceptance criteria guidelines for CDF and various system criteria.
5. Prioritization of the component using importance measure, the importance of component at system level is determined using Fussel-Vessely Method. This helps to priorize the component according to the percentage contribution to the system unavailability or toral risk. Using this prioritization one has to select the component, so the change in risk can not be more than acceptance criteria.
6. After importance measures calculation, select the component(s) for change the plant configuration during operation/maintenance/shutdown. Then compare the risk with acceptance criteria, if the risk is under acceptance limit for specified period of time, then the configuration can be changed otherwise not. With same configuration also calculate the allowable outage time.
7. Now calculate AOT for operating as well as for stand-by component . This tells the basis, for which component can take out of the system without affecting plants operation. After change in AOT calculate the risk and compare with acceptance criteria.
8. In sequence to configuration control and AOT calculation optimization of the Surveillance Test Intervals for the stand-by systems of the plant can help to increase both safety and availability of the system. The frequency and strategy for equipment testing should be controlled to confirm equipment functional operability, to minimize the risk from unavailability due to undetected failures, and to minimize the risk from unavailability due to tests and test induced failures. The effect of change in STI is on system unavailability, men-rem, cost of operation, and training of personnel. And parameters affecting system unavailability are test interval, testing time, human errors during maintenance/testing, degradation/ageing of the system/components occurred during maintenance/testing.
9. After obtaining the optimized STI, calculate system unavailability and CDF using new STI and compare the reuslts with acceptance criteria. If the results are acceptable for both system and plant level then optimize the economic risk with STI.

10. Now, after STI optimization, the planning and scheduling activities can be freezed with resource allocation. The planning is based on optimized STI results, and the STI is calculated using unavailability of components / systems or using risk.
11. Based on the importance ranking, surveillance test interval and Allowable outage time allocate the plant and manpower resources for the particular job during shutdown planning and scheduling.

CASE-STUDY CARRIED OUT FOR NUCLEAR REACTOR

Uncertainty Analysis

Uncertainty analysis for Nuclear Plant PSA was carried out at two levels, at system level and plant level. It may be noted that the error factor for all the system is taken as 3. This is due to the use of plant specific & generic data used for this analysis. Generally at component level an error factor of 2.0 is used if the data is plant specific and a factor of 3.0 is considered adequate for giving variability in generic data. Usually, uncertainty is represented by a probability distribution for this analysis the lognormal distribution was assumed. [8]. The Monte-Carlo simulation is carried out using RBOMMS for propagating uncertainty in the fault tree from component level to system level [9] and subsequently from system level to plant level [10]. The graph obtained for plant level are shown in figure 3.
The median value of CDF is comes out to be 4.50E-05/yr and the mean value is 1.74E-4/yr.

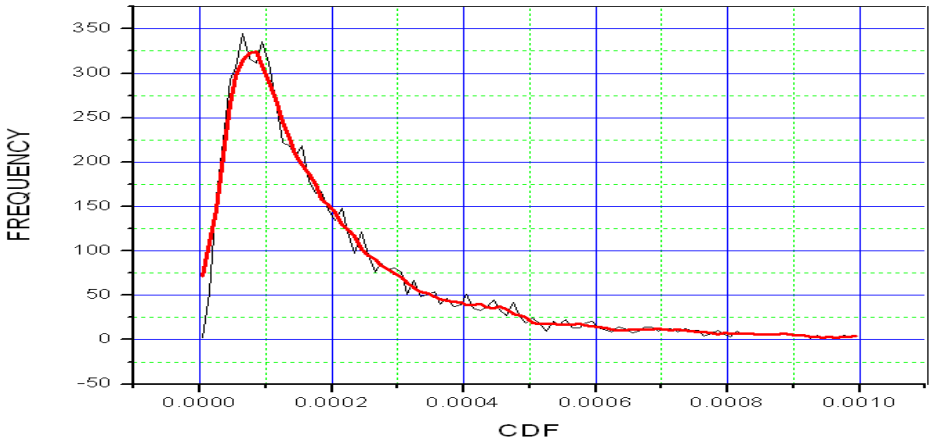

Fig. 3: Uncertainty Analysis at system level to plant level

Importance Measures

Nuclear power plants are designed according to the defense-in-depth principle, one single failure of a component or other basic event will probably not result in large accident. More likely, an accident will be the result of combination of multiple basic events. The PSA methodology determines all important cut-sets that could result in large accident. The final results of a PSA-study are then represented in the risk equation. In this equation risk can be measure such as, core damage frequency, expected dose, large release frequency, etc.
A risk importance measure gives an indication of the contribution of a certain component to the total risk.
Two measures of risk importance are identified which are useful in characterizing risk properties and in aiding decision making. The-two risk measures are termed the "risk achievement worth" and the "risk reduction worth".
In risk based operation and maintenance methodology and RBOMMS three importance measures are calculated for analysis:

- Fussell-Vessely Importance
- Risk achievement worth
- Birnbaum Importance

In Table 1, the Fussell-Vessely and Birnbaum importance measure from “RBOMMS” are given for reference configuration using RBOMMS.

Configuration Control

During the operation of a nuclear power plant, the availability of equipment changes due to equipment failures and maintenance activities. Also, the operating modes of the available equipment can change due to operational considerations. Plant configuration at a point in time can be characterized by the status of the equipment, e.g. out of service, open, closed, running, on stand-by, etc. For safety significant equipment, the equipment status can directly influence the risk. Even the configuration of non-safety related equipment can also have an important impact on the risk. For example, some testing activities could increase the probability of the occurrence of initiating events. Therefore, different combinations of equipment configuration, tests and maintenance activities will result in different levels of risk. The programme established to manage configuration related risk changes is called risk based configuration control.
An appropriate risk-based configuration control program would enable plant personnel to maintain the risk level of the nuclear power plant within an acceptable range during all the operational regimes.
There are two main tasks in the risk-based configuration control, risk planning and risk follow-up. Risk planning is a forward looking application of PSA and it consists of supporting the preparation, planning and scheduling of plant activities and configurations.

Table: 1 Results from "RBOMMS"

S.No.	Component ID	Component Code	Fussel-Vesselly Importance	Birnbaum Importance
1	33	V319	2.13E-01	1.00E+00
2	34	RD2	1.97E-01	1.00E+00
3	35	CCFPMP	1.78E-01	1.00E+00
4	36	CCFMVNJ	1.48E-01	1.00E+00
5	61	LISW/A	1.34E-01	2.33E-02
6	65	LISW/B	1.34E-01	2.33E-02
7	69	LISW/C	1.17E-01	2.04E-02
8	95	SW5360A	3.03E-02	9.60E-03
9	98	SW5360B	8.00E-02	1.56E-02
10	101	SW5360C	1.07E-01	1.80E-02
11	4	RCF	8.10E-02	1.00E+00
12	22	PP1	2.01E-02	7.13E-03
13	26	PP	2.01E-02	7.13E-03
14	17	PP3	1.60E-02	5.74E-03
15	93	ETC	1.12E-02	4.75E-03

A case-study for configuration control has been performed for integrating the importance of component(s) and time of configuration. Four configurations have been considered for the case study. Firstly the DG#1 i.e. Class III system redundant component was taken out for 10 days. Secondly, valve MV3101 and Class II power supply were taken out. Third, the top most important components V3139 & Rupturer Disc (RD) were taken out. Fourth, PP3 was taken out last in list of top 15 important components.

Allowable Outage Time (AOT)

The Allowable Outage Time for a particular system or component specifies the time period during power operation within which any repair or maintenance should be completed. AOTs are increasingly being defined for shutdown. If the outage during reactor operation is more than AOT, the plant operating configuration/mode must change, or the plant must be shut down.

The AOTs were originally defined for corrective maintenance. There is now increased agreement among plant owners and regulatory authorities that performance of planned preventive maintenance during power operation

introduces potential benefits for improved equipment reliability, improved operational flexibility and outage work planning, and reduced risk during plant outages. Therefore, AOTs are now also used to control times for preventive maintenance.

The performance of preventive maintenance and necessary corrective maintenance during normal power operation (or during shutdown) should be controlled to allow sufficient time for proper completion of the work and to minimize the risk from equipment unavailability while maintenance is in progress. For a risk based evaluation, the primary quantitative assessment focuses on the risk impact due to the AOT period. This requires assessment of three types of risks-

- Instantaneous risk while the component is in maintenance.
- Cumulative risk over the AOT period.
- Average risk over a long period (e.g. yearly), taking into account the frequency of maintenance performed on the component.
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In some cases, the optimum AOT may involve trade-offs between extended equipment unavailability during power operation and unavailability of the same equipment during shutdown conditions.
For analysis and case study, some of the redundant components of the system were chosen from the system component list to find the maximum permissible outage time during reactor operation. Observed results are presented in

Table 3: AOT for the ECCS components

S. NO.	EQUIPMENT DESCRIPTION	EQUIPMENT	MAXIMUM AOT (DAYS)
1.	Pump	PP-4	6.57
2.	Valve	MV-314	22
3.	Valve	MV-310	16.5
4.	Valve	MV-379	235
5.	Diesel Generator	DG-1	23

RISK BASED MAINTENANCE RESOURCES ALLOCATION

Insight obtained from the PSA model helps maintenance staff to optimize the maintenance programme as per the risk contribution from the equipments, i.e. to identify equipments requiring somewhat upgraded preventive maintenance and those which require corrective or extended test interval for their maintenance.

In the case study, from the risk ranking (Fussel-Vessely) of the components of the emergency core cooling system, components whose risk importance is less than $1*10^{-4}$ order were selected to study the effect on the system unavailability and CDF when their test interval is doubled. The test interval of the selected components was changed from 2160 hrs to 4320 hrs and the effect on the system unavailability and the CDF was studied. Results are presented below:

RESULTS:

(a) At test Interval 2160 hrs:

System unavailability = $5.23*10^{-4}$
CDF = $4.575*10^{-5}$

(b) At test interval 4320 hrs for selected components:

System unavailability = $5.28*10^{-4}$
CDF = $4.579*10^{-5}$

From the results of this study, it is observed that the components having importance (F-V) less than 1E-4 may be tested after a test interval of 4320 hrs (6 month), than the present test interval of 2160 hrs (3 months). Results indicated that by increasing the test interval to 6 months, the increase in system unavailability and CDF is not significant and the results are within the acceptance criteria. For rest of the components (not in the list) the test interval remains same, whereas the listed components can be tested during alternate test interval. Increase in test interval for the less important components will reduce the maintenance cost without compromising with the safety goals.

Risk-INFORMED SHUTDOWN SCHEDULING

The methodology for risk-informed shutdown scheduling has been developed. The methodology is briefly described using figure 4. In risk-informed shutdown scheduling the risk-based calculation using PSA results are form part of decision making in accordance with other various technical parameters [3]. In most of the nuclear reactor where online fuelling provision is not there, the Preventive maintenance schedules are made according to the fuelling outage. This gives the time for which shutdown will be there so according the maintenance jobs can be taken and other parameters can be given as input. Application of such methodology is expected to provide a basis for the effective utilisation of the available resources depending upon the risk from the plant equipments. At the same time, maintaining safety standards as set up be the regulatory bodies.

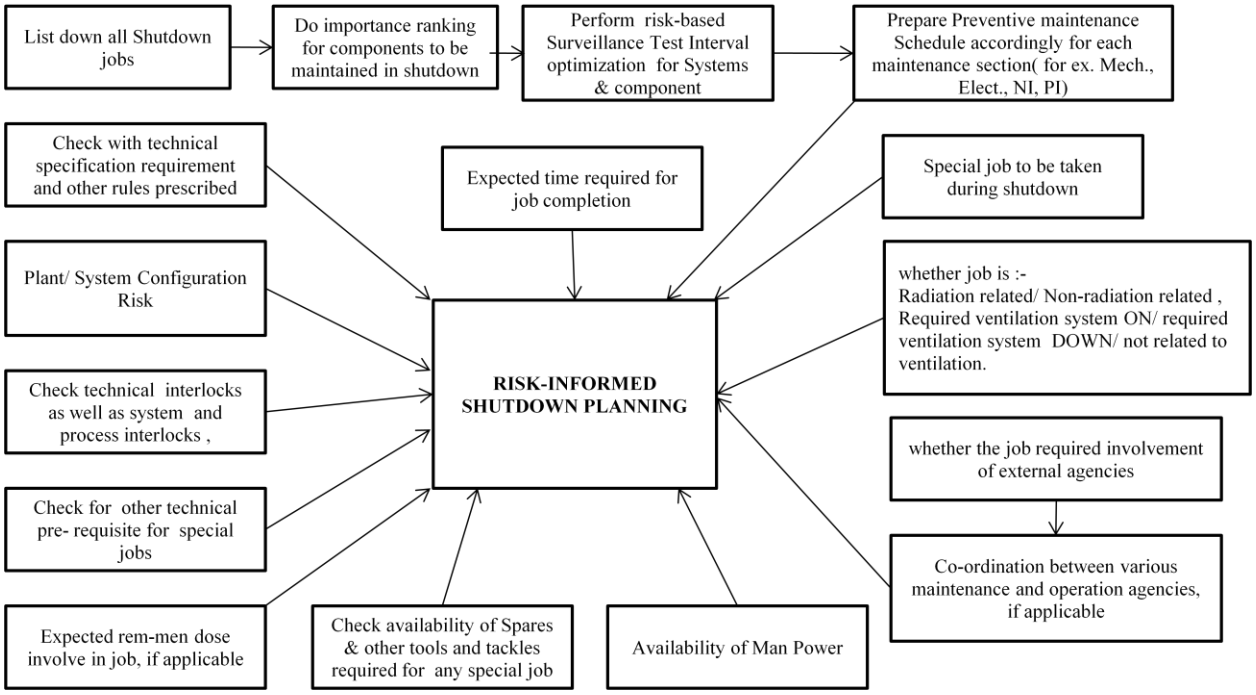

Fig. 4 Risk-informed shut down planning flow diagram

CONCLUSIONS

Risk-informed asset management methodology has been developed which mainly involve the resource allocation and shutdown scheduling planning. The case study has been carried out using RBOMMS software. Operations & Maintenance decision making plant managers and operating staff will be the main user of the methodology and software developed RBOMMS. RBOMMS enables plant operators and managers to evaluate the plant risks and problems associated with plant configuration and maintenance activities. The software has user friendly Graphical User Interface (GUI) for plant managers and operators with almost all important elements for risk-based management such as Core Damage Frequency (CDF) calculation, generation of risk profile graph for past configurations, estimates system unavailability and IE contribution to CDF, perform importance analysis and uncertainty analysis, store login sessions, comparison of risk-based surveillance test interval with traditional surveillance test interval, and scope for technical specifications, this system can also facilitates the shutdown maintenance planning and scheduling. In the risk-informed decision making, risk-based outcome(s) is/are the parameter(s) with several technical as well as non-technical parameters. A case study for nuclear research reactor

has been carried out for AOT calculation, configuration control and resources allocation. A risk-informed shutdown planning methodology also has been discussed in brief.

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