**TECHNIQUE TO EVALUATE
PROCESS CONTROL AND DATA HANDLING
INSTRUMENTATION**

W. R. MARKILLIE

AUGUST, 1967

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PROCESS CONTROL AND DATA HANDLING INSTRUMENTATION

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ABSTRACT

A figure-of-merit model was developed to evaluate several process control and data handling instrumentation concepts proposed for the Fast Flux Test Facility (FFTF). The model first provides for the consideration of each instrumentation concept according to its performance in terms of safety, operating continuity, data handling, control quality, human factors and flexibility. It then directs the comparison of that performance with process control and data handling requirements included as part of the evaluation technique. The result of such a comparison is a measure of instrumentation concept worth expressed both qualitatively and quantitatively. The measure of worth and the cost of each concept become a basis for comparing the concepts and lead to the selection of one of them for FFTF.

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TECHNIQUE TO EVALUATE
PROCESS CONTROL AND DATA HANDLING INSTRUMENTATION

W. R. Markillie

INTRODUCTION

The purpose of this report is to describe the figure-of-merit model developed to evaluate several process control and data handling instrumentation concepts for the Fast Flux Test Facility (FFTF) prior to selecting the one to be used as the basis for preliminary design.

The Fast Flux Test Facility (FFTF)⁽¹⁾ is conceived to investigate the behavior of fuels and structural materials subjected to the extreme conditions of neutron flux in breeder reactor environments. The facility will be uniquely suited for testing fuel in special closed loops that precisely control the environmental conditions while exposing the fuel to known, predictable neutronics. Testing may be a survey nature, a full developmental program, run-to-failure tests, or statistical proof tests. Auxiliary examination and test facilities are included to adequately characterize the test fuel before exposure in the reactor and to obtain data from the experiment after exposure. Since the FFTF is conceived to permit irradiation testing within the core of a liquid metal-cooled fast neutron reactor, it requires sophisticated controls over all process and test conditions to assure reactor safety, test data validity, and plant availability.

Many different process control and data handling instrumentation concepts are available throughout the control industry. Selecting the one instrumentation concept that most completely meets FFTF requirements is a complex task that involves the consideration of many factors. Because the instrumentation concept is related to so much of the design, construction, operation, and experimentation program, many people need to be involved in selecting it. All safety, experimental capability, and process

operating continuity concerns should affect the selection. Costs also should be considered. The analysis of process control and data handling instrumentation concepts and the selection of one of them comprise an extensive decision making process. The decision making should be as objective as possible. The analysis should be flexible enough to permit the consideration of complete systems or only portions of them. It also should be flexible enough to include changes in overall breeder reactor program emphasis. The decision making process should provide for documenting the reasons for selecting one instrumentation concept as opposed to another precisely enough to be useful for reference later in the project.

The figure-of-merit model described in this report was developed to minimize the complexity associated with analyzing process control and data handling instrumentation concepts and selecting one of them for FFTF. It was also developed to meet the objectivity, flexibility, and documentation requirements of the decision making process. During preliminary design, decisions will have to be made to trade-off one feature against another to optimize the facility's contribution to the breeder reactor program. The figure-of-merit model was developed also for use in those trade-off studies.

SUMMARY

A figure-of-merit model was developed to evaluate several process control and data handling instrumentation concepts proposed for FFTF. The model includes all the features of process control and data handling instrumentation that should be used in evaluating an instrumentation concept both qualitatively and quantitatively. These features are safety, operating continuity, data handling, control quality, human factors, and flexibility. Each feature is considered to be composed of several characteristics. For the qualitative evaluation, the performance of an instrumentation concept is determined characteristic by characteristic. This performance is then compared characteristic by characteristic with the process control and

data handling requirements described in the model. As a result of those comparisons, the instrumentation concept is placed, a characteristic at a time, in one of the six performance levels defined by the model. For the quantitative evaluation, value points are assigned to each performance level, high levels assigned more points than low levels. Points are summed for each feature according to the numbers of characteristics in each of the performance levels. This determines a figure-of-merit for each feature. Each feature is weighted depending on the importance of that feature in relation to all the others and in relation to the requirements of the complete facility. The sum of the products of each feature figure-of-merit and its weighting factor is computed to yield the numerical concept figure-of-merit. This is the measure of worth of the instrumentation concept.

In applying the model, it is first used to evaluate each proposed instrumentation concept. The results of those evaluations, together with the estimated costs of the instrumentation concepts, are then compared to determine the concept of greatest worth in terms of both performance and economy.

CONCEPT FIGURE-OF-MERIT

The concept figure-of-merit, the measure of worth of a control and data handling instrumentation concept to the FFTF, is based on these features of concept worth:

- Safety
- Operating continuity
- Data handling
- Control quality
- Human factors
- Flexibility.

Although all six features are interrelated and are difficult to consider separately, some ranking or weighting factor applied to each is required to produce a meaningful concept worth measurement. Concept characteristics that ensure the safety of the facility must be given more weight in selecting an instrumentation concept than characteristics that permit flexibility in experimentation. Weighting factors relate the worth of each feature separately to its worth among all the others and to its importance in meeting the FFTF requirements. The concept figure-of-merit, F/M, is given by the following expression:

$$F/M = W_S^{f/m_S} + W_{OC}^{f/m_{OC}} + W_{DH}^{f/m_{DH}} + W_{CQ}^{f/m_{CQ}} + W_{HF}^{f/m_{HF}} + W_F^{f/m_F},$$

where,

W is the weighting factor, a non-negative whole number less than or equal to 100, that relates the worth of each feature separately to its worth among all the others, and

f/m is the figure-of-merit, a whole number less than or equal to 100, associated with each feature.

The subscripts identify the feature being considered. For instance, W_S is the weighting factor associated with safety and f/m_{DH} is the data handling figure-of-merit.

WEIGHTING FACTOR DETERMINATION

The weighting factors to be used in computing F/M, the concept figure-of-merit, are shown in Table I. As shown in the table, safety is given primary emphasis in computing a concept figure-of-merit. To ensure that operating continuity and data handling, two features directly associated with the reactor's purpose of providing an irradiation testing capability, do not receive greater emphasis in selecting an instrumentation concept than does safety, their weighting factors are much smaller than the safety weighting factor. Control quality and human factors have an indirect effect on providing the irradiation testing capability through their influence on the ease, speed, and effectiveness of the reactor operation. Since control quality and human factors have an indirect effect, their weighting factors are smaller than the weighting factors associated with operating continuity and data handling. Since flexibility must not be incorporated into the instrumentation concept at the expense of other features, its weighting factor is smaller than the ones associated with control quality and human factors.

Since weighting factors appear as variables in the concept figure-of-merit expression, many different weighting factor selections are possible. By using a different set of weighting factors, the importance placed on a specific feature in the evaluation can be changed.

TABLE I. *Concept Features and Their Weighting Factors*

<u>Concept Feature</u>	<u>Abbreviation</u>	<u>Weighting Factor, W</u>
Safety	S	100
Operating Continuity	OC	40
Data Handling	DH	40
Control Quality	CQ	30
Human Factors	HF	30
Flexibility	F	20

FEATURE FIGURE-OF-MERIT DETERMINATION

In addition to the weighting factors used to compute the concept figure-of-merit are the figures-of-merit associated with each of the features used in comparing the instrumentation concepts. Each figure-of-merit is evaluated qualitatively and is a measure of the worth of the instrumentation concept in terms of the feature under consideration.

For the qualitative evaluation, each feature of the instrumentation concept comparison is considered to be composed of several characteristics. The performance of the concept is determined in terms of each characteristic and is then compared with the control and data handling requirements for that characteristic to place it in one of the levels shown in Table II.

TABLE II. *Performance Level Definitions*

<u>Performance Level</u>	<u>Definition</u>
I	The instrumentation concept performs in such a way that none of the requirements are met.
II	The instrumentation concept performs in such a way that part of the requirements are met part of the time or in part of the situations under consideration.
III	The instrumentation concept performs in such a way that all of the requirements are met part of the time or in part of the situations under consideration.
IV	The instrumentation concept performs in such a way that part of the requirements are met all of the time or in all of the situations under consideration.
V	The instrumentation concept performs in such a way that all of the requirements are met all of the time or in all of the situations under consideration.
VI	The instrumentation concept performs in such a way that the requirements are exceeded.

In general, the feature figure-of-merit, f/m , is given by:

$$f/m = K(N^I_a + N^{II}_b + N^{III}_c + N^{IV}_d + N^V_e + N^{VI}_f),$$

where,

K is the constant used to convert the summation in parenthesis from its scale to a scale common for all feature figures-of-merit;

$N^I, \dots, N^{VI}$ are the numbers of characteristics that are placed in the respective performance levels $I, \dots, VI$; and

$a, \dots, f$ are the value-point constants associated with the performance levels $I, \dots, VI$ and are used to convert the comparison from a qualitative evaluation to a quantitative figure-of-merit.

Numerical values may be assigned to $a, \dots, f$ with the largest, most positive value being associated with f , the constant for performance level VI ; the letters themselves may be carried through the algebraic manipulations to yield an algebraic expression for the concept figure-of-merit, F/M . Instrumentation concepts may be compared using the algebraic expressions by noticing the numbers of characteristics associated with the different performance levels. The better concept would be the one with more characteristics in levels V and VI than the other concept, taking account, though, of the weighting factors associated with each feature. Instead of comparing the algebraic expressions for F/M , numerical values can be assigned to $a, \dots, f$ and quantitative figures-of-merit computed.

The details of determining the figures-of-merit together with the requirements used in evaluating the instrumentation concept performance are described below for each feature being considered.

SAFETY FIGURE-OF-MERIT, f/m_S

Safety characteristics, which are incorporated into the control and data handling instrumentation to avoid, terminate, or limit the consequences of accidents, are evaluated in terms of the techniques used to ensure safety function performance. The safety figure-of-merit, f/m_S , is given by:

$$f/m_S = K_S (N_S^I a + N_S^{II} b + N_S^{III} c + N_S^{IV} d + N_S^V e + N_S^{VI} f),$$

where,

K_S is the scale factor for safety;

$N_S^I, \dots, N_S^{VI}$ are the numbers of safety characteristics that are placed in the respective performance levels I, $\dots$, VI; and

$a, \dots, f$ are the value point constants.

The requirements used to evaluate the performance of the instrumentation concept to determine the safety figure-of-merit are discussed characteristic by characteristic on the following pages.

SAFETY FIGURE-OF-MERIT, f/m_S Redundancy

The principle of redundancy, using two or more means to accomplish a given function or objective, is well established in the nuclear reactor industry and is used in some form in many reactor safety systems.⁽²⁾ It may be provided in several ways; a common technique is the duplication of critical elements.⁽³⁾ Another way is diversity, in which different process variables are involved in redundant subsystems.⁽⁴⁾ Sensor measurement information may be handled and reduced by different methods; either information pathway is able to initiate safety action.

Requirement:

1. Redundancy should be provided to deny a loss of protection because of single component, equipment, or channel failure.

SAFETY FIGURE-OF-MERIT, f/m_S Independence

The articles referenced in the section entitled Redundancy indicate that redundant elements or information flow paths should be independent to ensure that a single failure or improper operation does not produce a system loss of protection condition. Independence helps ensure that protection is denied only for multiple failures that occur uniquely at critical locations in the system.

Requirements:

1. Failures in one redundant element or path should not affect another redundant element or path.
2. Redundant elements or paths should not be subjected to common failure or improper operation situations.

SAFETY FIGURE-OF-MERIT, f/m_S Testing

Many failures that occur in safety instrumentation produce the same action that would be taken by the instrumentation in response to an out-of-limit condition. A system that produces such a response is known as a fail-safe system. Since not all failures cause fail-safe responses, testing is frequently provided to uncover those latent failures that do not initiate reactor scrams.⁽⁵⁾ Frequent testing is required to gain the greatest benefit from the redundancy provided in the instrumentation concept.⁽⁶⁾

Requirement:

1. The instrumentation concept must be able to be tested frequently enough and thoroughly enough to ensure its operability for all safety functions.

SAFETY FIGURE-OF-MERIT, f/m_S Self-Checking

Since failures occur randomly, a failure may occur immediately after one of the periodic tests and remain undetected until the next test. Self-checking can detect many latent failures, can alarm their presence for the operator, can switch failed elements or paths out of the system, and can switch operable elements or paths into the system.

Requirements:

1. Self-checking should be provided to ensure proper instrumentation performance during the time between periodic tests.
2. The occurrence of a failure or an improper operation should be alarmed to permit the operator to take remedial action for those failures or improper operations that do not permit failed elements or paths to be switched out and replaced with operable elements or paths.

SAFETY FIGURE-OF-MERIT, f/m_S Stability

The experimental testing environment is the result of extensive interaction among nuclear, thermal, and hydraulic phenomena and the process and experiment control equipment. Although the design of a facility includes the capability of process, experiment, and control equipment to respond to local disturbances, there is particular interest in ensuring that the overall system cannot be excited into oscillation. Such process and experiment instabilities may damage equipment and jeopardize safety.

Requirement:

1. The instrumentation concept should be arranged to avoid any tendency toward instability that might damage equipment and jeopardize safety.

SAFETY FIGURE-OF-MERIT, f/m_S Drift

Drift in portions of instrumentation equipment can sometimes lead to changes in set points and trip levels and consequently to undesirable process and experiment operating conditions. Checking for drift and taking appropriate corrective action can eliminate many of the undesirable effects associated with drift. Most effective in reducing drift is the elimination of the effects of such external conditions as pressure, temperature, and vibration on the control and data handling equipment.

Requirements:

1. The instrumentation concept should be arranged to minimize drift in safety trip points.
2. The instrumentation concept should be arranged to recognize drift in safety trip points and to initiate appropriate action to compensate for or correct the drift.

SAFETY FIGURE-OF-MERIT, f/m_S Fault Recognition

Since operating with hidden faults is detrimental to facility safety, faults should be able to be recognized as soon as they occur rather than being concealed until their discovery during periodic testing. The detrimental effects can be minimized if the faults can be recognized shortly after their occurrence and remedial action can be taken immediately. Such fault recognition applies not only to both process and experiment equipment and the associated control and data handling instrumentation, but also to the actions and activities of the operators and experimenters. An operator out-of-sequence action can be as detrimental to facility safety as can a faulty piece of process equipment.

Requirements:

1. The instrumentation concept should be able to recognize such faults as sensor failures, signal conditioning amplifier drift, equipment saturation, and operator action out of sequence.
2. The instrumentation concept should be able to take appropriate action in response to the faults, either in modifying safety and control operations or in bringing the fault to the attention of the operator.

SAFETY FIGURE-OF-MERIT, f/m_S Fault Isolation

Once a fault is recognized, its rapid isolation is required to minimize the time the equipment is out of service. Fault isolation can be accomplished through standard trouble shooting procedures in conjunction with specially provided equipment features. Thorough fault isolation that identifies all the aspects of the malfunction permits effective allocation of the available resources of repair equipment and maintenance staff members. Rapid fault isolation permits the facility management and the experimenters to make timely decisions about the effects of the fault on the irradiation testing program.

Requirement:

1. The instrumentation concept should be arranged to provide effective isolation of faults both in process and experiment equipment and in the associated safety and control instrumentation.

SAFETY FIGURE-OF-MERIT, f/m_s Power Reduction

The reactor and heat removal equipment are expected to experience significant thermal shock each time a scram is initiated from full power operation. Since the equipment cannot be expected to experience such thermal shock indefinitely without losing its strength, the number of times scram action would be required should be minimized. This is accomplished by initiating a gradual power reduction in response to abnormal operating conditions that are less severe than those conditions that require scram action. This capability in a sense catches an operating condition on a scram-action-bound course and begins gradual power reduction to avoid the scram action. The gradual power reduction reduces the detrimental effects of the shutdown on the reactor and heat removal equipment. The gradual power reduction also provides valuable time to take remedial action to eliminate the abnormal operating condition, thus permitting a return to full power operation to continue the experimental work.

Requirements:

1. The instrumentation concept should be arranged to minimize the number of times scram action is required by providing for a gradual power reduction to be initiated in response to abnormal operating conditions that are less severe than those that require scram action.
2. The power reduction capability should not prevent a scram from being initiated if scram action is required.

SAFETY FIGURE-OF-MERIT, f/m_s Facility Surveillance

Close surveillance over all facets of facility operations provides the information about the process and experiments that is necessary for safe operating conditions.

Requirements:

1. The instrumentation concept should be able to accumulate all the process and experiment variable and operating information required for safe operation.
2. The instrumentation concept should be able to monitor or sample the process and experiment variables frequently enough and thoroughly enough to ensure that required safety functions are not delayed.
3. The instrumentation concept should be able to monitor or sample the process and experiment variables frequently enough and thoroughly enough to ensure that the facility is under surveillance at all times.

SAFETY FIGURE-OF-MERIT f/m_S Operator Attention

For the operator to have adequate time to respond to abnormal conditions, pertinent information about facility conditions must be brought to his attention quickly.

Requirement:

1. The instrumentation concept should be able to display the occurrence of significant process and experiment condition changes that influence safety in such a way as to attract the attention of the operator to permit rapid and effective decision making.

SAFETY FIGURE-OF-MERIT, f/m_S Priority

Safety action must never take second place in the operation of the facility. Functions or operations of a critical nature that affect the safety of the facility must have associated with them a priority that is higher than the priority associated with functions or operations of a less critical nature.

Requirement:

1. The instrumentation concept should be arranged such that high priority operations are not delayed by low priority operations.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC}

The operating continuity figure-of-merit, f/m_{OC} , is a measure of those characteristics associated with keeping the facility operating long enough to perform the experiments and with prolonging facility life by reducing the number of instrumentation failure induced shutdowns. The operating continuity figure-of-merit is given by:

$$f/m_{OC} = K_{OC} (N_{OC}^I a + N_{OC}^{II} b + N_{OC}^{III} c + N_{OC}^{IV} d + N_{OC}^V e + N_{OC}^{VI} f),$$

where,

K_{OC} is the scale factor for operating continuity;

$N_{OC}^I, \dots, N_{OC}^{VI}$ are the numbers of operating continuity characteristics that are placed in the respective performance levels I, $\dots$, VI; and

$a, \dots, f$ are the value point constants.

The requirements used to evaluate the performance of the instrumentation concept to determine the operating continuity figure-of-merit are discussed characteristic by characteristic on the following pages.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Redundancy

The principle of redundancy, using two or more means to accomplish a given function or objective, is well established in the nuclear reactor industry and is used in some form in many reactor safety systems.⁽²⁾ It may be provided in several ways; a common technique is the duplication of critical elements.⁽³⁾ Another way is diversity, in which different process variables are involved in redundant subsystems.⁽⁴⁾ Sensor measurement information may be handled and reduced by different methods. The resultant control function is initiated only if adequate agreement exists among the different methods.

Requirement:

1. Redundancy should be provided to deny a loss of operating continuity because of single component, equipment, or channel failure.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Independence

Redundant elements or information flow paths should be independent to ensure that a single failure does not produce a system loss of operating continuity. Independence helps ensure that a loss of operating continuity results only from multiple failures that occur uniquely at critical locations in the system.

Requirements:

1. Failure in one redundant element or path should not affect another redundant element or path.
2. Redundant elements or paths should not be subjected to common failure or improper operation situations.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Startup

In preparation for startup, many tests and checks must be completed and the results must be recorded. There are so many different tasks and so many staff members involved that careful coordination is a necessity. Wasted effort in terms of duplication of work and excessive time spent in recording results only lengthens downtime and reduces at-power irradiation time. After criticality is achieved, during the ascent to power, evaluation of the performance of the heat removal equipment is required to ensure its proper operation and adequate capacity. Since the time required for startup and ascent to power extends over several operating shifts, it is vital for actual startup status to be passed on from one crew to another. Any technique, such as automatic checking and surveying for startup progress, that reduces the time required for startup without jeopardizing operating safety and effectiveness is desirable because it serves to lengthen the operating period.

Requirements:

1. The instrumentation concept should include characteristics that facilitate the performance of startup checks and procedures.
2. The instrumentation concept should be arranged to rapidly survey the status of the startup preparations from a central location.
3. The instrumentation concept should be arranged to periodically provide a record of the status of startup.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Closed Loop Adjustments

A closed loop is defined as an isolated circuit that permits precise control over all experimental parameters (such as flow, temperature, purity, pressure) and that includes in its circuit an in-core test section exposed to known, predictable neutronics. Implicit in the definition is a capability of changing or replacing irradiation specimens in the test section.⁽¹⁾ Experimenters using the facility for irradiation testing under varying coolant conditions in the closed loops require freedom of control adjustment and proprietary information protection throughout the time their testing is in progress. Adequate proprietary protection requires physical separation of the closed loop control stations and protection of the information accumulated during testing. Coordination of the activities of the experimenters is required because of the effect a single closed loop might have on the complete facility as a result of improper experimenter control action.

Requirements:

1. The instrumentation concept should permit the adjustment of each closed loop independently from separate control stations.
2. Adjustment of variables should not jeopardize plant operating continuity through experiment and process interaction or through instrumentation interaction.
3. The instrumentation concept should consider interacting effects among the closed loops in determining control actions.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Power Reduction and Process Equipment Bypassing

Gradual power reduction, initiated in response to abnormal operating conditions that are less severe than those conditions that require scram action, provides valuable time to take remedial action to eliminate the abnormal operating condition. Thus a return to full power operation to continue experimental work is permitted. Continued operation at a reduced power level during the time required to repair some piece of process or experiment equipment or continued operation at a reduced power level until the end of a normal operating period permits continued accumulation of valuable experimental data. Scram action that results from withdrawing process and experimental equipment from service and from unsuccessfully attempting to reduce the power level correspondingly to match the available heat removal capacity loses valuable irradiation testing time.

Requirements:

1. The instrumentation concept should be arranged to minimize the number of times scram action would be required by anticipating process and experiment conditions that might threaten the safety of the reactor and by correcting them before they become serious enough to warrant scram action.
2. A gradual power reduction capability should be initiated in response to abnormal conditions that are less severe than those conditions that require scram action.
3. Since the main heat removal system is to be partially redundant to permit continued operation at reduced power levels with some equipment out-of-service, the instrumentation concept should provide the capability to switch portions of the system into or out of service as required.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} On-Line Maintenance

Maintenance of process and experiment equipment and control and data handling instrumentation that can be performed during facility operation is valuable because it permits irradiation testing and experimentation to continue even though some of the facility equipment is out of service. A piece of equipment is removed from service for repair or periodic maintenance. Maintenance is followed by thorough bench testing of the piece of equipment. Even though the piece of equipment meets these tests and thus can be restored to service, its complete operability is not assured until it functions successfully as part of a system. On-line maintenance makes systems testing possible since it permits operation to continue and provides the functioning system in which the piece of equipment can be restored to service. An operating facility provides a much more thorough testing of a piece of equipment in conjunction with significant bench testing upon return to service than bench testing and a shutdown facility with no opportunity for testing under actual operating conditions.

Requirements:

1. As much of the instrumentation equipment as possible should be able to be maintained during plant operation.
2. Critical elements should be able to be withdrawn from service for maintenance with redundant elements performing their functions while they are out of service.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Fault Recognition

Since operating with hidden faults is detrimental to facility safety and test data validity, faults should be able to be recognized as soon as they occur rather than being concealed until their discovery during periodic testing. The detrimental effects can be minimized if the faults can be recognized shortly after their occurrence and remedial action can be taken immediately. Such fault recognition applies not only to both process and experiment equipment and the associated control and data handling instrumentation, but also to the actions and activities of the operators and experimenters. An operator out-of-sequence action can be as detrimental to facility safety and test data validity as can a faulty piece of process equipment.

Requirements:

1. The instrumentation concept should be able to recognize such faults as sensor failures, signal conditioning amplifier drift, equipment saturation, operator action out-of-sequence, and improper control command computation.
2. The instrumentation concept should be able to take appropriate action in response to the faults, either in modifying control or data handling operations or in bringing the fault to the attention of the operator.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Fault Isolation

Once a fault is recognized, its rapid isolation is required to minimize the time the equipment is out of service. Fault isolation can be accomplished through standard trouble shooting procedures in conjunction with specially provided equipment features. Thorough fault isolation that identifies all the aspects of the malfunction permits effective allocation of the available resources of repair equipment and maintenance staff members. Rapid fault isolation permits the facility management and the experimenters to make timely decisions about the effects of the fault on the irradiation testing program.

Requirement:

1. The instrumentation concept should be arranged to provide effective isolation of faults both in process and experiment equipment and in the associated control and data handling instrumentation.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Modular Construction

Modular construction of the control and data handling instrumentation minimizes maintenance time and effort. Any decrease in maintenance time immediately becomes an increase in the time available for experimenting and testing. Modular construction lends itself to standard maintenance procedures to ease the effort required to locate and repair faults. One module can be replaced quickly by another from available spares. Maximum utilization of the modular construction of the instrumentation is ensured by effective spare parts management to have a spare available when it is needed.

Requirements:

1. The instrumentation concept should use modular construction.
2. The instrumentation concept should be arranged to permit an adequate supply of spare parts to be available for expected module replacement.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Testing

Valid monitoring and testing of the process and experiment equipment and the associated control and data handling instrumentation is valuable in demonstrating operability under the conditions expected to prevail when operation is needed.⁽⁴⁾ Without adequate testing, faults may occur and remain in the equipment and instrumentation to the detriment of operating continuity and experimental data validity.

Requirements:

1. The instrumentation concept should be able to be tested frequently enough and thoroughly enough to ensure its operability for all operating functions.
2. Testing should neither interfere with the operation of the facility nor contribute to downtime.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Maintenance Training

The complexity of the control and data handling instrumentation determines not only the training required to prepare staff members to maintain the equipment but also the background and experience of the individuals considered for the maintenance staff. Requiring extensive background and experience limits the number of individuals qualified for the maintenance staff. Requiring extensive training lengthens the time required to prepare staff members for maintenance work. When many skills need to be developed, adequate training and performance evaluating can sometimes be overlooked. Response to abnormal circumstances can be less than desirable. Adequate training helps ensure effective maintenance response to equipment out of service conditions either for repair or test.

Requirements:

1. The instrumentation concept should be arranged to take advantage of easily developed maintenance skills.
2. In arranging the instrumentation concept, consideration should be given to the training required to develop a qualified maintenance staff.
3. The instrumentation concept should emphasize simplicity and require the development of only limited number of maintenance skills.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Maintenance Cost

Maintenance costs are indirect results of the experimental activity and as such do not contribute directly to fuel, materials, and coolant development. Funds required for maintenance reduce the funds available for experimentation. Minimizing maintenance costs permits an optimum allocation of funds directly among experimental activities.

Requirement:

1. The instrumentation concept should be arranged to minimize the maintenance costs associated with the following:
 - a. Time required for repair or periodic maintenance.
 - b. Number of staff members on the maintenance crew.
 - c. Special equipment required.
 - d. Spare parts inventory.

OPERATING CONTINUITY FIGURE-OF-MERIT, f/m_{OC} Maintenance Scheduling

Maintenance activities require close coordination to ensure the optimum allocation of resources to maximize the time spent in fuel testing. The dynamic aspects of plant, personnel, materials, tools, and unexpected breakdowns make maintenance scheduling a complex task involving a considerable number of computations and reshuffling of data. Mathematical analysis of a number of typical plants has shown that downtime costs with dynamic maintenance scheduling can be reduced by as much as 47 to 79% from what they would be with the usual method of scheduling maintenance work on a "first-in," "first-out" basis.⁽¹²⁾ Operations, maintenance, engineering, experiment, and management decisions need to be based on actual equipment conditions that are accumulated and reported currently.

Requirements:

1. The instrumentation concept should be arranged to optimize maintenance scheduling for the instrumentation equipment, the process equipment, and the experiment equipment.
2. The instrumentation concept should be arranged to record maintenance activities and provide an up-to-the-minute status report of out-of-service equipment.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH}

The data handling figure-of-merit, f/m_{DH} , is a measure of the performance of the instrumentation concept in terms of those characteristics associated with data acquisition, reduction, correlation, storage, retrieval, and display for both operation and experimentation functions. The data handling figure-of-merit is given by:

$$f/m_{DH} = K_{DH}(N_{DH}^I a + N_{DH}^{II} b + N_{DH}^{III} c + N_{DH}^{IV} d + N_{DH}^V e + N_{DH}^{VI} f),$$

where,

K_{DH} is the scale factor for data handling;

$N_{DH}^I, \dots, N_{DH}^{VI}$ are the numbers of data handling characteristics that are placed in the respective performance levels I, ..., VI; and

$a, \dots, f$ are the value point constants.

The requirements used to evaluate the performance of the instrumentation concept to determine the data handling figure-of-merit are discussed characteristic by characteristic on the following pages.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Acquisition

Operations, maintenance, and experimentation staffs require extensive information about process and experiment variables and equipment. Other vital information that directly affects the operation of the facility and particularly the process and experiment operating levels is operator and experimenter action. Extensive information acquisition enables thorough evaluations of facility operation to be performed. Such information is vital for making appropriate decisions and reviewing operating experience.

Requirements:

1. All pertinent process and experiment information should be acquired by the control and data handling instrumentation.
2. Information should be acquired rapidly enough to follow unexpected transients.
3. The instrumentation concept should acquire information about operator and experimenter action.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Authenticity

Continuous operation for the irradiation testing experiments is desirable only as long as the data being accumulated is valid and adequately describes the process and experiment conditions. Lost or questionable data renders the performance of irradiation experiments of little value and compromises the effectiveness of safety and control functions. Continually checking data for authenticity tends to initiate appropriate action to avoid accumulating worthless process and experiment data.

Requirements:

1. The information acquired by the control and data handling instrumentation should be analyzed for reasonableness to identify transducer and signal conditioning equipment malfunctions.
2. Unreasonable measurements should be designated as unreasonable to provide guidance for operator and experimenter decision making.
3. Proper ranging should be verified.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Reduction

Although process and experiment variable measurements are of use to the operators and experimenters, many times the values of most significance in their decision making are those that require computations using several pieces of raw data. An example is the evaluation of the heat removal system capacity at several different power levels during the ascent to the planned operating power level. Such an evaluation requires several computations and must be made at an intermediate power level prior to increasing power to the next intermediate level. Another example is the computation required to assess the adequacy of the experiments to determine incentives to continue or terminate an irradiation. Accumulating raw and reduced data in a form that can be used directly by automatic data processing centers for detailed analysis enables the experimenter to complete his evaluating and reporting accurately and rapidly. The presence of data reduction and analysis capability at the facility heightens the usefulness of the facility to experimenter organizations, since only a small resident team is necessary to handle the complete testing and evaluating workload.

Requirements:

1. The experiment and process measurements should be reduced to variables and units of direct engineering significance to the experimenter and the operator.
2. The information should be presented in a simple, concise way to permit rapid and effective decision making and experiment evaluating.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Storage

Good operating practice as well as AEC requirements provide for retaining process and experiment measurements as a history of facility operation. Frequently there is a need to review operating experience to identify incentives for changes in design and in operator and experimenter training. AEC safety audits many times include an extensive review of the process and experiment operating history. Retaining historical records permits a determination of operator and experimenter performance, numbers of thermal cycles experienced by the heat removal equipment, numbers of pump starts, and total operating hours. All such information is valuable for evaluating the operation of the facility.

Requirement:

1. The instrumentation concept should be arranged to store the experiment and process information in sufficient quantity and detail to permit an evaluation of the operating history of the facility and to verify facility compliance with safety limits.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Retrieval

Once a need arises to review portions of the operating history in storage, it is important to be able to retrieve the necessary information as quickly as possible and in the format that is most effective for use by the individual needing the information. Information presented for experimenter decision making would have some value for program management, but not as much as a presentation oriented directly to management's information needs. Relating operator and experimenter action to actual facility conditions and process and experiment equipment interactions can provide valuable information to all staff members associated with the facility, depending on the extent to which the various interactions and relationships are made clear by the retrieval format.

Requirements:

1. The instrumentation concept should permit rapid retrieval of stored experiment and process information for display, evaluation, and decision making.
2. The retrieval should lend itself to correlating variables among each other, with time, and with experimenter and operator action.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Proprietary Protection

Some of the equipment, coolants, control and measurement techniques, materials, and fuel element designs and expected capabilities developed for experimental use in the facility may be proprietary. Experimenters must be able to be guaranteed that information about their proprietary developments will be held in confidence. Experimenters need to have adequate means to safeguard information about their technical progress.

Requirements:

1. The instrumentation concept should be arranged to avoid unauthorized disclosure of proprietary information.
2. Proprietary protection for experimenters' developments should not preclude safe and effective control of the facility by the operators.

DATA HANDLING FIGURE-OF-MERIT, f/m_{DH} Continuity

Certain data may be so critical to the success of an experiment that its loss may render the experiment worthless. Data lost during a process or experiment abnormality may make it impossible to reconstruct the condition accurately enough to determine its cause and thus preclude its recurrence. Missing data may make it difficult to make effective, timely decisions about the progress of the irradiation program.

Requirement:

1. The instrumentation concept should be arranged to avoid losing experiment and process measurements, experimenter and operator decision records, and computations made using the raw measurement data.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ}

The control quality figure-of-merit, f/m_{CQ} , is a measure of the instrumentation concept worth in providing a safe, stable, accurately controlled irradiation testing environment. The control quality figure-of-merit is given by:

$$f/m_{CQ} = K_{CQ}(N_{CQ}^I a + N_{CQ}^{II} b + N_{CQ}^{III} c + N_{CQ}^{IV} d + N_{CQ}^V e + N_{CQ}^{VI} f),$$

where,

K_{CQ} is the scale factor for control quality;

$N_{CQ}^I, \dots, N_{CQ}^{VI}$ are the numbers of safety characteristics that are placed in the respective performance levels I, ..., VI; and

$a, \dots, f$ are the value point constants.

The requirements used to evaluate the performance of the instrumentation concept to determine the control quality figure-of-merit are discussed characteristic by characteristic on the following pages.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Accuracy

Accuracy in measurement and computation is a vital factor in the safe, effective control of the facility in providing an experimental, fast neutron flux environment. The measurement and computation accuracy is also of vital importance to the experimenter in his analysis of the results of his experiment.

Requirements:

1. The measurements and computations made by the instrumentation concept should be made accurately enough to adequately monitor and control the experimental environment.
2. The instrumentation concept should make measurements and computations accurately enough to provide valuable experimental information.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Speed

Sufficient speed of response of the various elements of the instrumentation concept is an important factor in safe, effective control of the facility in providing an experimental fast neutron environment. A rapidly responding instrumentation concept quickly overcomes process and experiment disturbances to return the systems to their preset operating levels.

Requirements:

1. The instrumentation concept should be arranged to respond rapidly enough to process and experiment disturbances to avoid detrimental effects to the plant and the experiments.
2. The instrumentation concept should be arranged to respond rapidly enough to process and experiment disturbances to maintain the testing environment as closely as possible at the desired operating condition.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Stability

The experimental testing environment is the result of extensive interaction among nuclear, thermal, and hydraulic phenomena and the process and experiment control equipment. Although the design of a facility includes the capability of process, experiment, and control equipment to respond to local disturbances, there is particular interest in ensuring that the overall system cannot be excited into oscillation. Meaningful experimentation requires a known, stable testing environment. Oscillation or other instability associated with the process, experiment, and control equipment in controlling the testing environment leads to questionable experimental results.

Requirement:

1. The instrumentation concept should be arranged to provide a stable environment that permits meaningful irradiation testing.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Transport Lag Compensation

Providing compensation for transport lag in controlling the process and experiment environments improves the control performance over that possible without such compensation.

Requirement:

1. The instrumentation concept should be arranged to take advantage of possible improvements in performance by providing for transport lag compensation.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Control Variations

Variations in control techniques are useful in that they permit optimum control depending on the current process and experiment conditions. Optimum control can be developed separately for startup, ascent to power, at-power, reduced power, or shutdown conditions. Different coolants may require significantly different control techniques for optimum closed loop operations. Satisfactory control at one operating level or under one set of conditions may not be satisfactory at another operating level or with another set of conditions. Variations in the control technique must make it possible to have stable control without regard for the operating level or the associated operating conditions.

Requirements:

1. The instrumentation concept should permit rapid changes in control approaches depending on facility operating level or experimental requirements.
2. The capability to operate various combinations of main heat removal system equipment for different operating conditions should be provided.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Drift

Drift in portions of instrumentation equipment can sometimes lead to changes in set points and trip levels and consequently to undesirable process and experiment operating conditions. Checking for drift and taking appropriate corrective action can eliminate many of the undesirable effects associated with drift. Most effective in reducing drift is the elimination of the effects of such external conditions as pressure, temperature, and vibration on the control and data handling equipment.

Requirements:

1. The instrumentation concept should be arranged to minimize drift in operating levels and in safety trip points.
2. The instrumentation concept should be arranged to recognize drift in operating levels and in safety trip points and to initiate appropriate action to compensate for or correct the drift.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Development Testing

Providing for as much complete system oriented testing as possible during the development of the control and data handling instrumentation helps avoid the need for last minute changes that postpone startup. Such testing prior to startup helps to verify the proper operation and interaction of all individual pieces of equipment as elements of the complete control and data handling instrumentation system. Separate aspects of the instrumentation such as control techniques can be tested before making them operate with other elements as a complete system.

Requirements:

1. Separate aspects of the instrumentation concept should be able to be tested during development to ensure their proper operation prior to assembly as a complete system.
2. The instrumentation concept should be able to be tested as a complete system during the development to verify and perfect its performance prior to its use in controlling the plant.

CONTROL QUALITY FIGURE-OF-MERIT, f/m_{CQ} Process and Experimental Equipment Interaction

Interactions are expected among the main heat removal equipments and the closed loops and their associated instrumentation. Operating each element or piece of equipment separately without any coordination among them may lead to unsatisfactory control conditions. Recognizing possible interactions during the development of the instrumentation equipment and providing for coordinated operation tends to encourage a more complete understanding of the process, experiment, and instrumentation systems.

Requirement:

1. The instrumentation concept should consider interacting effects among the closed loops, the main heat removal system, and the nuclear process in determining the control actions to be taken in response to the operators' control demands.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF}

Human factors are those characteristics incorporated into the control and data handling instrumentation to meet the broad goals of human economy and efficiency in work activity. Human engineering, engineering for human use, seeks to create situations in which human activities are carried on that the objectives of the activities are accomplished adequately with reasonable human cost.⁽⁷⁾ It is concerned primarily with these three aspects of man and his work: Obtaining information, making decisions, acting upon those decisions. The human factors characteristics are evaluated in terms of the requirements developed from a study of several references^(8, 9, 10, 11). The human factors figure-of-merit, f/m_{HF} , is given by:

$$f/m_{HF} = K_{HF}(N_{HF}^I a + N_{HF}^{II} b + N_{HF}^{III} c + N_{HF}^{IV} d + N_{HF}^V e + N_{HF}^{VI} f),$$

where,

K_{HF} is the scale factor for human factors;

$N_{HF}^I, \dots, N_{HF}^{VI}$ are the numbers of human factors characteristics that are placed in the respective performance levels; I, $\dots$, VI; and

$a, \dots, f$ are the value point constants.

The requirements used to evaluate the performance of the instrumentation concept to determine the operating continuity figure-of-merit are discussed characteristic by characteristic on the following pages.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF} Information Presentation

It is inherent in human engineering considerations that only essential information should be presented to the operator and experimenter. Extraneous information may be distracting. Presenting all vital information right in front of the operator enables him to have information for his consideration without his having to look around for it. Information presentation that attracts the operator to the most urgent situations first, in spite of the normal distractions of the control room, makes it possible for the operator to make rapid judgments and to take safe and effective control actions. Having to search for needed information or to wait excessively long for its presentation may make the required control action ineffective because of tardiness.

Requirements:

1. The information should be presented when and where it is needed to permit timely decision making.
2. Visual displays should be located to make the information readily available and should be arranged for optimum use.
3. The instrumentation concept should be arranged to attract the attention of the operator to information of the highest priority first.
4. The occurrence of process faults and abnormalities should be presented to the operator immediately and should be recorded automatically to ensure that the actual sequence of occurrence is available for operator decision making and subsequent analysis.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF} Information Communication

Information display that permits the operator to recognize correlations among the process and experiment variables and time enables him to develop a more complete understanding of the interaction of the systems under his control. Simple, automatic and standard operator interpretation and decision making ensures that certain relationships among variables and conditions initiate similar response from all operators. Lack of understanding of systems interactions on the part of operators may lead to nonstandard responses and may place effective process and experiment control in jeopardy. Display of experiment information that communicates the complex interaction of experiment variables permits the experimenter to grasp significant aspects of the performance of his fuel element or other test pieces and the associated closed loop that would not be clear if the information were presented in raw form as separate independent measurements.

Requirements:

1. The instrumentation concept should provide guidance to the operator in helping determine his response to an unexpected circumstance by indicating its primary cause, any dangerous or unexpected coincident side effects, and his most reasonable course of action.
2. The concept should permit the operator to concentrate on the process or the experiments rather than on the instrumentation.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF} Periodic Checks

Safe, effective operation and experimentation requires extensive startup, safety trip limit, and process surveillance checks. These checks can become monotonous for the operator and experimenter. Reducing the time required for the various periodic checks in conjunction with startup and ascent to power permits more time to be spent in irradiation testing.

Requirements:

1. The instrumentation concept should be arranged to minimize the time and monotony associated with periodic operating and experimenting checks.
2. The information display should permit the operator to examine trends in process and experiment variables and the status of equipment, thus enabling him to maintain a close surveillance over the facility.
3. The operator should be able to check the adequacy of the experimental data quickly and thoroughly to assess incentives for terminating experiments.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF} Control Devices

Control devices are the elements of the instrumentation concept that are used directly by the operator and experimenter to control process and experiment variables and to operate equipment. Having too many control devices imparts undue complexity to the choices available at the console for initiating control action. Having too few control devices limits the ability of the operator to exercise effective supervision and direction of the systems of the facility. Control device arrangement greatly affects operator and experimenter effectiveness.

Requirements:

1. The number of control devices should be at the minimum that is consistent with the purpose of the facility.
2. The control devices should be easily identifiable and arranged for optimum use.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF} Control Action

The action phase of the operator's job consists of his muscular activities that result from control decisions. Included in those muscular activities are such things as moving control devices or holding them stationary. In the performance of those activities, certain positions, angles, directions, speeds, sizes, amounts of friction, and amounts of inertia are optimum in terms of human performance. Conditions different from the optimum typically result in poorer performance. Control action that is consistent with the direction of the actuating element or process variable ensures that the operator develops a feel for the changes in process and experiment conditions to be expected as he initiates control action. A single action pathway for accomplishing a specific control function avoids indecision and confusion. A single action pathway permits standard control procedures to be used. Automatic checking of operator and experimenter action for appropriateness minimizes the number of scrams that result from inappropriate control action. A complete record of operator and experimenter action provides the information required to correlate changes in process and experiment variables with the control actions.

Requirements:

1. The conditions that affect operator control action should be optimized for maximum operator performance.
2. The instrumentation concept should provide only one action pathway to produce a given effect.
3. The instrumentation concept should be arranged to check operator action for appropriateness, to permit verification of the control command, and to record operator action.

HUMAN FACTOR FIGURE-OF-MERIT, f/m_{HF} Training

Beginning training early in the project ensures the timely development of a qualified operating staff. During construction and equipment installation, the control and data handling instrumentation is not always available for operator training. Simulation can be used as a training aid and permits operators to become accustomed to the control of the facility, to develop standard responses to specific situations, to recognize the interaction among systems, and to develop confidence in responding to emergency conditions. Simulation can also be used as a training aid after facility startup to permit the operators to become familiar with proposed control changes prior to their application to the facility. Since standard control action procedures simplify the actions to be taken by operators in response to process and experiment situations, using such procedures simplifies the training operators require. On-the-job training continues during operation as the operators increase their ability to respond to unexpected situations by becoming aware of the extensive interaction among process and experiment variables.

Requirements:

1. The instrumentation concept should lend itself to being simulated to provide adequate operator training well in advance of startup and after startup in preparation for operating with proposed control changes.
2. Instrumentation concept control action procedures should be standardized to simplify the training required.
3. The visual display should be arranged to permit on-the-job, during-operation training by encouraging a deepening awareness on the part of the operator for the interaction among process and experiment variables.

HUMAN FACTORS FIGURE-OF-MERIT, f/m_{HF} Operating Staff

The operating staff controls the process and experiment equipment and maintains surveillance over the progress of the experiments. The operating staff is also associated with experiment planning, process analysis, and procedure development. Optimum utilization of the operating staff helps ensure effective economical facility control and facility support. Control and data handling instrumentation that is sized and arranged in a way that takes into consideration the body dimensions of the operator helps ensure his efficiency and effectiveness as part of the man-machine system.

Requirements:

1. The concept should be arranged to optimize the utilization of the operating staff by minimizing the number of operators actually required for process and experiment surveillance and control.
2. The design of the instrumentation concept should take into consideration the body dimensions of the staff members who will operate the equipment.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F

Flexibility in the control and data handling instrumentation should be provided to permit changes in response to varying experimental needs throughout the life of the facility. As the facility is operated, the experience gained will no doubt suggest instrumentation changes that would increase the irradiation testing capability and operating continuity. The instrumentation should have those characteristics that permit such changes. The flexibility figure-of-merit, f/m_F , is given by:

$$f/m_F = K_F(N_F^I a + N_F^{II} b + N_F^{III} c + N_F^{IV} d + N_F^V e + N_F^{VI} f),$$

where,

K_F is the scale factor for flexibility;

$N_F^I, \dots, N_F^{VI}$ are the numbers of flexibility characteristics that are placed in the respective performance levels I, $\dots$, VI; and

$a, \dots, f$ are the value point constants.

The requirements used to evaluate the performance of the instrumentation concept to determine the operating continuity figure-of-merit are discussed characteristic by characteristic on the following pages.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Control Technique

Since the facility is conceived as an experimental tool, program needs might well be expected to change in such a way that different control techniques may be necessary. For instance, it may be necessary to change the controlled variable in a feed-back control loop. An experimenter may need to use a control equation that is different from the one used originally. Experience in operating the process and experiment equipment may suggest that more effective and efficient control techniques may be used for improved control performance.

Requirements:

1. The instrumentation concept should lend itself to such variations in the control techniques as changing the variables monitored and the actuators operated for specific functions.
2. The instrumentation concept should permit variations in the control equation to take advantage of experience with the facility as it is operated.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Experiment Control

Since the facility is conceived as an experimental tool, it is desirable to have as much freedom of control for the closed experimental heat removal loop operator as possible. Control freedom permits extensive variation in fuel and materials exposure conditions. It is also desirable to have control freedom for the experimenter to vary coolants and fuel and materials exposure conditions from experiment to experiment. The more flexibility the experimenter has in selecting test conditions, the more valuable the facility is to him as an experimental tool.

Requirements:

1. Provision should be made in the instrumentation concept to permit as much freedom of control for the closed loop operator as possible.
2. Freedom of control for the closed loop operator should not jeopardize the success of the experimental program by interrupting operating continuity.
3. The instrumentation concept should permit broad changes in test conditions from experiment to experiment.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Data Handling

The experimenter may need more or less process and experiment variable information than that provided for during instrumentation development and experiment planning. Different information presentation formats may be desirable to facilitate detailed analysis at an automatic data processing center. Some experimenters may need to have an increase in the number of data points handled as a result of special instrumentation associated with their fuel elements. Changes may occur in data handling needs from experiment to experiment or they may apply to all experiments.

Requirements:

1. The instrumentation concept should lend itself to changes in the process and experiment variables being monitored to permit the experimenter to obtain the actual information needed.
2. The information should be able to be presented in whatever format and in terms of whatever variables are of most interest to each experimenter.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F New Equipment

As the experimental program progresses, and as experience is gained with the operation of the facility, incentives can be expected to become apparent for adding new process and experiment equipment. Flexibility in the control and data handling instrumentation permits such equipment additions to be made without drastically disrupting the operating and experimenting activities that require the use of the instrumentation during the modification.

Requirement:

1. The instrumentation concept should be arranged to permit the addition of new process and experiment equipment without having to deny control and data handling capability to the facility throughout the time required for the modification.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Ease

Flexibility in the instrumentation concept permits changes to be made in response to the needs of the experimenters. Providing flexibility in the instrumentation concept permits the experimenter to modify his experimental program quickly and effectively in response to results and evaluations of testing already completed. The experimenter is thus able to take advantage of technological breakthroughs, such as in the field of fuel development. The ease of making the changes is a factor in determining the extent to which the instrumentation concept can be responsive to experimental requirements.

Requirement:

1. The instrumentation concept should be arranged to permit changes in control techniques and in experiment control and the addition of new equipment fairly easily to be able to be responsive to the needs of the experimenters.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Speed

Flexibility in the instrumentation concept permits changes to be made in response to the needs of the experimenters. Providing flexibility in the instrumentation concept permits the experimenter to modify his experimental program quickly and effectively in response to results and evaluations of testing already completed. The experimenter is thus able to take advantage of technological breakthroughs, such as in the field of fuel development. The speed with which the changes can be made is a factor in determining the extent to which the instrumentation concept can be responsive to experiment requirements.

Requirement:

1. Instrumentation concept changes and equipment additions should be able to be accomplished rapidly to avoid the need for extensive downtime and to be as responsive as possible to the program needs of the experimenter.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Operating Level Changes

Operating level changes may be expected to be necessary in response to process and experiment equipment malfunctions to balance heat generation with heat removal capacity. Operating level changes may be expected to be necessary also in response to changes in the experimental program to provide different fuel element environmental conditions.

Requirement:

1. The instrumentation concept should be arranged to permit changes in the normal operating levels of both the closed loops and the process itself.

FLEXIBILITY FIGURE-OF-MERIT, f/m_F Project Development

Even though facility requirements, both those associated with the process and those associated with the experimental program, are considered thoroughly during the early phases of the project, further definition of the requirements sometimes suggest incentives for change. If the changes can be made without discarding vast portions of the work already complete, necessary changes can usually be made. Since the instrumentation concept must be process and experiment oriented, and since it must be responsive to changes made in the process and experiment systems, a concept that is arranged to accommodate changes during the early phases of the project is desirable.

Requirement:

1. The instrumentation concept should be arranged to accommodate reasonable changes in the process and experiment systems without having to discard vast portions of the instrumentation concept development already complete.

EVALUATION PROCEDURE

This section describes the steps to be taken in systematically applying the figure-of-merit model. The control and data handling instrumentation concepts to be evaluated should have been defined and described as thoroughly as possible. Evaluations early in a project, of course, must be made of concepts that lack complete definition. As the design progresses, more detailed evaluations are possible and may be used for trade-off studies. Although the model was developed to evaluate instrumentation concepts as complete systems, some of the characteristics can be more successfully evaluated by considering the concepts as composed of many smaller subsystems. The approach to be taken depends on the stage of the design and the characteristic being considered. A single evaluation may include both the complete system approach and the subsystem approach. For instance, human factors and data handling can be evaluated more meaningfully using the complete system approach than the smaller subsystems approach, because of the need of the operator to have an overall view of the facility. Control quality can be readily evaluated by considering each feedback control loop separately, except for those characteristics associated with loop interaction. Then, a complete system approach to the evaluation would be more meaningful.

After the instrumentation concepts to be evaluated have been selected and described, the following steps should be performed for each concept to determine the concept figure-of-merit, F/M.

1. Determine the performance of the complete instrumentation concept or a portion of the concept in terms of the first characteristic shown in Table III. Here are some of the questions that could be considered:

Is redundancy used in the design of the safety features?

Is redundancy adequate?

Is the complete safety system redundant or only part of it?

Is the redundancy provided by equipment or information?

2. Compare the performance of the complete instrumentation concept or a portion of the concept with the requirements for redundancy in the section on Safety Figure-of-Merit, f/m_S .
3. Assign that performance to a level according to the performance level definitions in the section on Feature Figure-of-Merit Determination and the comparison made in Step 2 above.
4. Place a check mark in Table III in line with redundancy under the performance level assigned in Step 3.
5. Do Steps 1 through 4 for the other characteristics listed in Table III.
6. Count the number of check marks in each performance level column and place that number in line with TOTAL in the appropriate column. The number placed there in the level I column is N_S^I as shown in the table.
7. Transfer the numbers in line with TOTAL, the N_X^Y values, to the safety figure-of-merit expression.
8. Transfer the N_X^Y values in Step 7 to Table IX, the concept figure-of-merit, F/M .
9. Do Steps 1 through 8 for the other features using Tables IV through VIII as appropriate.
10. Do Steps 1 through 9 for each complete instrumentation concept or portion of a concept under consideration.
11. Assign values to a , $\dots$, f , and compute a numerical concept figure-of-merit.

The instrumentation concepts may now be compared by noticing the numbers of characteristics that fall in the different performance levels. A concept with all check marks in performance

level VI is better than one with all its check marks in performance level V. If the distinction is not that obvious, the comparison may be made using the numerical figures-of-merit computed in Step 11. The concept of greatest worth in terms of performance is the concept with the largest figure-of-merit. Since the selection of an instrumentation concept also includes cost considerations, complete Table X by entering the figure-of-merit and estimated cost for each concept. The concept of greatest worth in terms of both performance and economy is the concept with the largest figure-of-merit and the smallest estimated cost.

If Table X shows that the more desirable concept is too expensive and that the more economical concept is too poor in performance, other concepts can be developed that trade some of the high performance for a lower estimated cost. The new concepts are then evaluated using the figure-of-merit model to prepare a new Table X. From Table X the concept of greatest worth can be selected.

TABLE III. *Safety Figure-of-Merit*

Characteristics	Performance Levels					
	I	II	III	IV	V	VI
Redundancy						
Independence						
Testing						
Self-Checking						
Stability						
Drift						
Fault Recognition						
Fault Isolation						
Power Reduction						
Facility Surveillance						
Operator Attention						
Priority						
<hr/>						
Total	N_S^I	N_S^{II}	N_S^{III}	N_S^{IV}	N_S^V	N_S^{VI}

$$f/m_S = K_S (N_S^I a + N_S^{II} b + N_S^{III} c + N_S^{IV} d + N_S^V e + N_S^{VI} f)$$

$$= \frac{100}{12f} (a + b + c + d + e + f)$$

TABLE IV. *Operating Continuity Figure-of-Merit*

Characteristics	Performance Levels					
	I	II	III	IV	V	VI
Redundancy						
Independence						
Startup						
Closed Loop						
Adjustments						
Power Reduction and Process						
Equipment Bypassing						
On-line Maintenance						
Fault Recognition						
Fault Isolation						
Modular Construction						
Testing						
Maintenance Training						
Maintenance Cost						
Maintenance Scheduling						
<hr/>						
Total	N_{OC}^I	N_{OC}^{II}	N_{OC}^{III}	N_{OC}^{IV}	N_{OC}^V	N_{OC}^{VI}

$$f/m_{OC} = K_{OC} (N_{OC}^I a + N_{OC}^{II} b + N_{OC}^{III} c + N_{OC}^{IV} d + N_{OC}^V e + N_{OC}^{VI} f)$$

$$= \frac{100}{13f} (a + b + c + d + e + f)$$

TABLE V. Data Handling Figure-of-Merit

Characteristics	Performance Level					
	I	II	III	IV	V	VI
Acquisition						
Authenticity						
Reduction						
Storage						
Retrieval						
Proprietary Protection						
Continuity						
	—	—	—	—	—	—
Total	N_{DH}^I	N_{DH}^{II}	N_{DH}^{III}	N_{DH}^{IV}	N_{DH}^V	N_{DH}^{VI}

$$\begin{aligned}
 f/m_{DH} &= K_{DH} (N_{DH}^I a + N_{DH}^{II} b + N_{DH}^{III} c + N_{DH}^{IV} d + N_{DH}^V e + N_{DH}^{VI} f) \\
 &= \frac{100}{7F} (a + b + c + d + e + f)
 \end{aligned}$$

TABLE VI. Control Quality Figure-of-Merit

Characteristics	Performance Levels					
	I	II	III	IV	V	VI
Accuracy						
Speed						
Stability						
Transport Lag Compensation						
Control Variations						
Drift						
Development Testing						
Process and Experimental Equipment Interaction						
<hr/>						
Total	N_{CQ}^I	N_{CQ}^{II}	N_{CQ}^{III}	N_{CQ}^{IV}	N_{CQ}^V	N_{CQ}^{VI}

$$f/m_{CQ} = K_{CQ} (N_{CQ}^I a + N_{CQ}^{II} b + N_{CQ}^{III} c + N_{CQ}^{IV} d + N_{CQ}^V e + N_{CQ}^{VI} f)$$

$$= \frac{100}{8f} (a + b + c + d + e + f)$$

TABLE VII. Human Factors Figure-of-Merit

Characteristics	Performance Levels					
	I	II	III	IV	V	VI
Information Presentation						
Information Communication						
Periodic Checks						
Control Devices						
Control Action						
Training						
Operating Staff						
Total	—	—	—	—	—	—
	N_{HF}^I	N_{HF}^{II}	N_{HF}^{III}	N_{HF}^{IV}	N_{HF}^V	N_{HF}^{VI}

$$f/m_{HF} = K_{HF} (N_{HF}^I a + N_{HF}^{II} b + N_{HF}^{III} c + N_{HF}^{IV} d + N_{HF}^V e + N_{HF}^{VI} f)$$

$$= \frac{100}{7f} (a + b + c + d + e + f)$$

TABLE VIII. *Flexibility Figure-of-Merit*

Characteristics	Performance Levels					
	I	II	III	IV	V	VI
Control Technique						
Experiment Control						
Data Handling						
New Equipment						
Ease						
Speed						
Operating Level Changes						
Project Development						
	—	—	—	—	—	—
Total	N_F^I	N_F^{II}	N_F^{III}	N_F^{IV}	N_F^V	N_F^{VI}

$$f/m_F = K_F \left(N_F^I a + N_F^{II} b + N_F^{III} c + N_F^{IV} d + N_F^V e + N_F^{VI} f \right)$$

$$= \frac{100}{8f} (a + b + c + d + e + f)$$

TABLE IX. *Concept Figure-of-Merit*

$$F/M = W_S f/m_S + W_{OC} f/m_{OC} + W_{DH} f/m_{DH} + W_{CQ} f/m_{CQ} + W_{HF} f/m_{HF} \\ + W_F f/m_F$$

$$= W_S \frac{100}{12f} (a + b + c + d + e + f)$$

$$+ W_{OC} \frac{100}{13f} (a + b + c + d + e + f)$$

$$+ W_{DH} \frac{100}{7f} (a + b + c + d + e + f)$$

$$+ W_{CQ} \frac{100}{8f} (a + b + c + d + e + f)$$

$$+ W_{HF} \frac{100}{7f} (a + b + c + d + e + f)$$

$$+ W_F \frac{100}{8f} (a + b + c + d + e + f)$$

$$= \frac{10^4}{12f} (a + b + c + d + e + f)$$

$$+ \frac{4 \times 10^3}{13f} (a + b + c + d + e + f)$$

$$+ \frac{4 \times 10^3}{7f} (a + b + c + d + e + f)$$

$$+ \frac{3 \times 10^3}{8f} (a + b + c + d + e + f)$$

$$+ \frac{3 \times 10^3}{7f} (a + b + c + d + e + f)$$

$$+ \frac{2 \times 10^3}{8f} (a + b + c + d + e + f)$$

TABLE X. *Concept Figure-of-Merit and Estimated
Cost Comparisons*

Concept	Figure- of-Merit	Estimated Cost

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