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A Status Report Regarding Industry Implementation of Safety Parameter Display Systems

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

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ABSTRACT

This report provides a summary of the results of the U.S. Nuclear Regulatory Commission staff's review of installed safety parameter display systems (SPDS) at 57 nuclear units. The staff describes its rationale and practice for determining acceptability of some of the methods for satisfying the various requirements for SPDS as well as some methods that the staff has not accepted.

The staff's discussion of identified strengths and weaknesses should aid licensees in solving some of the problems they may be experiencing with their SPDS.

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I. INTRODUCTION

Beginning with the TMI Action Plan, NUREG-0660 (Ref. 1), NRC has issued several regulatory and review guidance documents relevant to the requirement for all licensees and applicants to install a safety parameter display system (SPDS). Documents issued included the following:

- NUREG-0737, Clarification of TMI Action Plan Requirements (Ref. 2)
- NUREG-0696, Functional Criteria for Emergency Response Facilities (Ref. 3)
- NUREG-0835, Human Factors Acceptance Criteria for the Safety Parameter Display System, Draft Report for Comment (Ref. 4).

On December 17, 1982, Generic Letter No. 82-33 transmitted Supplement 1 to NUREG-0737 (Ref. 5) to all licensees and applicants. Supplement 1 condensed existing NRC guidance regarding emergency response capability into one document. The SPDS, TMI Action Plan Item I.D.2, was one of the five items addressed in Supplement 1 to NUREG-0737.

When Supplement 1 to NUREG-0737 was issued, the staff recognized that the action plan items regarding emergency response capability were far-reaching concepts with a high degree of interrelationship. Also at that time, some licensees indicated that their Commission-approved schedules for implementing these requirements could not possibly be met. Therefore, in Supplement 1, the staff took a less prescriptive approach to applying its requirements. First, the requirements were stated as general guidance that would not alter or replace previous guidance, but would put it in perspective by identifying the elements that the staff believes essential to upgrading emergency response capability. Second, because the requirements were described in a guidance document (Supplement 1 to NUREG-0737) and were actually imposed as requirements by other, plant-specific regulatory mechanisms, such as commission confirmatory orders or license conditions, all licensees and applicants had the opportunity to negotiate reasonable, achievable, plant-specific schedules.

Because the staff believed that the SPDS could provide significant safety improvement to nuclear power plant control rooms in a relatively short time, licensees and applicants were urged to install a system without undue delay. Further, the NRC allowed licensees and applicants to install the systems without prior approval to ensure that the NRC review process would not delay SPDS implementation. However, licensees and applicants were given the option of pre-implementation review and approval if they so desired.

On December 26, 1984, the NRC "Standard Review Plan" (SRP), NUREG-0800 (Ref. 6), was revised to incorporate Section 18.2, "Safety Parameter Display System," and Appendix A to SRP Section 18.2, "Human Factors Review Guidelines for the Safety Parameter Display System." This revision described the acceptance criteria, review procedures, and applicable guidance for NRC staff to use in reviewing SPDS.

Based on its operating license reviews at plants under construction, the staff discovered that serious technical problems existed in the implementation of SPDS at some units. To determine whether these problems were being experienced at operating plants as well, the staff visited six operating reactors from July to November 1985. At the conclusion of this survey, the staff reported the following findings in NUREG/CR-4797 (Ref. 7):

> Observations from these visits strongly suggest that utilities may be having major difficulties in designing and implementing their SPDSs. As long as two years after having been declared operational, three of six SPDSs were found to be highly unreliable, displayed inaccurate information, and offered considerable potential for misleading and confusing operators. Several of these SPDSs appeared to face many months of continued developmental effort. Operator acceptance was often very poor because operators had not been involved in the development process and because the systems were so undependable and unreliable; negative attitudes in some cases extended also to supervisory and management personnel. In short, if the SPDSs reviewed were representative, many SPDSs may not achieve the goal of aiding control room operators in rapidly and reliably determining the safety status of the plant during an emergency.

The staff subsequently issued NRC Inspection and Enforcement (IE) Information Notice (IN) 86-10, "Safety Parameter Display System Malfunctions" (Ref. 8) to inform licensees of the results of the survey program. Since February 1986 when IN 86-10 was transmitted, the staff has received several requests for extensions of implementation schedules, requests for clarification regarding the definition of an "operational SPDS," and questions about SPDS deficiencies and their resolution. These requests appear to indicate that confusion still remains regarding the basic requirements for SPDS, the staff's review process for SPDS, or both.

This report was developed to describe the staff practice for determining the acceptability of some of the methods used to implement the SPDS requirements. The following sections document various methods used by applicants and licensees to meet the SPDS requirements. The report also discusses the rationale used by the staff to determine whether an SPDS was acceptable or unacceptable. By providing a history of its past reviews, with a full discussion of staff practices and exceptions, the staff expects that industry will be better able to understand and implement acceptable SPDSs.

II. DISCUSSION

The following sections restate the major requirements for SPDS and describe some of the various methods by which licensees and applicants have responded to those requirements. The staff rationale and practices for determining the acceptability or unacceptability of each method is stated and explained.

When a licensee's or applicant's method for satisfying a requirement was unacceptable, the staff rationale and practice is fully explained, including the underlying basis for the requirement and associated regulatory guidance. The discussion of staff practices sometimes necessitates the definition of terms, general principles, and assumptions. When this is the case, these items have been highlighted by underscoring or as notes within the text.

III. EXAMPLES OF SPDS FEATURES OBSERVED IN PAST REVIEWS

III.A. RAPID, RELIABLE, CONCISE DISPLAY

> The SPDS should provide a concise display of critical plant variables to the control room operators to aid them in rapidly and reliably determining the safety status of the plant. Although the SPDS will be operated during normal operations as well as during abnormal conditions, the principal purpose and function of the SPDS is to aid the control room personnel during abnormal and emergency conditions in determining the safety status of the plant and in assessing whether abnormal conditions warrant corrective action by (control room) operators to avoid a degraded core. This can be particularly important during anticipated transients and the initial phase of an accident. (NUREG-0737, Supplement 1, Section 4.1.a)

This requirement is interpreted by the staff as containing five essential elements or concepts:

- concise display
- critical plant variables
- rapid response
- reliable
- conditions when SPDS should be operational

These elements are discussed below, except for the concept of critical plant variables that is discussed in Section III.F of this report.

III.A.1. Concise Display

Of the units reviewed thus far, 37 acceptably satisfied this requirement. Twenty-six units did so by providing a single display of critical variables on a cathode-ray tube (CRT) device. Others provided two CRT displays in a side-by-side configuration, usually with plant process variables on one screen and radioactivity control variables on the other. The staff found this method acceptable contingent on the full set of SPDS variables being "continuously displayed" (see III.B.2 for acceptable methods of providing continuous display).

Twenty units provided a single CRT display augmented by conventional control room instruments. The staff accepted this method only in those cases in which it was impractical to include the data from the conventional display on the CRT display because it was not part of the computer data base; the conventional

display was easily readable from the SPDS user's position; the parameter displayed on the conventional display was defined as part of the SPDS parameter set; and, a commitment was made to preserve the visual relationship of the SPDS and the conventional display.

In several cases the actual words or values on the conventional display could not be read from the SPDS user's position. However, in some of these cases the staff found this situation acceptable because the information being transmitted was a simple status, e.g., on/off light, or open/close light and the display was enhanced by either pattern-recognition or location highlighting. In a few cases the staff did not accept the mixed mode display concept. In one system the conventionally displayed information was required to be read but could not be, and it was not amenable to pattern recognition. In the others, the conventional display was not in the SPDS operator's field of view and would necessitate a change of the operator's position to be read.

The basis for the requirement for a concise display stems from the lack of centralized display capability in the TMI-2 control room. Control room personnel could not easily develop an overview of plant conditions in the TMI-2 control room because the available displays were widely dispersed and provided component-level information. This situation hampered decision-making because it did not facilitate the comparison of variables or the integration of various symptoms within the same timeframe. At the same time it induced some unproductive behaviors such as fixation on a limited set of plant variables, and undue attention to irrelevant plant anomalies while safety functions were in jeopardy. Therefore, the staff found unacceptable any SPDS that made it necessary for the user to leave the SPDS to gather information necessary to assess the status of the critical safety functions, or otherwise caused the operator to turn attention away from the primary SPDS location.

III.A.2. Rapid Response

Note: The staff assumes that in order for a control room operator to determine the safety status of the plant rapidly, five conditions should exist:

(1) Information presented should represent current plant conditions, i.e., real-time data,

(2) Information should be sampled at a rate that assures that no meaningful data, or trends in that data, will be missed, i.e. the sample rate should be sufficient to assure that data is of appropriate resolution;

(3) Information should be updated on the display often enough to assure that changes in plant status will not be masked or lost by the passage of time, i.e, update rate should be consistent with, and sufficient to represent, expected variations in plant safety parameters;

(4) Information should be rapidly accessible to the operator, i.e, system response times of about 2 to 3 seconds and no greater than about 10 seconds maximum;

(5) Information should be in a simple, easy-to-understand format that can be rapidly comprehended.

Many of the SPDSs reviewed by the staff satisfied this requirement by installing systems that provide real-time data that is sampled and updated at meaningful rates. Acceptable sampling rates were judged in the context of required resolution, e.g, reactor coolant system (RCS) pressure requires data resolution in terms of seconds while certain radiation levels need (or can only) be sampled every 30 seconds, 60 seconds, or several minutes. In its reviews, the staff urged licensees and applicants to minimize differences between sampling rate and update rate so that operators would not be misled, e.g., a variable that is updated on the display screen every 2 seconds but is sampled only once a minute will appear to be stable, when it may in fact be increasing or decreasing. The staff exercised flexibility in applying these principles during reviews, depending on the instrumentation available and the variable being measured.

Acceptable systems provided data that was consistent with conventional control room instruments. They also provided simple displays that allowed immediate recognition of normal, abnormal, and emergency conditions. System response times to operator commands were 10 seconds or less, from the initial keystroke or cursor movement to updated screen.

Note: Good human engineering practice prescribes that system response time to requests for graphic output, such as typical SPDS displays, should be no greater than about 10 seconds. When system response time exceeds 15 seconds, the operator should be provided with feedback that there will be a delay in servicing the user's request or command.

Overall, these characteristics yielded systems with which an operator can see a current, accurate overview of the plant in ten seconds or less. Most of these are enhanced by summary status indicators or pattern-recognition aids that allow operators to see at a glance whether any plant safety function is abnormal.

A few systems did not display real-time data for at least some of the SPDS variables. Because the SPDS is intended to coordinate a variety of widely distributed control room instruments into one concise display, real-time or near real-time data is necessary to provide the operator with an overview of the plant that is the equivalent of and is consistent with the control room instruments it represents.

Some systems were found deficient because sampling rates were too slow. Others were deficient because sampling rates could be changed without the knowledge of the operators. In cases where the sample rate was too slow, it was the staff's judgement that significant changes in plant state could be masked and operators could be misled. In cases where the sampling rates could be changed, the operators were generally not aware that the sample rates were variable and could be changed--they assumed that all data was being sampled at a rate equal to the display update rate. Because there were no mechanisms in place for controlling changes in sample rates and operators were unaware of this capability, these changes presented some risk that operators would be misled or confused by the SPDS if the sampling rates were changed.

- Eleven units had systems that the staff found to be unacceptably slow in displaying changes in plant safety status. Several of these were found to be unacceptable because the system did not update data automatically. Rather, these systems would take a "snapshot" of plant conditions when requested to do so by a user. This feature was found to be unacceptable because (1) the data displayed is quickly outdated; (2) it may not be a representative sample of plant conditions; (3) discrimination of trends necessitates the operator doing successive iterations of manual updates; and (4) in some systems, there is a risk that an old display screen could be mistaken for new data.

  Some systems were unacceptable because the response to operator commands was unpredictably variable and slow. Generally, these were systems in which SPDS shared time with other functions or which were overloaded. The unacceptably slow response times ranged from about 30 seconds to several minutes. Usually these systems would also vary in response times such that operators never knew whether the system had accepted a command and was executing it or had missed the command, ignored the command, or crashed completely. In some systems this led operators to try to key in the command again which would "lock up" the keyboard and disable the system for minutes or hours.

  Some systems were deficient in not allowing operators rapid access to data. Such systems were generally "command-driven," requiring that the user remember or look up an alphanumeric command and key it in. These systems were found to be unacceptable if a trained operator could not quickly call up an SPDS display. The reviewers found a system unacceptable if operators had to consult point identifier directories and could not find correct entries, or if they had frequent mis-keying errors that resulted in long response times.

III.A.3 Reliability

Note: The staff defines reliability at the system level. Therefore, acceptable systems are those that are reliable in terms of hardware, software, and operator performance. Reliability, as defined here, includes two general concepts: (1) reliability--the degree to which the system will repeatedly produce the same results under identical conditions over time and (2) validity--the degree to which the system will produce correct and accurate results that the user will believe, i.e., rely on. Of the 57 units reviewed thus far, 12 have installed systems that were considered adequately reliable.

From the hardware point-of-view, these systems are characterized by the use of backup storage and automatic restart capabilities, uninterruptable power supplies (UPS), independent and redundant hardware for critical parts of the system, on site or near-site maintenance support, and adequate inventories of spare parts.

Regarding software reliability, these systems were developed using verification and validation (V&V) methodology equivalent to that described in NSAC-39, "Verification and Validation for Safety Parameter Display Systems" (Ref. 9). This methodology provides some assurance that the SPDS software has been adequately designed, implemented, and tested.

From the operator performance perspective, the reliability of these acceptable systems was tested by some form of "man-in-the-loop" test program in which trained operators used the system during emergency event scenarios. Operators were trained in SPDS operation prior to declaring the SPDS operational in the control room. The perception of operators interviewed at these plants is that the SPDS is as reliable as (or more reliable than) any other instrument in the control room. Generally, operators at these plants use SPDS routinely and on a daily basis.

Note: The term "operator" as used in this document refers to "SPDS operator" or user; those users are defined by each licensee and may include Shift Supervisors, STAs, and emergency response facility personnel as well as control room operators.

Reliable systems also provided some method of data validation. Minimally, they all provided at least a comparison of redundant sensor readings for consistency, and range-checks to identify failed instruments. Most also provided other methods such as coincident logic schemes, and analytical algorithms to shift setpoints during mode changes. These characteristics yielded systems with estimated or measured computer availabilities of greater than 99 percent, and that operators were reasonably confident that it could be relied upon to display plant data correctly.

Many systems were found to be unreliable, suffering from frequent failures ranging from keyboard "lock-up" to total system crash. Although these systems contained some of the characteristics of acceptable systems, such as multiple processors and UPS, they also contained design flaws that allowed single failures of hardware or software to take the system down frequently and/or for long periods of time. Nine systems displayed inaccurate or incorrect information that could mislead operators. False alarms were also common. These problems undermined operator confidence in relying on the SPDS. In fact at several plants, operators were instructed not to use SPDS at all. In general, these systems were not designed using an acceptable V&V program. At several plants, the SPDS was declared operational and installed in the control room before development of the design was complete and before operators were adequately trained. Under these circumstances, operators learned to mistrust the SPDS. In many cases, "man-in-the-loop" testing was not done prior to declaring the SPDS operational. Most plants with unreliable systems had inadequate maintenance and software quality control programs as well.

These systems were unacceptable either because they were so unreliable that operators did not use them--thus, they did not provide aid to the operator as required by Supplement 1 to NUREG-0737 or because they provided inaccurate or false information that could mislead operators, thus posing a serious safety question. In instances where the staff found SPDSs that had inaccurate or false information, licensees were instructed to shut the system off to prevent operators from using bad data that might lead to unsafe operation of the facility.

Although no SPDS was judged unacceptable based solely on shortcomings in its V&V program, it was apparent to the staff that those plants that did not implement a good V&V program concurrent with their design process were usually plagued by single-failure flaws in the hardware configuration, significant software errors, and poor acceptance by operators. High reliability should be built into a system by means of V&V methodology, good software maintenance, and established quality assurance policies. Test programs alone cannot assure that a system will provide reliable information under the full scope of emergency conditions, nor can one-time test programs address the viability of a system over time if uncontrolled or undocumented modifications are possible.

Because there is no single measure of system reliability, the staff's judgment has been based on three general measures in combination: (1) estimated or measured computer availability (equal to or greater than 99 percent), (2) observed inaccuracies and false alarms during an NRC audit, and (3) operator survey results. The last two of these have been given the most weight because they reflect the reliability of the final product, the data being displayed, rather than reflecting the reliability of the tools being used to process and generate the final product. No SPDS has been found unacceptable based on only one of these measures. Each is used as a confirmation of the others.

Because data validity and system reliability have such a great impact on the usability of SPDS, examples of specific problems are included below to provide further insights to licensees and applicants for avoiding common pitfalls.

III.A.3.a. Data Validity

Lack of Data Validation

Some systems failed to incorporate data validation techniques of any kind. These systems did not fulfill the requirement to provide a reliable display and in effect, complicated the operator's task of recognizing challenges to plant safety. Lack of data validation places the burden of identifying valid readings on the operator. Little benefit is gained from placing unvalidated readings of loop temperatures, for example, on a computer screen in addition to the control boards. In some cases, the operator was presented with averages of unvalidated inputs. In these cases, the averaging process may even mask a failed input from the operator, thus the operator will be misled by incorrect information. For example, in a PWR with three reactor cooling system pressure transmitters, one of which is failed high, system pressure would have to be below 1100 psi before an SPDS average of unvalidated inputs would indicate a concern. Furthermore, the input of unvalidated values to algorithms that determine critical safety function status can produce incorrect status indications.

Errors in Single Numerical Computer Points

Most SPDS systems have at least a few data points that do not agree with the analog or digital data that is displayed on the control room boards. In almost every case, this situation can be avoided. The most common of these errors are described below.

Some SPDS flow indications are continuously invalid or incorrect during normal operations. This destroys the credibility of SPDS as a tool to be used and trusted to display plant safety information. For example, during normal power or hot standby operation of the plant, numerous systems are not operating or are in a standby mode. Examples of these systems include containment spray, auxiliary or emergency feedwater, safety injection systems, diesel generators, and wide range containment sump level monitors. Flow and pressure instruments associated with these systems should indicate zero flow and low or atmospheric pressure when the systems are in standby. Because of electronics drift, the millivolt or milliamp signal equivalent to these zero conditions is not an absolute, fixed value. In addition, some systems in standby actually develop pressures slightly less than atmospheric or less than the calibrated static head. Because most SPDS systems use a fixed value as the zero range-check validation point, when instrument output falls slightly below this value, the point is falsely indicated either as invalid or as a negative flow value. This problem has been eliminated by some system designers by lowering the range-check set point value slightly and by allowing a small range of near-zero values to be interpreted as zero.

Most SPDSs have at least a few problems with digital computer points (e.g., two-state signals, such as open-shut and on-off). The problem is manifested by displays that erroneously indicate open valves as being shut, running pumps as being off, etc. These problems are apparently caused by the systems incorrectly interpreting the voltage at which the input changes state.

Occasional problems are caused by wide range instruments being used as inputs to computer points having a very low setpoint for an alarm. A good example of this problem is the typical alarm associated with increasing containment pressure. These alarms are typically set at values from about 1.0 to 2.5 psig (depending on reactor type). The control room alarm (annunciator) is usually driven by a narrow range pressure instrument with a typical range of - 5.0 to +10.0 psig. In many instances, these narrow-range instruments are not used as inputs to the SPDS; only wide-range instruments with ranges of -5.0 to +60.0 psig are input. The wide-range instruments often have the same full scale signal voltage change as do the narrow-range instruments. Therefore, a minor voltage change on the wide-range instrument may equate with a pressure change of 2 or 3 psig, thereby causing spurious pressure alarms on SPDS. When the wide range instrument is read in the control room, within the accuracy of the scale, it will appear to be reading zero, while the SPDS computer point is swinging from -2.0 to +2.0 psig.

Some computer points fluctuate wildly because of signal lead ground loops and current drain problems. These problems appear on the non-1E side of the electrical isolators.

Errors in Averages and Other Processed Data

SPDS computer points fall into two distinct categories: discrete and processed (or composed). Discrete computer points use a single analog or digital instrument as an input while processed points are computed within the SPDS computer or an associated computer using a combination of inputs from several sensors. Most SPDS systems perform a simple maximum-minimum range check to validate discrete points. Composed points can have a variety of redundant

is different as well. Therefore, many coolant system levels are measured with two sets of instruments: one set calibrated for operating conditions and the other calibrated for shutdown conditions. Measurements from these two sets of instruments should not be combined unless some adjustment is made for the fact that they are calibrated for different coolant densities.

Inadequate Identification of Data Quality

Most SPDS systems use one of several techniques for indicating suspect or poor data points. These methods include color changes, backlighting, flashing, superscript and subscript characters, and replacement of numerical data with characters such as asterisks (*****). The following problems have been observed with these techniques:

Several SPDS systems reviewed allow CRT terminal operators to manually replace real input data with other values. This procedure was judged satisfactory if the inserted data could be somehow highlighted or designated as being an inserted value and if the number of personnel having system security codes allowing such action was limited and administratively controlled.

However, on some SPDS systems the fact that data had been manually entered in place of real input data was not detectable by any visual cue and could be done by anyone, without the knowledge of the operators, from any terminal attached to the host computer (in some cases, from as far away as a corporate office located miles from the site).

In some cases, data which fails a validation check is highlighted with the same visual cue as data points that have exceeded an alarm setpoint. Rapid discrimination of visual cues is impossible when these cues have more than one meaning, i.e., "invalid data" and "parameter outside of normal range."

Removal of Data Points Known to Be Invalid

Quite often some of the analog instruments used as inputs to the SPDS will be out of service because of hardware failure or surveillances in progress. Unless an SPDS has a very good validation scheme for each parameter, there is a need to be able to take computer points out of scan easily. On many systems, the process of taking failed points out of scan is quite easy. One process, for example, involves the completion of a short approval form and a few keystrokes by system maintenance personnel. However, there are systems in which taking a point out of scan is nearly impossible.

In some systems, the data points are coded in assembly language rather than being resident on a disc file or table. In order to remove a point from scan, the computer system personnel must shut down the entire system and perform assembly language programming. Because this method is more complex, some failed computer points could still be resident in the system and indicate bad data for months after the problem with the instrument has been corrected.

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sensor algorithms applied to ensure their validity. Some SPDS systems use composed points, such as averages of several like sensors, but apply no validation checks to these composed points beyond the simple range-checks applied to the discrete points. A simple example of a composed and validated computer point is as follows:

> Four reactor pressure instrument inputs to an SPDS are first range-checked as discrete points. All of the inputs that pass the range check are then compared with each other. Those falling outside of a predetermined standard deviation of the average of the points are rejected. The remaining points are then re-averaged to provide the composed and validated point.

When adequate data validation techniques are not applied, SPDS performance suffers. Typical problems identified by the staff are described below.

- Using a single, auctioneered highest core exit temperature (CET) as the input to an algorithm may cause the resultant value to be inaccurate if any single CET fails high.

- Using the raw input from differential-pressure reactor vessel level instrumentation systems may cause erroneous level readings as the plant pressure and coolant pump combination change.

- Using simple averages of several, unvalidated loop temperatures and pressures causes the composed points to read in error when any one of the inputs fail.

Other problems arise when composed points, made up of inputs from more than one loop or section of a system, are used where a discrete or single loop point would be more appropriate:

- Cases have been observed where a T-cold composed point, consisting of the average of the T-cold inputs from all 4 loops of a PWR, was used in a pressurized thermal shock (PTS) detection algorithm. The Emergency Operating Procedures (EOP) and PTS limits were based on evaluating each loop separately, with the coldest loop being of concern. If a composed point is to be used in this algorithm, the auctioneered coldest value would be more appropriate.

- The use of an average BWR suppression pool (SP) temperature as an input to an algorithm which is used to monitor for the hottest point in the SP is likewise, not appropriate.

The staff also noted cases where inappropriate parameters were used by composed point algorithms. An example is the composed point algorithm used to calculate reactor pressure vessel (RPV) level at several BWRs. At these plants, this algorithm averaged the readings of all level instruments without regard for the conditions for which the instruments were calibrated. These level measurements were made using a differential pressure method. To determine level from a differential pressure measurement, the density of the fluid being measured must be known. Then level is the differential pressure divided by the density. Since the temperature of reactor coolant is much different during normal operation than it is during shutdown, coolant density

is different as well. Therefore, many coolant system levels are measured with two sets of instruments: one set calibrated for operating conditions and the other calibrated for shutdown conditions. Measurements from these two sets of instruments should not be combined unless some adjustment is made for the fact that they are calibrated for different coolant densities.

Inadequate Identification of Data Quality

Most SPDS systems use one of several techniques for indicating suspect or poor data points. These methods include color changes, backlighting, flashing, superscript and subscript characters, and replacement of numerical data with characters such as asterisks (*****). The following problems have been observed with these techniques:

Several SPDS systems reviewed allow CRT terminal operators to manually replace real input data with other values. This procedure was judged satisfactory if the inserted data could be somehow highlighted or designated as being an inserted value and if the number of personnel having system security codes allowing such action was limited and administratively controlled.

However, on some SPDS systems the fact that data had been manually entered in place of real input data was not detectable by any visual cue and could be done by anyone, without the knowledge of the operators, from any terminal attached to the host computer (in some cases, from as far away as a corporate office located miles from the site).

In some cases, data which fails a validation check is highlighted with the same visual cue as data points that have exceeded an alarm setpoint. Rapid discrimination of visual cues is impossible when these cues have more than one meaning, i.e., "invalid data" and "parameter outside of normal range."

Removal of Data Points Known to Be Invalid

Quite often some of the analog instruments used as inputs to the SPDS will be out of service because of hardware failure or surveillances in progress. Unless an SPDS has a very good validation scheme for each parameter, there is a need to be able to take computer points out of scan easily. On many systems, the process of taking failed points out of scan is quite easy. One process, for example, involves the completion of a short approval form and a few keystrokes by system maintenance personnel. However, there are systems in which taking a point out of scan is nearly impossible.

In some systems, the data points are coded in assembly language rather than being resident on a disc file or table. In order to remove a point from scan, the computer system personnel must shut down the entire system and perform assembly language programming. Because this method is more complex, some failed computer points could still be resident in the system and indicate bad data for months after the problem with the instrument has been corrected.

A few systems operate with the SPDS program on computer chips. In order to take a point out-of-scan or to make any other modification to the system, new chips are required. This process can again take several months, during which time the system displays inaccurate data to the operators.

Algorithm Errors

Some systems displayed inaccurate information, false alarms, or both because of problems with programming algorithms. This was complicated in a few cases, because the SPDS operators did not fully understand the algorithms that drive certain displays. Examples are provided below.

Some reactivity control algorithms that are intended to be anticipated-transient-without-scram (ATWS) indicators do not use any input from the reactor protection system or trip breakers. Because of this, the top level displays are continuously alarmed falsely anytime reactor power is above about 3 to 5 percent. The alarms would work as ATWS indicators following a trip, but may be ignored by the operators since they have grown accustomed to seeing the false alarm during normal plant operations.

One SPDS reviewed did not actuate any of the top level safety function alarm algorithms until after a trip occurred. The operators were unaware of this and believed the system to be very reliable since they had never observed any alarms during normal power operation.

Some PWR SPDS system algorithms use a makeup-letdown flow mismatch to detect a leak or break in the reactor coolant system (loss-of-coolant accident [LOCA]). Because programmers did not take into account the portion of coolant diverted for RCS pump seals and for coolant lost via normal minor identified leakage, the LOCA alarm was continuously illuminated.

III.A.3.b. Reliability/Availability

SPDS System "Lockups" and "Re-Boots"

About 30 percent of the SPDS systems reviewed to date have demonstrated frequent system "lockups" under both normal and heavy usage. To be assured that such problems do not occur in an operational environment, systems could be tested at full expected loading, with all available terminals in use. Once developed, a system load test procedure can be run at any time. The system could also be tested in conjunction with the annual emergency exercise or during a planned plant trip (scram).

The source of observed system lockups fall into about four categories and are somewhat equally distributed. These categories are:

- software problems in the graphics terminal(s)
- host computer software problems (in particular the display driver portions)
- CPU communications bus data errors
- errors and lack of capacity on remote terminal communications links

Lockups are most frequently initiated by one of the following reasons or activities:

- Heavy system loading during multiple terminal or peripheral use, such as occurs following a reactor trip.

- The lack of display feedback messages such as "WAIT - PROCESSING" causes casual systems users to continue to input commands while system is processing previous commands.

- Lack of user training or complexity of commands causes keyboard entry errors resulting in system lockup. The problem of user training seems worse at sites where the SPDS is served by the same host computer as the emergency response facility (ERF) data systems. ERF users may only use the systems a few times per year.

These kinds of problems with system reliability and data validity reduce the credibility of the SPDS. The basis of the requirement for high reliability is the need for operators to believe data. If they doubt the accuracy, the correctness, or the timeliness of data, operators will look elsewhere for information. If this happens often enough, the operators will begin to ignore the SPDS because it increases the data-gathering workload rather than decreasing it.

For the SPDS to be effective, it must aid operators in rapidly and reliably determining a plant's safety status. Those systems that the staff has found to be unacceptable do not provide such aid, and may, in fact, mislead or confuse operators.

III.A.4 Conditions When SPDS Should Be Operational

Of the 57 SPDSs evaluated, all adequately satisfied the requirement to install an SPDS that is designed to operate during normal, abnormal, and emergency conditions.

The staff's initial guidance (NUREG-0835, Draft Report; NUREG-0696) regarding the conditions under which an SPDS should be operational called for the SPDS to be available during all plant modes. In Supplement 1 to NUREG-0737, the staff reduced the acceptable operating scope of the SPDS to "normal operations, abnormal and emergency conditions," i.e., all modes above cold shutdown. Some plants have also elected to include the cold shutdown and refueling mode as part of the SPDS' scope. The staff finds this to be a desirable extension of the SPDS scope of application.

III.B. CONVENIENT LOCATION AND CONTINUOUS DISPLAY

Each operating reactor shall be provided with a Safety Parameter Display System that is located convenient to the control room operators. This system will continuously display information from which the plant safety status can be readily and reliably assessed by control room personnel who are responsible for the avoidance of degraded and damaged core events (NUREG-0737, Supplement 1, Section 4.1.b).

This requirement contains two additional elements that were not discussed in the preceding section:

- o convenient location
- o continuous display.

III.B.1 Convenient Location

The term "operator" is defined here in the broad sense of SPDS operator or user. The staff's only strict requirements with regard to convenience have been that the SPDS be in the control room and that it be convenient to the licensee defined user(s), e.g., reactor operators, senior reactor operators, shift technical advisor, shift supervisor. A corollary principle is that the SPDS should not interfere with control room operations, e.g., interfere with physical or visual access to other control room instruments.

Only 17 units failed to satisfy this requirement. An extreme example was a SPDS CRT that was suspended from the ceiling of the control room, too far from the floor to be read by anyone in the control room. This display was obviously not convenient to any user.

III.B.2 Continuous Display

A continuous display is needed for an effective SPDS because it affords the operator almost immediate access to the most important information about plant safety. Acceptable SPDS systems had this information displayed continuously. Operators did not need to search among various displays or page through irrelevant information to get a current overview of plant safety status or to be aware that plant status was changing. Plant safety status information should always be displayed in the control room, not hidden among rows of instruments or buried under "pages" of CRT displays. The staff makes the distinction that information that is "continuously available for display" is not the equivalent of a continuous display.

Twenty-one of the 57 SPDS reviewed satisfied this requirement by either providing a dedicated, single display of plant variables, or by providing a hierarchy of display "pages" on a single CRT with perceptual cues to alert the user to changes in the safety status of the plant. The remainder were found to be unacceptable because they provided neither a continuous display of variables nor an alerting mechanism, such as safety function status indicators.

III.C Isolation From Safety Systems and Procedures and Training

The control room instrumentation required (see General Design Criteria 13 and 19 of Appendix A to 10 CFR 50) provides the operators with the information necessary for safe reactor operation under normal, transient, and accident conditions. The SPDS is used in addition to the basic components and serves to aid and augment these components. Thus, requirements applicable to control room instrumentation are not needed for this augmentation

(e.g., GDC 2, 3, 4 in Appendix A; 10 CFR Part 100; single-failure requirements). The SPDS need not be qualified to meet Class 1E requirements. The SPDS shall be suitably isolated from electrical or electronic interference with equipment and sensors that are in use for safety systems. The SPDS need not be seismically qualified, and additional seismically qualified indication is not required for the sole purpose of being a backup for SPDS. Procedures which describe the timely and correct safety status assessment when the SPDS is and is not available, will be developed by the licensee in parallel with the SPDS. Furthermore, operators should be trained to respond to accident conditions both with and without the SPDS available (NUREG-0737, Supplement 1, Section 4.1.c)

This requirement contains two additional elements not yet discussed:

- o isolation from safety systems
- o procedures and training

III.C.1 Isolation from Safety Systems

In order to protect safety systems from electrical and electronic interference, the SPDS must be isolated from equipment and sensors that are used in safety systems. Examples of acceptable isolation devices and relevant test conditions are listed in Table 1.

The following table lists isolation devices used in the SPDS systems which have been reviewed and approved by the staff. As noted in the list, the maximum credible fault (MCF) testing varied from plant to plant even for the same isolators. Therefore, care must be taken to assure that in any future applications of these devices, licensees verify that the plant-specific application does not exceed the capability of the device. Most of the referenced reports and qualification tests are proprietary and are therefore unavailable for release from NRC. Other devices have been tested but must have the test results submitted to the NRC for review and approval.

Note: relays with contact-to-coil isolation have been approved for several applications; systems utilizing fiber optic cable have not been required to perform maximum credible fault tests because of the inherent isolation characteristics of the cable.

Table 1. Isolation Devices

Manufacturer/Supplier	Maximum Credible Fault Test and/or Applicable Topical Reports
ACROMAG Series 700 MODELs 712-L,H; 722-TL-Y	MCF 120VAC@15A
Analog Devices, Series 289	MCF 120VAC@15A MCF 120VAC@30A
Computer Products Inc	Optical Fiber
E-MAX, Digital and Analog	MCF 120VAC@20A
Energy Inc; MODELs 156, 159, 1622,993 Analog 00798; Digital 01026-17	MCF 480VAC@10A, MCF 120VAC@20A, MCF 140VDC@10A
Fischer and Porter, 50EK1000	MCF 120VAC@30A
Foxboro, M 66B-CO I/I, M 66G-OW E/I	WCAP 7508-L
Foxboro N-2AO-2VI, Spec 200	MCF 140VAC@20A, MCF 140VDC@20A
GA Tech, RM-80	GA E-255-1333
General Electric ERIS, GEMAC-550 GEMAC-550	Optical Fiber, NEDE 30284P, MCF 120VAC@20A
Hewlett Packard	MCF 120VAC@30A
Honeywell, HFM 5000-03	Optical Fiber
INTRONIC 1A-184	MCF 120VAC@30A
Kaman Science Co.	MCF 120VAC@30A
Motorola	Optical Fiber
Potter Brumfield, MDR	See GE-ERIS
Reliance Electric Co, ISOMATE	MCF 120VAC@30A, 125VDC@70A
Rochester Inst. Sys, 4400 SERIES	MCF 140VDC@5A, 120VAC@20A MCF 24VDC@3A, 130VAC@50A MCF 140VDC#50A, 132VAC@50A

Table 1. (cont.)

Manufacturer/Supplier	Maximum Credible Fault Test and/or Applicable Topical Reports
RIS SC-326	MCF 120VAC@20A
Robertshaw 572-C2	MCF 120VAC@20A
Simmonds Precision	MCF 120VAC@20A
Struthers Dunn Inc, CX-3016 NE CX-3918 NE DX-3917 NE	MCF 132VDC@500A, 528VAC@2000A CX-3918 Qualified by Comparison with CX-3916
Technology For Energy Corp (TEC), SYSTEM 2200, TEC 156 Analog	MCF 120VAC@20A MCF 130VAC@50A
TEC 159 Optical	MCF 120VAC@20A
TEC 980 Analog	MCF 120VAC@20A
TEC 981 Optical	MCF 120VAC@20A
Validyne, MUX MC370AD-QZ	Optical Fiber
Westinghouse 7100	WCAP 7824, 7819
Westinghouse 7300	WCAP 8892A
Westinghouse Nuclear Instrumentation System	WCAP 7506-L, 9011, 7819
Westinghouse Core Cooling Monitor System	WCAP 10621
Westinghouse RVLIS Isolator MODEL 2343D63G02 Opto-Coupler	MCF 240VAC@20A, 140VDC@20A
Westinghouse, PSMS/PERMS	MCF 580VAC@20A, MCF 250VDC@20A

III.C.2 Procedures and Training

In general, the requirement to develop procedures and training for safety status assessment and accident response with or without SPDS was addressed by licensees and applicants in their upgrading programs for emergency operating procedures (NUREG-0737, Item I.C.1). These programs introduced function-oriented procedures into the control room. The basic premise of the function-oriented concept is that critical safety functions should be constantly monitored and maintained during an emergency response. Inherent in the concept, therefore, is the delineation of tasks describing the timely and correct safety status assessment and accident response. Most plants do not specify in the emergency procedures which instruments to use for accident response. Some plants include notes and cautions in their procedures to limit the use of certain instruments, including SPDS, during certain transients and accidents.

Twenty-one units acceptably satisfied the requirement to provide procedures and training for safety status assessment and accident response with or without SPDS. They did so by (1) providing upgraded emergency operating procedures (EOPs) that contain safety status assessment tasks, (2) training operators how to use SPDS (e.g., during simulator or requalification training), (3) training operators how to carry out accident responses both with and without SPDS, and (4) providing an SPDS users' manual in the control room for easy reference.

The remaining plants did not acceptably satisfy this requirement. At many plants training deficiencies were identified during operator interviews and SPDS demonstrations when SPDS-trained users made obvious errors and showed confusion or misunderstanding. These deficiencies were of sufficient magnitude to diminish the effectiveness of the SPDS or to increase the potential for operator error. For example, at one plant a primary user of the SPDS believed that a certain color code denoted that there were not enough valid inputs to ascertain the status of a safety function. In fact, the meaning of the color code in this system was "critical safety function in jeopardy." The failure of users to understand such basic SPDS functions and operation provided primary evidence of poor or infrequent training. No system was found unacceptable based on the performance or the assertions of only one user--evidence was confirmed through multiple interviewees/users and through a review of the details of the training program itself.

Deficiencies were found at a few units because the licensee did not provide an SPDS users' manual in the control room. These were plants in which interviewees/users showed some confusion concerning operation of the SPDS that could have been resolved if an easy-to-use reference manual had been available in or near the control room.

The requirement for having procedures and training for accident response both with and without SPDS evolved from the staff's concern that, because of the SPDS's convenience and usefulness, operators could become over-reliant on the SPDS. The SPDS is intended as an aid to operators, to be used in addition to existing control room instrumentation, and should, generally, not be used in place of existing instrumentation. An exception is when the SPDS displays processed information that is not available elsewhere -- in any case, operators should not take action based on the SPDS alone.

III.D. SELECTION OF INFORMATION FOR DISPLAY

> There is a wide range of useful information that can be provided by various SPDS. This information is reflected in such staff documents as NUREG-0696, NUREG-0835, and Regulatory Guide 1.97. Prompt implementation of an SPDS can provide an important contribution to plant safety. The selection of specific information that should be provided for a particular plant shall be based on engineering judgment of individual plant licensees, taking into account the importance of prompt implementation (NUREG-0737, Supplement 1, Section 4.1.d.)

This requirement includes two essential elements:

- o selection of information for display
- o prompt implementation.

III.D.1 Selection of Information for Display

As indicated in Supplement 1 to NUREG-0737, licensees should define the content of SPDS displays. Two restrictions to this general principle were applied: (1) the minimum acceptable set of information must be sufficient to represent the status of plant safety functions (this item is discussed in detail in Section III.F below), and (2) the information set must not be so large that meaningfulness, accessibility, or other human factors are negatively affected.

Most plants acceptably satisfied this requirement by providing evidence that the design of the content of SPDS displays was reasonable, systematic, and based on credible analyses. Typically, acceptable programs included the following elements:

- o a definition of system requirements and the needs of defined users
- o coordination with tasks identified in the systems/task analysis performed during the development of upgraded EOPs and/or performance of the detailed control room design review (DCRDR)
- o consideration of any new instrumentation needs identified during the implementation of Regulatory Guide 1.97
- o coordination with the content of training programs
- o consideration of user preferences.

Seventeen SPDS designs were judged unacceptable because of the information that was selected for display. The most common deficiency was omissions in the information set, i.e., insufficient information to adequately represent plant safety status (see III.F below for further details). A few suffered from the opposite problem--information overload. These latter systems provided too much information in relation to the presentation format, e.g., too many variables on a single primary display led to readability problems, or too many "pages" of information with a poorly designed access system caused operators to become "lost" in a maze of irrelevant displays.

The basic intent that underlies this requirement is that licensees are best qualified to judge what critical information needs to be gathered together into the concise display called SPDS. However, the staff defined the basic plant safety functions that should be represented in a minimally effective SPDS.

III.D.2 Prompt Implementation

Thus far, the staff has not rejected any reasonable implementation schedule for SPDS. In order to allow licensees to implement promptly, the staff's review and approval process was not placed in the critical path. Unless requested to do so by the licensee, the staff does not review and approve an SPDS prior to its implementation. The staff has given as much early guidance as possible to licensees, but the SPDS review is generally a post-implementation evaluation. The staff has also attempted to expedite the implementation process by relaxing some of its earlier positions on SPDS. For example, the requirement for Class 1E qualification or a Class 1E backup was deleted in favor of simply requiring a highly reliable system. Also, the staff's review regarding selection of parameters was tempered by the consideration that the staff would not require additional information that would necessitate the installation of new sensors and instrumentation loops, but rather would limit its requirements to existing instrumentation. In these and other ways, the staff has tried to accommodate licensees in the prompt implementation of SPDS.

Although no plant has specifically been cited for delays in implementation, the record of the industry is not good on this point. By the staff's estimate, approximately 75 percent of all plants still do not have a fully operational SPDS in their control rooms, more than 5 years after the issuance of Generic Letter 82-33 which called for prompt implementation of SPDS.

III.E HUMAN FACTORS AND SPDS DISPLAYS

> The SPDS display shall be designed to incorporate accepted human factors principles so that the displayed information can be readily perceived and comprehended by SPDS users (NUREG-0737, Supplement 1, Section 4.1.e).

This requirement is rooted in the human factors problems that contributed to the accident at TMI-2. The staff, through this requirement emphasized the need to incorporate good human factors principles in the design of equipment rather than attempting to backfit the principles in a superficial way. Properly designed systems incorporated the needs and limitations of users into the design from the very start of the design process. This resulted in systems that do the job, are easy to use and understand, do not cause confusion, frustration, or errors, and that users can rely on when making critical decisions during an emergency.

Of the 57 units reviewed, only 12 have fully satisfied this requirement. Staff review of this requirement included an evaluation of the design process and portions of the verification and validation (V&V) program, as well as an audit of the SPDS displays, interfaces, and environment.

Plants that satisfied the requirement to incorporate human factors principles into their SPDS design did so by providing evidence that user needs were identified during the initial design phases, that specifications and acceptance criteria for optimizing the display and control interfaces were established, that operators were involved in the design process either as members of the design team or as reviewers, and that the V&V program included appropriate human factors reviews and "man-in-the-loop" testing. The effectiveness of these programmatic efforts was confirmed by the staff through an audit of the SPDS in its operating environment. Those systems that were found to have few and minor human factors discrepancies satisfied this requirement. Guidance and information in this area can be found in NUREG-0700, "Guidelines for Control Room Design Reviews", (Ref. 10) and NUREG-0800, Chapter 18.2 "Standard Review Plan, Safety Parameter Display System; Appendix A-Human Factors Review Guidelines for Safety Parameter Display System," (Ref. 6).

Systems found unacceptable regarding this requirement often suffered from deficiencies in the SPDS interface that were not the result of random oversight. These systems lacked proper design input from human factors specialists and operators. Standards, specifications, and acceptance criteria for human factors considerations, such as system response time, operator feedback, control room standards and conventions, and operator preferences were generally not established and, therefore, not incorporated into the design. More often than not, these systems were not subjected to "man-in-the-loop" testing and operator acceptance was poor.

Numerical magnitudes of SPDS parameters and time-history plots should be displayed to resolutions useable by the operator. One time-history plot the staff reviewed could resolve data only to a value equivalent to the height of a CRT character resulting in very poor trend plot resolution. For example, reactor pressure vessel (RPV) pressure could only be resolved to 125 psi from the trend plot. Thus, one to 125 psi appeared as 125 psi, and 126 psi appeared as 250 psi.

Another case was reviewed in which the ordinate divisions of all trend plots were established automatically by dividing the full range by three. Thus, percentage plots appeared as 0, 33.33, 66.67, 100%. An Auxiliary Feedwater system (AFW) flow plot appeared as 0, 3333.32, 1.67E+05, 2.50E+05 gallons per hour. Not only is it difficult to estimate volume between the major graduations but the two decimal point accuracy just adds useless visual "noise" to the display.

III.F. MINIMUM PLANT PARAMETERS FOR DISPLAY

The minimum information to be provided shall be sufficient to provide information to plant operators about:

(i) Reactivity Control
(ii) Reactor Core Cooling and Heat Removal from the Primary System
(iii) Reactor Coolant System Integrity
(iv) Radioactivity Control
(v) Containment Conditions

The specific parameters to be displayed shall be determined by the licensee (NUREG-0737, Supplement 1, Section 4.1.f).

Of the 57 units reviewed, 25 were found to have a sufficient set of SPDS parameters to monitor the five defined safety functions.

The tables that follow show sample variable sets for PWRs and BWRs which have been found acceptable.

While the samples illustrate sets of variables which have been found acceptable, SPDS systems contain inputs from many additional variables. There have also been numerous alternatives and substitute variables approved for SPDS systems. Staff evaluations of the parameters selected for SPDS systems have been conducted on a plant-specific basis, and take into consideration plant design, Emergency Operating Procedures (EOPs), Emergency Plan Implementing Procedures (EPIPs), and status of NRC approval of R.G. 1.97 variables.

Examples are provided below for some of the more frequently approved alternatives to the sample variables.

Pressurized Water Reactors

Hot leg temperature (T-hot) is included in Table 2 as an acceptable parameter because, when combined with other variables, it provides an indication of the viability of natural circulation. Other variables that acceptably satisfy the same functional requirement are: loop delta temperature, core exit temperature and T-average.

Emergency core cooling system (ECCS) recirculation flow (e.g., residual heat removal (RHR) or decay heat removal (DHR) system flow) is desirable as an indication of removal of heat from the primary coolant system and containment. Where RHR (DHR) flow was not available, combinations of the following parameters have been approved: RHR (DHR) pump run status, delta T across RHR (DHR) heat exchangers, delta T across service water systems supplying the RHR heat exchangers, and RHR (DHR) service water system flow. The combination must be adequate to monitor, with a degree of confidence, the adequacy of heat removal from the primary system when the steam generators are not available for this purpose.

Containment sump level is a desirable indicator for the onset of a coolant system leak or break. In the absence of sump level, parameters such as the following have been approved: sump high level alarm, sump pump run time, sump pump flow totalizer, sump pump run status. In order to be satisfactory, the types of substitutes listed should have an alarm function on the top level display (e.g., excessive sump pump run time).

Table 2. Safety Parameters for Pressurized Water Reactors

Safety Function	Representative Parameters for Display
1. Reactivity control	Power range instrumentation Intermediate range instrumentation Source range instrumentation
2. Reactor core cooling and heat removal from the primary system	RCS level Subcooling margin Hot leg temperature Cold leg temperature Core exit temperature Steam generator pressure RHR (DHR) flow
3. Reactor coolant system integrity	RCS pressure Cold leg temperature Containment sump level Steam generator pressure Steam generator level Steam generator blowdown radiation
4. Radioactivity control	All effluent stack monitors Steamline radiation Containment radiation
5. Containment conditions	Containment pressure Containment isolation status

Table 3. Safety Parameters for Boiling Water Reactors

Safety Function	Representative Parameters for Display
1. Reactivity control	Average power range monitors Source range monitors
2. Reactor core cooling and heat removal from the primary system	RPV water level Drywell temperature
3. Reactor coolant system integrity	RPV pressure
4. Radioactivity control	All effluent stack monitors Offgas monitor Containment radiation monitor
5. Containment conditions	Drywell pressure Drywell temperature Suppression pool temperature Suppression pool level Containment isolation status Drywell hydrogen concentration Drywell oxygen concentration

The radioactivity control safety function of SPDS should include all major monitored effluent pathways points (stacks and vents) which are potential release points for fuel gap activity. Separate ventilation exhausts for areas such as hot machine shops and radwaste need not be included. Computed release rates (Ci/sec, UCi/sec, etc.) are the desirable SPDS top level variable, but release concentrations and raw monitor readings (CPM, MR/HR, etc.) are acceptable (i.e., not using a flow rate input).

Because the main steam line (or steam generator) radiation monitors on PWRs are usually located upstream of the main steam isolation valves (MSIVS), they can be used both to assess radioactivity within the secondary system when the MSIVs are closed, and to monitor releases to the environment through the atmospheric dump and safety valves. In a few cases main steam line monitoring was not available. In those cases the staff accepted less preferred methods of satisfying this aspect of the radioactivity control safety function.

Containment hydrogen concentration is also a desirable parameter for SPDS. However, in the rare instances where NRC has previously approved an off-line hydrogen monitoring system in a safety evaluation report (SER) under Regulatory Guide 1.97 review, the SPDS reviewers have found these systems acceptable for SPDS use.

Boiling Water Reactors

Guidance for the input of radioactive material effluent points are essentially the same for BWRs as those discussed above for PWRs. BWRs that have incorporated a secondary containment control guideline in their EOPs frequently use several reactor building area radiation monitors (ARMs) and process radiation monitors (PRMs) as inputs to the SPDS top level displays. These inputs provide early indication of problems outside the drywell (containment).

Because BWR safety relief valves (SRVs) exit the main steam lines upstream of the MSIVs and the MSL radiation monitors, and because they discharge to the suppression pool or torus, BWR MSL radiation monitors are a desirable, but not mandatory, input to SPDS.

Drywell (containment) hydrogen and oxygen concentrations are both desirable inputs to the SPDS. However, with most BWR drywells now being rendered inert with nitrogen, oxygen concentration becomes the more important parameter. Therefore, in some cases, BWRs with inert drywells are not required to use hydrogen concentration as an input to SPDS, but are required to use oxygen concentration.

A close review of Tables 2 and 3 reveals that intermediate range nuclear instrumentation (NIs) is listed for PWRs, but not for BWRs. A staff survey of licensee computer systems input, showed that 61 percent of the reactor sites had not included intermediate range instrumentation on their computer systems. The intermediate range parameter is desirable, but the difficulty of programming the range switch position input to create a meaningful parameter overrides the benefit of using the intermediate range. Only 2 or 3 reactor sites have a computer system which has been programmed to make real use of intermediate range NI data.

PWRs and BWRs

One desirable method for monitoring containment or drywell isolation valve status is to employ an algorithm which uses both the isolation demand signals and the valve position indications. This allows a rapid assessment of both the demand for an isolation and the successful completion of valve re-alignment. For some SPDS systems, where only the isolation demand signals have been used, NRC has approved the system if containment isolation valve position is readily available to the SPDS operator on a nearby control board. The use of control board indication to supplement SPDS in this case has only been approved where the control board display was in a the direct field of view of the SPDS operator, was confined to one area of the control board, and where status could be determined at a glance. Some licensees have rewired isolation status matrices to make all of the status lights (including spare tiles) operate together (e.g., all lighted) upon a successful isolation, thereby providing the necessary visual conciseness.

The sample parameter list shows only nuclear instrument (NI) computer points under the reactivity control safety function. Although some licensees have used only NIs in their reactivity control algorithms, most have used other inputs such as scram (or trip) breaker position, reactor protection system (RPS) trip status, rod position indication, and coolant boration level in addition to the NIs, to create an algorithm which serves as both an ATWS indicator and a loss of shutdown margin indicator. Only NI inputs are required, but the greater sophistication of using additional inputs is a desirable enhancement.

There have been a few other plant-specific approvals of acceptable substitutes and omissions of parameters, but the examples provided above cover the most common cases.

The staff has found that the SPDS parameter selection was inadequate at 29 units. The most common reason was the omission of variables representing the heat removal, radioactivity control, and containment conditions safety functions, e.g. containment isolation status, radiation variables, containment hydrogen and oxygen concentration, and RHR (DHR) flow.

Sections III.F.1 and III.F.2 below provide a summary of the rationale used by the staff in past reviews to determine what variables constituted a sufficient set of SPDS parameters. The variables are described in tabular form in Tables 2 and 3. As the basis to determine what set of SPDs parameters were adequate, the staff considered the emergency procedures guidance developed by owners' groups and vendors, as well as other industry guidance documents, such as "Guidelines for an Effective Safety Parameter Display System Implementation Program" (Ref. 11) and NSAC/21, "Fundamental Safety Parameter Set for Boiling Water Reactors" (Ref. 12).

III.F.1 Acceptable Parameters for PWRs

III.F.1.a. Reactivity Control

The rate of change in neutron production (neutron flux) is a fundamental neutronics parameter for assessing the status of plant reactivity control.

Neutron flux can be directly monitored by control room instrumentation for the entire range (0-100%+) of reactor power. In a PWR, this range is typically represented with three monitors: the source range monitor, the intermediate range monitor, and the power range monitor.

Other parameters (e.g., rod-in position indicators, reactor trip indicators, boronometers) may provide useful information; however, they are less direct indicators of the overall status of the reactivity control function in that they may provide information that is inconclusive or possibly misleading.

III.F.1.b. Core Cooling and Heat Removal

There is no one measured parameter that directly indicates the status of the core cooling and heat removal safety function. Instead, several indicators are cited which when used in conjunction, do provide a strong inference of the status of core cooling removal for the broad spectrum of scenarios and conditions.

The first of these parameters is subcooling. During subcooled heat removal, this variable provides a direct verification of the viability of core cooling as well as some quantification of the core cooling margin. Subcooling is used in the emergency guidelines as a key criterion to determine the status of the core cooling function. RCS level is an indicator of primary system inventory, a necessary heat transfer medium for core cooling and heat removal. It is used in the guidelines to monitor for an inadequate core cooling (ICC) condition. Core exit temperature is an important indicator because it is used to determine the viability of the natural circulation mode of heat removal. Together with RCS pressure, core exit temperature is also an input to the subcooling monitor.

Core exit temperature is a key parameter used in emergency guidelines to monitor for the onset of ICC conditions. Hot leg temperature and cold leg temperature are key indicators used in determining the viability of natural circulation as a mode of heat removal. For certain subcooled conditions, these parameters may indicate natural circulation status when core exit temperature may not. In this case, the hot and cold leg temperatures would be relied upon to ensure adequate natural circulation (per PWR guidelines). Steam generator level is an indicator of the availability and proper control of the secondary system heat sink for the heat removal critical safety function. SG pressure is a key indicator of the viability and integrity of the secondary system. Steam generator (or steamline) pressure is also an indicator used in emergency guidelines to determine the viability of natural circulation as a mode of heat removal (not applicable to combustion engineering (CE) plants). RHR (DHR) flow is a key indicator to determine the viability of the heat removal system used when the secondary system is not the principal heat removing system (i.e., large LOCA, ECCS; normal shutdown RHR). Other parameters may be considered, such as RCS average temperature and feedwater flow. These parameters, however, are not considered as versatile over a spectrum of plant conditions, as direct an indication of status of the function being monitored, and/or necessary since the parameters suggested above provide the same rapid functional information.

III.F.1.c. RCS Integrity

Perhaps the single most informative parameter to be monitored in a PWR is RCS pressure. Its RCS integrity applications are: (1) it is a principal indicator of RCS integrity, and (2) it is a key parameter used for brittle fracture considerations. In conjunction with RCS pressure, cold leg temperature is also a key parameter for brittle fracture considerations. Containment sump level is a key indicator to identify a LOCA-type breach of RCS integrity, particularly for smaller leaks during which RCS pressure may not be changing. It also is an indicator of the viability of the ECCS recirculation mode of heat removal. Steam generator status (some combination of pressure, level, radiation) is a key (and usually the most rapid) indicator of a steam generator tube ruture type breach of RCS integrity.

Parameters contributing to this status indication are also proposed as key monitors of other critical safety functions.

III.F.1.d. Radioactivity Control

Three variables are generally considered acceptable for the monitoring of radioactivity control for SPDS: stack monitors, steamline monitors, and containment monitors. These three monitors allow a rapid assessment of radiation status for the most likely radioactive release paths.

For PWRs, radiation can be released directly to the atmosphere through two paths. One is through stacks, which are monitored by stack monitors, and the other is through the main steam safety valves, which is monitored by the steam line monitor. The stack monitors are normally used during power operation to measure fission products (such as iodine, cesium and the noble gases), which may be vented to the atmosphere. These monitors will also measure the radiation released to the atmosphere during an accident if the containment is not isolated.

The steam line monitor also measures radiation releases to the atmosphere when the main steam safety valves are open during plant transients and on turbine trip. The steam line monitor is also important in measuring the radioactivity on the secondary side during a steam generator tube rupture if it is located upstream of the atmospheric dump valves and safety valves.

The containment monitor is essential for measuring the radioactivity in the containment atmosphere, especially when the containment is isolated following an accident. If for any reason containment integrity is breached, an estimate of the offsite doses can be made based on containment radiation readings. The monitor can also provide an indicator of the amount of fuel damage to the reactor core.

Other available radiation monitors may be used but are not considered essential to SPDS. These secondary considerations include vital control area monitors, such as the control room, to which access may be necessary after an accident. Monitoring primary coolant radioactivity levels is presently performed by sampling and analysis in the sampling room. The continuous activity monitors

presently available are of limited value because of their isolation on containment isolation signal. Although the post-accident sampling system eventually provides a representative sample for evaluation, direct, continuous monitoring is not presently part of the SPDS design. Such a new PWR design requirement is considered outside the scope of the current SPDS review.

III.F.1.e. Containment Conditions

The following three key parameters should be monitored by the SPDS to provide a rapid assessment of containment conditions:

- Containment pressure,
- Containment isolation, and
- Containment hydrogen concentration.

Containment pressure is a direct indication that containment integrity may be threatened by overpressurization. Also, as the containment pressure increases, it provides the driving force that can cause the containment environment to escape to the atmosphere through leaks in the containment structure.

For the more likely accident scenarios that cause the containment pressure to increase, the containment environment is at saturated conditions. Hence, if the containment pressure is known, the containment temperature can be determined: therefore, it would not be necessary to measure containment temperature. For the few less probable accident scenarios in which the containment pressure increases but the containment environment is superheated, the superheated conditions only exist until the containment sprays are activated (shortly after the start of the accident). Because of the short period during the containment environment is superheated, there is little need to know the amount of superheat in the containment environment by monitoring the containment temperature. Equally important, generic emergency technical guidelines do not require operator actions based upon a rapid assessment of containment superheating.

A primary function of the containment is to prevent release of radioactive gases and particulates to the environment. By monitoring the demand signal and actual status of all isolation valves, there is assurance that when demanded, the known process systems pathways penetrating containment have been secured. Also, by monitoring the status of all isolation valves, the containment purge and/or vent system's supply and exhaust line valves will also be monitored. Hence, a separate display of the status of these valves on the SPDS is not a requirement.

Containment hydrogen concentration is a key parameter to monitor for containment combustible gas control. For some accident scenarios, hydrogen can be produced and released to the containment. Combustion of large amounts of such hydrogen has the potential for causing the containment structure to fail. The monitoring of the oxygen concentration is not necessary for large dry containments since these containments have an oxygen-rich atmosphere during normal operations.

III.F.2 Acceptable Parameters for BWRs

III.F.2.a. Reactivity Control

The rate of change in neutron production (neutron flux) is a fundamental neutronics parameter for monitoring the status of the plant reactivity control. The average power range monitors (APRMs) and source source range monitors (SRMs) represent the principal SPDS neutron flux indicators for reactivity control. APRMs calculate the neutron flux and provide a single power level representing the average value for all core regions. The plant Technical Specifications require the APRM to be operable during all modes of operation except cold shutdown. SRMs are necessary to monitor the reactivity status during shutdown and startup.

Other parameters considered for reactivity control were control rod position or control rod status lights ("all in"). Control rod position indication is useful but of limited value since an indication of partial insertion would leave the power level indeterminate. For some plants, identification of the control rod insertion level is an involved procedure requiring the use of a computer console to call up rod bank positions. One specific exception to this is an SPDS which incorporates a scram event status target light on the SPDS display. This was reviewed and accepted by the staff as a substitute for the SRMs based on the condition that the scram status is continuously monitored and receives input from the SRMs.

Boiling water reactors presently use a standby liquid control system (SLCS) to inject boron into the reactor coolant system. Its purpose is to shut down the reactor and maintain shutdown in the event the control rod drive system is inoperable. Unlike PWRs, BWRs do not contain boron under normal operating conditions, and boronometers are not part of the BWR design. The injection of boron would be sufficiently identified through the APRM instrumentation already part of the SPDS. Since boronometer instrumentation is not part of the BWR design, we consider such a new design requirement to be outside the scope of SPDS reviews.

III.F.2.b. Core Cooling and Heat Removal

The primary parameter for indicating of core cooling is reactor pressure vessel water level. General Electric (GE) analyses show that it is unlikely that fuel damage will occur as long as the core is two-thirds covered. Also, the Emergency Procedure Guidelines (EPG) are keyed to important operator actions at various water levels. A knowledge of total core flow, although useful information, is not considered an essential parameter for a rapid assessment of core cooling and heat removal safety function since an adequate water level is sufficient for this purpose. Also, the EPGs do not address core flow as a key indicator, which is consistent with this conclusion.

Heat removal monitoring under conditions other than emergency conditions (e.g., shutdown cooling) is provided by variables associated with the shutdown cooling mode of the residual heat removal system (RHR). Also, for containment cooling and low pressure coolant injection (LPCI) modes of the RHR, water is circulated from the suppression pool through the RHR heat exchangers to the spray

headers and the reactor pressure vessel back to the suppression pool. Since the suppression pool provides a heat sink when the main condenser is isolated, the suppression pool temperatures and water level should be monitored to indicate the status of heat removal capability.

Consideration was given to the status of the core spray system flow as a parameter for the heat removal safety function. Either the low pressure spray system or high pressure spray system are capable of automatically providing adequate core cooling to prevent fuel damage. However, since the EPGs have keyed operator actions to vessel water level (such actions as verification of system actuation), it is water level that still remains the essential core cooling indicator. Although ECCS injection status is important as follow-up verification of a response to a rapid initial determination of inadequate water level, the first assessment of a potential core cooling problem through water level serves the purpose of SPDS.

III.F.2.c. Pressure Vessel Integrity

Reactor pressure vessel pressure is a fundamental parameter for monitoring reactor coolant system integrity since a sudden decrease could be indicative of a breach of the coolant system. Increasing reactor pressure could indicate a loss of adequate heat removal, and a subsequent challenge to RCS integrity. (Drywell Pressure is considered of secondary interest relative to vessel integrity: an increase in drywell pressure results from a coolant system break. However, since drywell pressure is a fundamental parameter for containment integrity, it was included as part of the SPDS.)

III.F.2.d. Radioactivity Control

Three radioactivity monitors are considered essential for the radioactivity control safety function. The station vent stack monitor is important since it measures noble gas radiation and allows for decay of the short-lived nitrogen 16 isotope. The vent stack release rate is also an important parameter used in the generic EPGs. A containment activity monitor is essential since it provides the status under containment isolation conditions (station vent stack monitor is unavailable). An off-gas post-treatment effluent monitor also measures noble gas activity and is considered essential if it represents a separate effluent point from the station vent stack monitor. Like the station vent stack monitor, it is not continuously available following containment isolation.

Other useful monitors may be proposed but are not considered essential for SPDS. The monitors selected should measure delayed activity to avoid N-16 interference (7-sec half life). The performance of ionization chambers makes them least preferred for this application; therefore, the HVAC (exhaust) monitors are not considered essential for SPDS. The main steam line monitor is a gamma ion chamber which measures N-16 and is not considered essential for SPDS. The standby gas treatment monitor, located between the HVAC monitors and the plant stack vent, is considered a secondary parameter (not essential for SPDS). Monitoring the radioactivity reator vessel water level is presently performed by sampling from the recirculation system loops and analysis in the sample room. The continuous sampling system activity monitors presently used are not useful following isolation. Although the post-accident sampling system eventually provides a representative sample for evaluation, direct, continuous monitoring is not presently part of the SPDS design. Such a new BWR design requirement is considered outside the scope of the current SPDS review.

III.F.2.e. Containment Conditions

Several essential parameters are fundamental to the containment conditions safety function. Drywell pressure is considered a primary variable for status indication since a rise in drywell pressure eventually results in a reactor trip and is the primary threat to containment integrity. Other primary variables related to containment integrity are monitored to determine the status of the suppression pool heat absorption capability and containment environmental conditions. These are drywell temperature, suppression pool temperature, suppression pool water level, and containment temperature (Mark III only). In addition, hydrogen* and oxygen monitors should be included on the SPDS to monitor the potential for hydrogen deflagration. Containment isolation valve status is also a primary indicator of a potential release path, provides necessary assurance that these paths are closed, and is therefore considered essential for SPDS parameter display.

IV. DEFINITION OF AN OPERATIONAL SPDS

In the staff's past reviews, controversy has occasionally arisen over the staff's interpretation of orders or license conditions that require the licensee or applicant to have a fully operational/operable/operating/functional SPDS installed in the control room by a certain, negotiated date. Although different terms were used to define the concept of operability, the staff's intent is that the control room be provided with a safety parameter display as required by Supplement 1 to NUREG-0737. The staff has considered an SPDS operational, if it is described as follows:

- Has been fully tested, installed, accepted, and turned over to plant operations for use.

- Provided the defined function of SPDS, i.e., display the minimum information sufficient to allow operators to assess plant safety status; specifically, display sufficient information to monitor the five safety functions defined in Supplement 1 to NUREG-0737.

- Provided valid, reliable information in a continuous display.

- Functions as a system that includes clearly written procedures for its use and operators that have been fully trained to operate and interpret its displays.

The staff discovered several SPDSs that had been declared operational, but were in fact, so unreliable that operators would not or could not use them. Generally, these systems were not fully tested and were undergoing significant de-bugging and modification. These systems also exhibited chronic system-wide or functional failures, often without adequate warning to alert operators that the SPDS displays were invalid, inaccurate, or outdated. These problems were compounded by lack of adequate operator training regarding SPDS.

* not necessary for inerted containments

The staff's practice to determine whether an SPDS is operational has been that, if operators cannot routinely use the SPDS to determine the status of all five safety functions, for whatever reason, it is not operational. For example, if there is not enough valid information being displayed (as defined by the licensee's list of approved SPDS parameters) to allow operators to assess one or more of the safety functions (as defined in Supplement 1 to NUREG-0737, Section 4.1.f), the SPDS is not operational.

Unreliable hardware and software, and lack of adequate training are common reasons that SPDSs do not function properly even after being declared operational. The staff practice generally has not challenged licensees' claims that their SPDS is operational unless the SPDS has chronic reliability problems, the operators are poorly trained or not trained at all, and the SPDS is providing invalid information for significant periods of time (i.e., longer than necessary for normal maintenance or software programming work orders to be executed).

In summary, the staff finds acceptable an SPDS that fully provides its required function as evidenced by the ability of operators to determine the status of all five safety functions identified in Supplement 1 to NUREG-0737.

V. SUMMARY

The staff has provided examples of SPDS features and characteristics that acceptably satisfy the requirements for an SPDS. Definitions, assumptions, and general principles that are basic to staff practice during evaluations of SPDS were also provided. This discussion should clarify some of the confusion that surrounds implementation of the requirements for the SPDS, and provide a common conceptual framework for the post-implementation reviews, audits, and inspections that lie ahead. The SPDS is an important initiative in the industry's effort to improve emergency response. The purpose of this report is to communicate to the industry acceptable ways of implementing the SPDS requirements so that deficient systems may be improved as necessary, that systems still under development may be optimized, and that the regulatory review process may be streamlined by providing licensees with sufficient information to forewarn them of likely problem areas.

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This report provides a summary of the results of the U.S. Nuclear Regulatory Commission staff's review of installed safety parameter display systems (SPDS) at 57 nuclear units. The staff describes its rationale and practice for determining acceptability of some of the methods for satisfying the various requirements for SPDS as well as some methods that the staff has not accepted.

The staff's discussion of identified strengths and weaknesses should aid licensees in solving some of the problems they may be experiencing with their SPDS.

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