

《Technical Note》

**Display System Design Based On The Abstraction Hierarchy**

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**Abstract**

Plant monitoring algorithm developments seem to be saturated which means that display system to show the results from the algorithm should be the well-defined and interactive tools for operator's diagnosing, controlling, restoring the abnormal plant situations. On the other hand, very little generalized display design concepts and evaluations are available. Events that are unfamiliar to operators and that has not been anticipated by designers may cause great threats to the nuclear power plant system safety operation. The abstraction hierarchy, considered most popular display design methodology but not generalized for nuclear power plant design space, has been proposed as a representation frame work that can be adopted to design interfaces and supports operators in diagnosing overlooked events that should have been considered to operate plant safely. However most practical plant display systems do not fully stick to this design concept but partially rely on their philosophy from design experiences. Abstraction hierarchy display design concept will be described and the trend of Advanced Control Room(ACR) CRT design will also be presented with the conventional display for the several type of plants. Consequently this complementary material should be of interest to designer and regulators concerned with nuclear power plant.

**1. Introduction**

Most of the plants have the dedicated CRT for the process variables monitoring and historical data analysis. Individual process variables are selected and composed by certain algorithm to produce informative data. The plant system consisting of many components, instruments and gauges is so complicated that it's not simple to display plant status on the display page efficiently. If computer-based monitoring systems only display the field sensor values, as one gauge is for one sensor in main control room panel,

without analyzing and integrating the independent variables to generate informative forms of data which can help operator to understand the plant status quickly, the goal of computer-based monitoring system can not be maximized. Also the design of computer-based display page only based on the Piping and Instrumentation Diagram (P&ID), as control panel does, is not a good configuration. Thus computer-based monitoring system should analyze, integrate, and extract information to enhance operator's understanding. To do this, display page set should include abstract function about plant status

[1].

Even though several experimental and commercial plants have their own display design basis and philosophies, they mainly rely on the design experiences in color coding and symbology and generally try to follow the Multi-level Flow Modeling (MFM) [2]. MFM based on the abstraction hierarchy is a possible language for formalizing Safety Parameter Display System (SPDS) design. There is experimental stuffs for MFM based on abstractions hierarchy like Riso GNP [2, 3] and Halden [4] experiments that have been performed using only higher level of abstraction. The results from those experiments are telling that only the higher level of abstraction makes a remarkable performance of overall feel of plant but shows a drawbacks in diagnosing a unanticipated events because there were no lower level of abstractions like Piping and Instrumentation Diagram. According to the [5], display page domain has 5-level of abstractions. These 5-level of abstractions for conceptual design phase are actually strongly coupled in implementation phase. Especially in the lower level, most CRT display design uses P&ID, attributed to Physical Form in MFM model, to help operator diagnose the specific components status. There are no big variations to design Physical Function and Physical Form layer. A lot of experimental and practical plants have tried to use the bigger portion of screen for dynamic display. However in the higher level, there are different approaches to implement those levels. In this complementary paper, the implementation of the higher level will be covered by analyzing and comparing several experimental and Advanced Control Room (ACR).

## 2. Multi-level Flow Modeling (MFM) and Experiments

Abstraction hierarchy design concept employs Multi-Level Flow Modeling Interface methodology. The first level of interface based on the abstraction hierarchy representation to be implemented empirically is

influenced by Lind's Multi-Level Flow Modeling (MFM) grammar. The greatest advantage of MFM is that it provides designer with a formal language for plant design based on first principles (i.e., mass and energy conservation law). The first implementation of a multi-level interface on the abstraction hierarchy was conducted in the early 1980's at Liso National Laboratory in Denmark. This research was conducted within the context of the Generic Nuclear Power Plant (GNPP) [6], a very simplified simulation of the pressurized water reactor (PWR) power plant. MFM created for GNPP concentrated on the representation at the level of Abstract Function. Accordingly all of the display contains information of mass and flow topology. GNPP page consists of 15 pages which is organized in a roughly hierarchical structure with the different level in the hierarchy corresponding to different levels of aggregation or resolution. Interestingly higher and lower levels of plant function was represented in term of mass and energy. No information, or depiction of physical components was made available. The representation available in the GNPP display set can be made more explicit by mapping them in the two dimensional problem spaces shown in Fig. 1. The space is defined by an abstraction hierarchy along the vertical axis and a decomposition or part-whole hierarchy along the horizontal axis. With regard to the former, higher levels represent the system in functional terms and lower levels of represent the system in physical terms. The part-whole hierarchy, on the other hand, describes the system at various levels of resolution. Although these two dimensions are orthogonal conceptually, in practice they are actually coupled. It is possible to describe the plant at a very coarse grain by viewing it as a whole. A more detailed description can be obtained by describing the plant in terms of its various subsystems. Most detailed description one in which the system is described in terms of its individual components. While doing the experiment in GNPP using the transient scenarios, there were some problems. As intended, the strategies used by most

subjects in searching through the display page set followed a "zooming in" pattern beginning with search at a high level of description and then narrowing in on the faults by looking more detailed. However particularly those who with less technical background, had a problems in understanding the meaning and implications of the information represented by the

MFM icons [6]. On the basis of these initial results, plans were made to modify the GNPP display set by adding the second level of abstraction, Physical Function [7]. This new display set thereby provides operators with both physical and functional plant representation as well as provides a means for mapping between the two. This changes attempted to address the limitations that were observed with the earlier display set and tells that human diagnosing strategies need both the higher level of abstraction, Functional level in Fig. 1 and the lower level of representation, physical level in Fig. 1. However this revised GNPP display set was never fully implemented, and thus data are not available to determine whether or not the proposed changes would indeed beneficial.

Another experiment with MFM (abstraction hierarchy interface) for GNPP was conducted as the Halden Reactor Project in Norway to evaluate how well the MFM displays based on the abstraction hierarchy supported fault diagnosis performance. As with the Riso GNPP, several subjects were given theoretical

and practical training before experimental session. Some of experimental conditions differ from Riso GNPP. Regardless of how many subjects diagnose plant status successfully, all subjects followed intended top-down search strategy. The comments provided by subjects after experiment were also reminiscent of the finding of the Riso experiment. Subjects found it difficult to diagnose transients only in terms of the abstract concept of MFM. Also all subjects would have preferred to have more about the state of the physical components. In spite of this, subjects tend to use top-down strategy to search for the faults. Consequently, the implication is that the MFM grammar is useful to represent the higher level of abstractions and the way of human thinking to diagnose starts from abstract and coarse level to specified and part level along the diagonal in Fig. 1. However display representing the physical components are required at lower levels.

### 3. Abstracted and Conceptual Display Design

There has been a significant research to generalize display design concept and to supports operators in understanding the plant status in normal and abnormal events precisely. The classes of events in nuclear power plant are most challenging because operators will not be rely on a solution built in by the

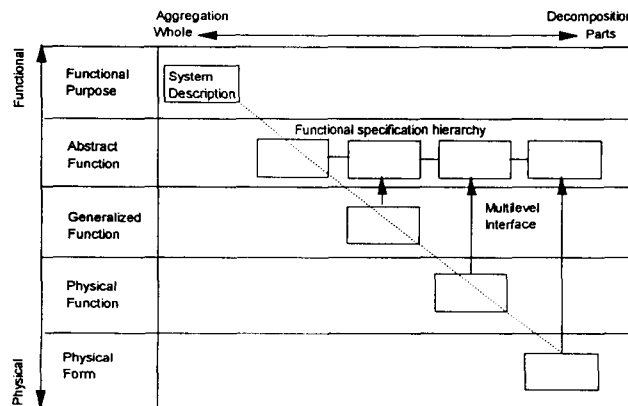


Fig. 1. 2-Dimensional Conceptual Display Design Space for Abstraction Hierarchy

designer's foresight. Instead they will have to analyze the unfamiliar situation and improve a solution themselves. There will always be a chance that significant events can be overlooked and therefore not included in the set of design basis. Despite the fact that unanticipated events can play the critical role in plant safety, very few approach to interface design for NPP control room makes an explicit attempt to provide operator with the support needed to cope with such events. The abstraction hierarchy is an exception because it was intentionally developed to provide the operator with an informational basis for coping with unfamiliar and unanticipated events. It provides the framework for identifying and integrating the set of goal relevant constraints in a given work domain. Each level in the hierarchy represents the different class of constraints. For process control system, five levels of constraints digrammed in Fig. 1 have been found to be useful. Functional Purpose that is most abstracted level in abstraction hierarchy contains the purpose for which the system was designed. Abstract Function displays the causal structure of the process in terms of mass, energy, information, or valve flows. Generalized Function includes the basic functions that the plant is designed to achieve. Physical Function includes the characteristics of the components and the connections between them and Physical Form displays the appearance and spatial location of those components very similar to PID. The higher abstraction levels represent relational information about system purpose, whereas the lower levels represent more element data about physical implementation. There are several experimental and practical implementation based on this design concept and/or similar design concepts. Some experimental display system based on MFM hires process icons to implement Abstract Function level(See reference [1] for more details on process icons). However non-trivial disadvantage was that those process icons are not familiar to those who with less training and nuclear background. The higher level abstraction has served as conceptual display design basis and proven to be

efficient for reasoning the unanticipated and overlooked events in display design stages. Several Advanced Control Room(ACR) designs based on the abstraction hierarchy are in progress. Even though most ACR designs hire their own design basis, philosophy, and methodology from experiences, eventually have focus on providing inferencing aids for unanticipated events or events that have been omitted in the display design phase. The common trend among them is that every display page screen is being spent to display dynamic portion contrary to the conventional one.

#### **4. ACR Implementations Based on Hierarchy Abstractions**

During the past decades, several power plant manufacturers have adopted multi-level functional representation as basis for their Advanced Control Room(ACR) designs. The SPDS design of new Westinghouse ACR [8-11] was based on the abstraction hierarchy framework. The design of the plant itself was conducted with the aids of MFM grammar [12]. The strategy adopted by Westinghouse in designing multi-level interface differs substantially from the other experimental implementation described above. Westinghouse ACR did not adapt MFM icons. Another difference is that both functional and physical information were made available with the mechanism for moving between these two. The functional displays represent the functional relationship between process variables. In contrast to the Riso and Halden display, the emphasis is on dynamic, higher order of information rather than static system structure. The physical displays represent the equipments that realizes the system functions, as well as the way in which that the equipment is organized. These displays are basically Piping and Instrumentation Diagram(P&ID) with state information about any relevant support systems. As seen in the Fig. 2, graphical representation for relationship between the parameters is hired to enhance the operator's reasoning efficiency.

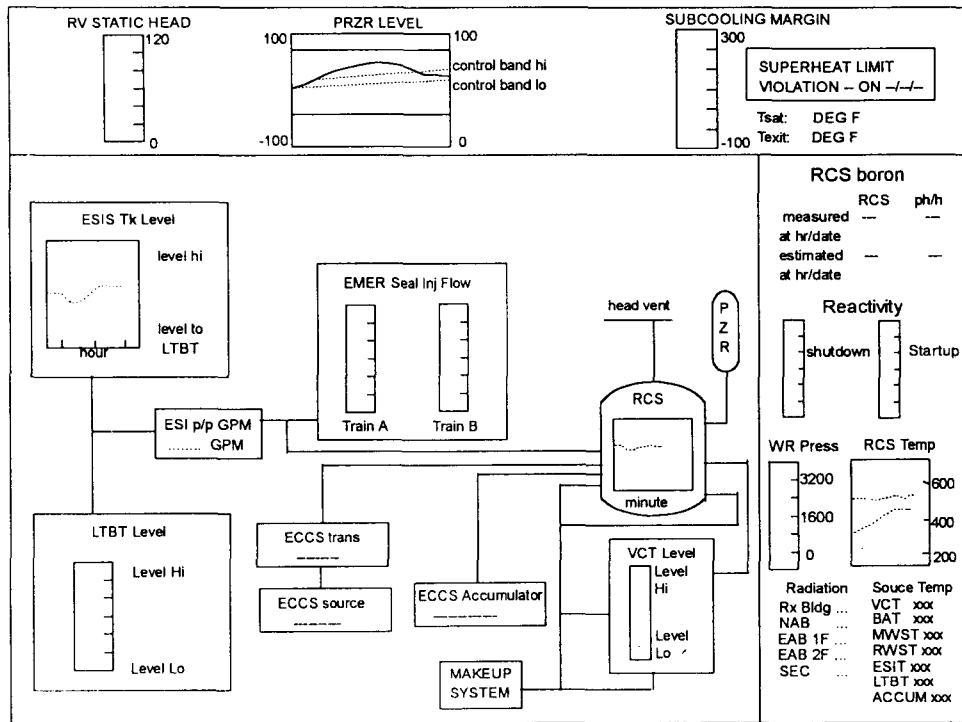


Fig. 2. Functional Display in Westinghouse ACR (Some is Left out for Clarity)

More dynamic display representing causal structures between the subsystems and historical data (trend) outweighs the static information on display page. The Toshiba's ACR design for a next generation BWR plant has a number of components, including decision support system for incident and accident management system and comprehensive intelligent man-machine interface [13-15]. As with the Westinghouse, Lind's MFM grammar was used to develop a hierarchical functional representation of the plant.

The design of the Toshiba intelligent interface is based on the 2-dimensional abstraction decomposition space described by Rasmussen. The lower level of physical display is based on PID format and one thing worth while noting is that the Rankine cycle display is used for Abstraction Function level. In addition to providing representations for the various area in the problem space in which operator's worked, this interface design also supports a mechanism

for navigating between hierarchical representations. Toshiba's design is the most faithful industrial implementation of the abstraction hierarchy in that it directly adopts 2-D means-end/part-whole spaces.

Nuplex-80+ SPDS design that is similar to Korean Standard Nuclear Power Plant (KSNPP) display system is in progress. The presentation of plant process on CRT display pages containing separate information that must be viewed independently might prevent operator from gaining an overall "feel" of plant status. The interesting approach to make operators get the overall plant feeling is being done not only in CRT design but also in Main Control Panel design. In the Nuplex-80+ control room, a large display called IPSO (Integrated Process Status Overview) is mounted on benchboard to provide the information that operator requires for quickly accessing overall plant status.

IPSO panel, 6 feet high and 8 feet wide, is pres-

enting 12 system information and using the same color coding, dynamic, highlighting, graphic layout and information coding feature in the CRT design. Actually IPSO is the part of CRT display page and correspond to the higher level of abstraction in the abstraction hierarchy design space. CRT display pages under the IPSO are composed of three levels, one for general monitoring, one for system components, and one for detail diagnosis. Nuplex-80+ display page access is accomplished by primarily through the use of MENU option and DIRECTORY page [16].

GRADIENT (GRAPhical Dialogue Environment) project was a large-scale research efforts under the ESPRIT initiative. The aim of the project was to investigate the use of graphics and knowledge-based dialogue to support both operators and designers of industrial process control systems. As one of the partner in this project, Asea Brown Boveri(ABB) has developed a working intelligent prototype interface, called MARGRET[17-19]. The heart of the MARGRET system is a functional model that describes the plant at various levels of abstractions. This model is similar

to the abstraction hierarchy representation. The plant model is used as a knowledge base to drive the decision support systems and graphic interface. The MARGRET system is a rare implementation of the multi-level and the multi-window concepts. The various features that have been designed to allow operators to pan and zoom across the hierarchy plant representation seem to provide a flexible and natural way of accessing information.

Ecological interface design(EID) is a novel theoretical framework, based on the skills, rules, and knowledge taxonomy[20], that has been proposed for designing interfaces for complex human-machine interface system. The EID also adopts the abstraction hierarchy as a work domain representation that can then be used as a basis for interface design. The goal of EID is to reveal the various layers of constraints inherent in the work domain in such a way as to take advantage as much as possible of operator's powerful capabilities for perception and action while attempting to provide the appropriate support for comparatively more intense and more error-prone problem solving

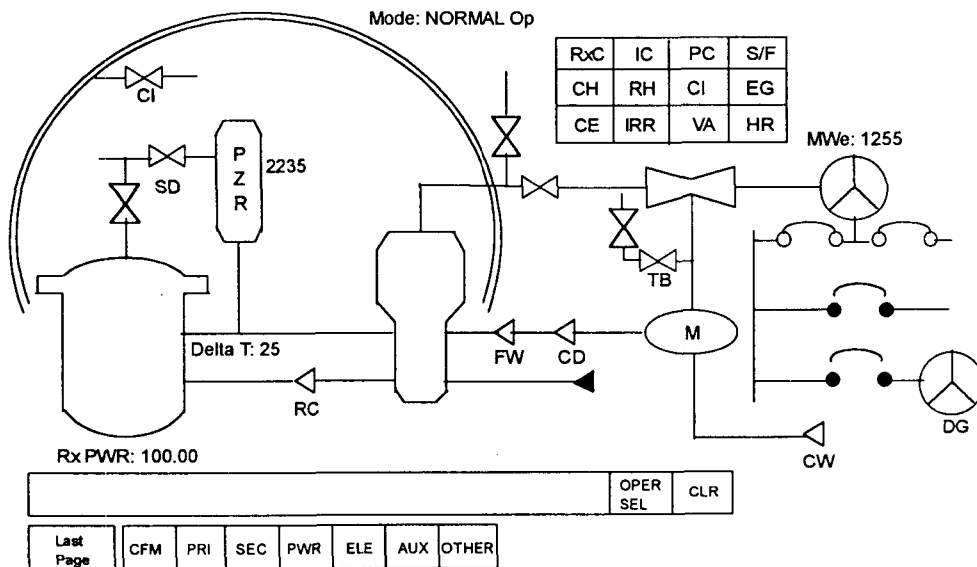


Fig. 3. IPSO Display in Nuplex-80+ (Some Portion is Omitted for Clarity)

activities. Thermo-hydraulic process simulation, called DUal REservoir System Simulation (DURESS) uses abstraction hierarchy to develop ecological interface. The physical information concerning the state of all components and goal variables of DURESS is called P interface. The general format of P interface is based on the traditional P&ID. The functional interface of DURESS is referred to as P+F interface in Fig. 4 because it contains both physical information (states of all components) and higher order functional information (e.g. mass and energy topologies) and thereby represents all levels of the abstraction hierarchy for DURESS. Unlike the previous simulation, DURESS implemented the P and F interfaces into one display page which means P+F interface contains physical representation while physical information is shown in P interface. In DURESS experiment, It was found that diagnosis performance was significantly correlated with memory for the functional variables which means that accurate diagnosis was associated with accurate memory for functional variables. In contrast, diagnosis performance and memory for physical variables were not significantly correlated. This result

indicates that the higher order of functional information represented in the P+F interface is important in diagnosis. Thus this would be good justification for those who have doubt in higher order functional information representation.

Up to now, recent conceptual display design concepts and its applications have been presented. Some of those examples were truly based on the experimental. However in practical plants, those concepts are not fully implemented as it was suggested but There should be some kind of tools and/or pages for integrating individual process variable for operator's quick plant status perception. In maneuvering the display page, there is no independent display directory for maneuvering. The operator can directly access the page so that he/she want to scan by pressing the keyboard containing all the kind of display pages.

### 6. Implementations of the Higher Level Abstraction

As mentioned before, Five abstraction hierarchy based on MFM was suggested to make operator pow-

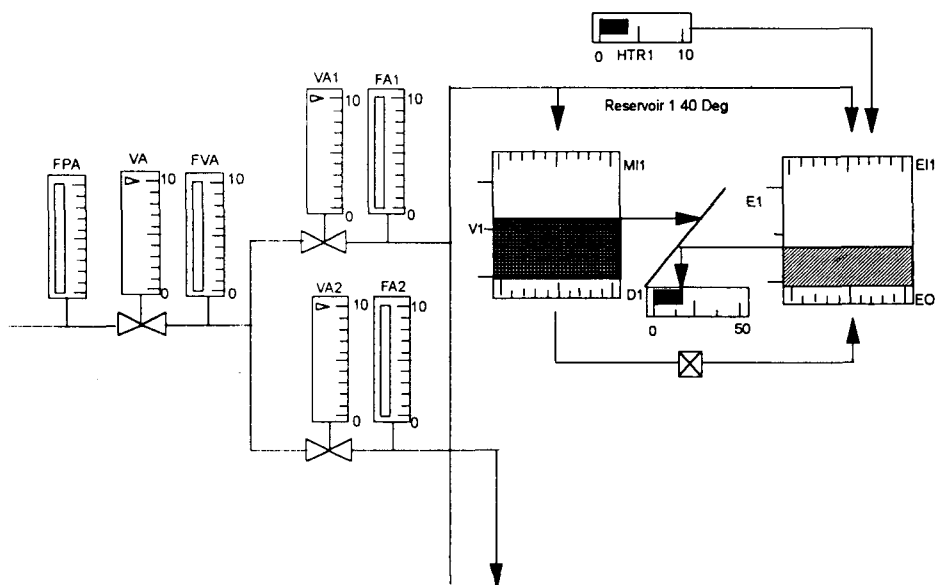


Fig. 4. Typical Ecological Display for P+F Interfaces

erful in monitoring the unanticipated events and fast diagnosis. The first level of abstraction is Functional Purpose which is naturally achieved by cooling the core with liquid-phase water. It can be system goal of the highest level of abstraction. There can be other system goals but their final meaning should be the same as above regardless of the description. The second level of abstraction is Abstract Function. It's not simple to describe the Abstract Function of the system especially in the complex nuclear work domain because there are a lots of components which has its specific role to keep the plant stable. According the NUREG-1150[25], the principal contributor to endanger plant is the following events; (1) Small Loss-Of-Coolant Accident (LOCA), (2) Large LOCA, (3) Seal LOCA, (4) Anticipated transient without scram (ATWS). Actually this is lessen learned from TMI-2 accident. After that operator must be keenly aware of the coolant inventory within the plant process loop. From these data, Beltracchi presented Model based conceptual design for monitoring reactor coolant[26]. In broad terms, the plant systems that contain coolant mass and regulate water flow are ten times larger than the number of system regulating the heat source. This means that controlling and monitoring coolant is a very important to plant safety. He used the law of conservation of mass to modelling the Abstract Function level. Abstract Function in the Fig. 1 is maintained by the law of conservation of mass and coolant. According to the reference, the General Function of plant system is nuclear safety by cooling the core with liquid-phase water. See reference [26] for more details.

A lots of plant specific setpoints should be one of the display parameter selection criteria. Those setpoint should be kept for plant safety. However those individual setpoints have no meaning in real time monitoring which means that there should be extra time to spend in aggregating and analyzing functional setpoints for diagnosis exact plant status. There are several means of bridging the gap between goal and display of individual and system variables. One

of those is EOP. EOP embodies the set of rules by which operator evaluates specific variables and take corrective actions to restore the plant into normative states. Most of EOP may be event-driven and function-driven. This kind of procedures support rule-based behavior and not knowledge-based procedure. Rule-based behavior would be adequate provided scenario in the plant are all in the procedure. However due to the complexity of plant it's not feasible. We must count on the operator's knowledge-based behavior as the mean for overcoming omission and short-coming in the procedure. In a word, means-end structure for reasoning is needed in Abstract Function level to cover these disadvantages. Recently Beltracchi has presented model-based display design using the Rankine heat engine cycle. he has provided the conceptual display design by emphasize reactor coolant monitoring and tried to narrow the gap between the theoretical and practical operation by presenting the model-based display. Even though several assumptions were introduced to make this model, this is good contributions for overcoming the gap between theoretical abstraction and practical implementation in CRT.

## 7. Conclusions

In addition to displaying the plant process variables to operator, computer-based monitoring system is required to have more inferencing and diagnosing capabilities for overlooked events in the display design phase. Unfortunately most of plant have no proper structure to cope with those events. In this report, the commercial display system based on MFM abstraction hierarchy is presented. Most of ACRs adapt the abstraction technology and spending more display screen to display the dynamic information, eventually functional variables based on time basis. Regardless of the plant type, they are trying to display abstracted functional information to cope with the unanticipated events diagnosis. Those approaches for the higher level of abstraction are different



but the lower level displays for the specific components status are generally implemented by P&ID. The display in future should have much more extents of benefits. For that display system shall provide more powerful and interactive tools for safe plant operation. In higher level of abstraction most of ACRs have tendencies like the below. The first is that much more screen is spent for functional information display. The second one is that most of ACRs are trying to provide highly abstracted level of plant for event diagnosing for unanticipated and overlooked events. The third one is that most ACRs try to display functional causal structure by dynamic graphics and provide overall feeling of plant. Conventionally display have been just a tool for display many sensor values from fields and just a combination of PID format expansion and text dynamic except some of trend function. Some other plants don't even have the display like that. Eventhough there aren't many generalized abstractions based on MFM for practical implementation, several plants try to adapt the abstraction hierarchy concept for their ACR CRT design. This should be of interests for designs and regulations in nuclear power plant work domain.

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