



***EXAMINING CONCEPT OF OPERATIONS IN
FUTURE PLANTS***

John M. O'Hara, James Higgins, and William Brown
Brookhaven National Laboratory

Joel Kramer and J. Persensky
U. S. Nuclear Regulatory Commission

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Energy Sciences and Technology Department

Brookhaven National Laboratory

P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

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John M. O'Hara, James Higgins, and William Brown

Brookhaven National Laboratory
Upton, New York USA 11973
ohara@bnl.gov; higgins@bnl.gov; wsbrown@bnl.gov

Joel Kramer and J. Persensky

U.S. Nuclear Regulatory Commission
Washington, DC 20555
jjk1@nrc.gov; jjp2@nrc.gov

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ABSTRACT

This paper will examine the results of this research that focus on future concepts of operations. Our approach was to look at current technological developments in the areas of reactor technology, I&C technology, and human-system integration technology and to make projections into the near and longer-term future concerning their potential impact on human performance. The results were discussed in terms of three aspects of concepts of operations: functional staffing models, plant automation, and training and qualifications. Significant changes to each are anticipated and discussed. Research will be needed to address these changes in order to provide for confidence that changes to concepts of operations are accomplished in ways that maintain public safety.

1. INTRODUCTION

A new commercial nuclear power plant has not been built in the United States in over two decades. However, the US is seeing a renewed interest in nuclear power and is exploring the possibility of constructing new reactors within the next decade (DOE, 2000). Looking longer-term, the US is participating in the international effort to identify and develop the next generation of commercial nuclear power plants as part of the International Generation IV reactor initiative and through the DOE Nuclear Energy Research Initiative (NERI). NERI was established to address and help overcome the principal technical and scientific issues affecting the future use of nuclear energy in the US. In September of 2003, DOE published an implementation strategy for Generation IV reactors (DOE, 2003).

The vision for future plant designs includes ambitious goals of improved economic competitiveness, reliability, and safety (DOE, 2003). The realization of these goals will require designers to take full advantage of the emerging advances in reactor technology, instrumentation and control (I&C) technology, e.g., smart sensing, automated monitoring and diagnostic systems, and the computation and simulation capabilities.

In turn, these technologies are likely to drive significant changes in the plant concept of operations, including the relative roles of human and system resources in plant

monitoring and control, the design of HSI, and the tools provided for personnel to plan, interact with each other, and accomplish their tasks.

In order to assure that a technical basis exists to support reviews of near-term Generation III+ designs and longer-term Generation IV designs, the US Nuclear Regulatory Commission (NRC) is conducting research to identify human performance and I&C issues and address them as needed. One such area is the concept of operations.

This paper will examine the results of this research that focus on future concepts of operations. A full report of the research can be found elsewhere (O'Hara et al., 2004).

2. APPROACH

When one looks to the present, there are only a few advanced reactors in operation (none in the US) and their operating experience is limited and generally not available in the general literature. For reactor designs that have yet to be built, information concerning their concept of operations or the design of their control rooms is limited at best (for reactors of near-term deployment) and non-existent at worse (for reactor concepts of longer-term deployment, i.e., Generation IV designs.)

Thus our approach to examining concept of operations was to look at current technological developments and to make projections into the near and longer-term future. Three different, yet related, perspectives were examined for their potential impact of human performance: reactor technology, I&C technology, and human-system integration technology. A variety of different sources of data were used, including: literature, contacts with relevant organizations, industry workshops, and site visits conducted by project personnel.

3. CONCEPT OF OPERATIONS

NUREG-0711 (NRC, 2004) defines a concept of operations with respect to:

- the relationship between personnel and plant automation including the responsibilities of the crew for monitoring, interacting, and overriding automatic systems
- anticipated staffing levels
- how personnel interact with HSI resources such as the distribution of HSIs between the main control room and local control stations, configuration of personnel workplaces such as working at a single large workstation or individual workstations, the types of information to which each crewmember will individually have access, and the types of information that should be displayed to the entire crew
- coordination of crew member activities, such as the interaction with auxiliary operators and coordination of maintenance and operations

With respect of future plants, especially Generation IV concepts, some of this more detailed information is not available. However, we can begin to anticipate future operations along three dimensions: functional staffing models, plant automation, and training and qualifications. Each will be discussed below.

3.1 Functional Staffing Models

Current plants have a large number of on-site personnel organized into functional groups including operations, maintenance, engineering, administration, and security. From an operations perspective, a plant is controlled by a crew including numerous individuals both in the control room and out in the plant. Shift staffing and training of plant personnel is a very costly aspect of plant operations and will certainly be one area new designs will address.

Thus we can expect that Generation IV reactor technology will be fundamentally different than the current fleet of LWRs and will require new visions of how to operate and staff the plant. The identification of these visions should be technologically based and treated as an integral aspect of design. Once identified, the evolutionary path to achieving the selected operational model should be identified.

Since it is premature to consider actual plant staffing in advanced designs, we will use the term "functional staffing model" to indicate different general approaches to achieving general functions personnel perform, such as operations, troubleshooting, maintenance, emergency planning, etc. To illustrate the diversity of possibilities, some candidate models include:

- onsite, multiperson crew for one reactor that handle all plant functions, although it may require augmentation for some functions (current operational model)
- onsite, multiperson crew for multiple reactors (similar to the current operational model except now the crew performs its functions across more than one reactor)
- onsite, reduced staff with a single individual for one reactor
- onsite, reduced staff with a single individual for multiple reactors
- decentralized functional groups (see example below)
- fully remote operations (no personnel onsite).

Once identified, the selected model should become a design driver for many other aspects of design, such as levels of automation, staffing and qualifications, HSI design, personnel training, etc. To use one example, consider a decentralized functional groups model. The plant (consisting of multiple reactor modules) will be staffed with a very small number of onsite personnel. Unlike today's operational environment, the on-site crew is largely made up of technicians who oversee the highly automated operation and occasionally perform a minor operations or maintenance task. This crew has reduced training. Responsibly for all but normal operations are handled by off-site specialists who either come to the plant when needed (for maintenance, for example) or perform their tasks remotely. For example, a very highly qualified crisis team will assume control (possible from a remote location) when a disturbance occurs. Due to the low probability of such an accident, this team is available for many reactor sites. This model will support Generation IV economic goals because of the greatly reduced staffing and training burdens. It will also support safety goals because this highly trained team would be responsible for nothing but handling crises, thus their level of expertise and ability to use analysis tools would be superior to what could be attained when a single crew is responsible for everything (today's model).

This is only an example, and operational models will have to be identified, tested, and designed into the Generation IV plant. Research is needed to define and evaluate alternative models using modeling techniques and simulation facilities. The research should not only define the endpoint vision for Generation IV plants, but also the evolutionary strategy to get there.

Tools and techniques will be needed to perform analyses that can evaluate staffing models. Such analytical approaches for evaluating staffing requirements for complex systems have been evolving over the past few years. Human behavioral modeling techniques, such as task network modeling and discrete event simulation, have been developed and tested by the U.S. Army and Navy, and some of these techniques have been accredited by the U.S. Department of Defense for use in HFE analyses during system design and engineering. These human behavioral modeling techniques and tools need to be developed or adapted to determine staffing for advanced reactors. The use of such analytical models could enhance the efficiency and effectiveness of the advanced plants while promoting safe operations.

3.2 Plant Automation

A proper mix of human and automatic systems is needed to maximize overall human-system efficiency, reliability, and safety for the selected models of operations. In older plants, the allocation of functions to human and automatic systems was fairly straightforward: they were either automated (i.e., controlled automatically) or manually performed by plant personnel. However, as computers have become more involved in process control, the nature of automation has changed. We will focus on two such changes here: varying degrees of automation and automation beyond controls.

Varying Degrees of Automation

With modern computer and control technology automation is no longer "all or none." That is, a process function does not have to be either automatic or manual. It can be both. In part to minimize the potentially negative effects of automation on human performance (such as loss of situation awareness and complacency) and to provide for a more intelligent application of automation, there can be greater integration of human and automatic processes in the same control activity. This takes several forms. For example, control of a process can be shared. A process sequence is broken up into discrete chunks and the chunks are automated. However, transition from one chunk to the next requires human intervention. Advanced Boiling Water Reactor (ABWR) startup is an example of this type of approach. A similar application is when a control sequence can be partially automated, but human intervention is needed to provide information not available to the automatic controller.

Another type of automation is dynamic allocation. In this case, a function can be performed by either automatic systems or by humans. The decision as to who controls the function is made dynamically based on situational considerations, such as the overall workload of personnel.

Automation Beyond Controls

Historically “automation” has meant automating a control function or process. However, computer-based systems offer the opportunity to provide "intelligence" in the HSIs themselves to "automate" cognitive activities typically performed as part of the decision-making by plant personnel. Thus, we need to think more broadly about the concept of automation.

In this context, the term "agents" is often used to generically refer to who/what is performing an activity; i.e., agents are entities that do things. Figure 1 illustrates the generic activities an agent must perform so that functions can be achieved. The agent must monitor the plant to detect conditions indicating that a function has to be performed. The agent must assess the situation and plan a response. Once the response plan is established, it has to be implemented by sending control signals to actuators. The agent must also monitor the function via the monitoring activity to determine that the function is being accomplished and to replan if it is not. Finally the agent must decide when the function has been satisfactorily achieved. Human or machine agents can perform any one or all of these activities.

An "alarm system," for example, is an *automated monitoring and detection* system that alerts operators via visual and/or auditory displays when parameters deviate from specified limits or setpoints. However, as more and more functionality is given to HSIs, they evolve toward automatic systems. For example, the only difference between a typical computer-based procedure and an automatic process system is the control. The procedure can monitor, assess, and plan a response (essentially a paper procedure is a response plan strategy). Most computer based procedures (CBP) stop at that. If a CBP is also given the means to initiate control signals, it becomes an automatic system.

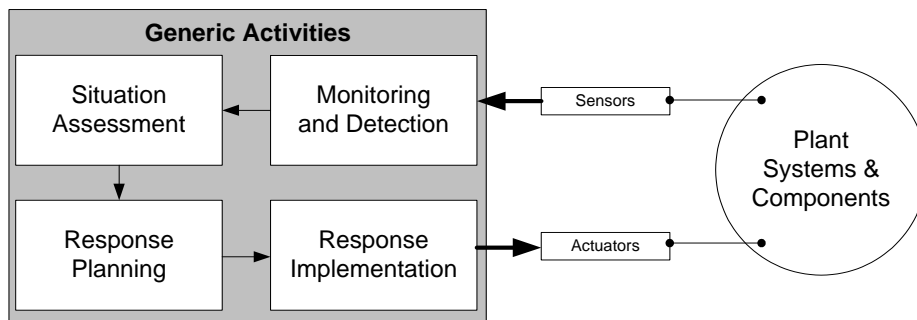


Fig. 1 Generic activities performed by agents

When all of these activities are completely accomplished by plant personnel, the function is said to be "manual." When all of these activities are completely accomplished by machine agents, the function is said to be "automated." When both human and machine agents are involved, the function is "shared."

Research will be needed to develop a technical basis for allocating functions to system or human resources. The research elements include:

- establishing the relationship between level of automation required by functional staffing concepts

- determining the level of information required to keep operator informed of automation status
- developing methods to minimize the negative effects of automation on personnel, such as operators loss of situation awareness, loss of vigilance, and skills degradation
- developing strategies for transitioning from automatic to manual control

3.3 Training and Qualifications

The new staffing models and the commensurate changes in automation will have to be supported by changes to training and qualifications. Research is needed to define the training and qualification requirements for plant personnel based on the functional staffing models selected. Qualifications include training, education, and experience. The knowledge and abilities required of different staffing functions need to be defined.

Training philosophies and approaches themselves are likely to change based on technological developments. Developments such as the use of distributed training, embedded training, and virtual reality may alter the way plant personnel develop and maintain their knowledge and skills.

4. CONCLUSIONS

Visions for the concept of operations of Generation IV plant designs have to be identified and analyzed as a technological part of the system in support of overall Generation IV design goals. These visions become design drivers for the development of automation, HSI design, and other human factors aspects of the plant. They become significant design inputs to other plant systems as well, such as I&C systems, which will have to provide sufficient instrumentation, computing, and control to achieve new concepts of operations.

In addition to the Generation IV vision, an evolutionary migration strategy to achieving the vision should be established to provide proof of concepts and to develop public support. In support of both of these endeavors, a regulatory approach to accommodating these changes has to be in place to maintain public safety.

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