

# Development of a New Methodology for Function Allocation in Small Modular Reactors

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## 1. Introduction

A distinct characteristic of Small Modular Reactors (SMRs) is that multiple modules are operated from a single centralized control room. Their design emphasizes advanced automation, passive safety systems, and inherent safety features, which reduce operators' direct manual actions while increasing monitoring and supervisory responsibilities compared with conventional large nuclear power plants (NPPs). Consequently, operator roles, staffing plan, and the concept of operations (ConOps), including the management of various plant conditions, differ significantly from those of large plants [1].

The deployment of SMRs requires regulatory approval throughout the design, construction, and operational stages, supported by human factors engineering (HFE) programs that include functional requirements analysis (FRA) and function allocation (FA). FRA identifies the functions necessary to achieve overall plant objectives, while FA determines whether these functions are performed by humans, automation, or a combination of both [2].

Conventional FA approaches, however, face some challenges when applied to SMRs, including limited consideration of passive and inherent safety features, difficulties in identifying operator's monitoring and backup roles, and limited attention to operator support systems. To address these issues, this study proposes an FA methodology based on the allocation process described in NUREG/CR-3331 [3] and introduces a worksheet to systematically document the results.

## 2. Literature Survey

In this section, several FA methodologies are reviewed, and their challenges associated with applying them to SMRs licensing processes are discussed.

### 2.1 FA Methodologies

Fitts et al. proposed an approach that distinguishes the comparative advantages of humans and machines, as outlined in Table 1 [4]. This methodology facilitates allocation decisions by assessing the relative suitability of each agent for performing specific functions. Early discussions of FA are largely based on the Fitts list or related follow-up research.

Table I: Fitts' List

Humans appear to surpass present-day machines in respect to the following	Present-day machines appear to surpass humans in respect to the following
Ability to detect small amount of visual or acoustic energy	Ability to respond quickly to control signals, and to apply great force smoothly and precisely
Ability to perceive patterns of light or sound	Ability to perform repetitive, routine tasks
Ability to improvise and use flexible procedures	Ability to store information briefly and then to erase it completely
Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time	Ability to reason deductively, including computational ability
Ability to reason inductively	Ability to handle highly complex operations, e.g., to do many different things at once
Ability to exercise judgement	

NUREG/CR-3331 introduces an allocation decision matrix, illustrated in Fig. 1, to support FA decision-making. The approach conceptually represents FA by evaluating the comparative performance capabilities of humans and machines.

The matrix is divided into six regions according to performance capabilities, where "U" denotes unacceptable, "P" preferred, "a" automation, and "h" human. For example, functions classified within the  $U_h$  region are assigned to automation because of the very limited performance capability of humans. Functions falling within this region should be reevaluated for potential redesign and incorporated only as a last resort, even when already reflected in the system design. [3,5].

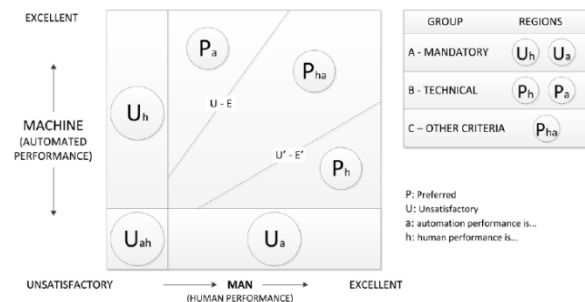


Fig. 1. Allocation decision matrix from NUREG/CR-3331

2.2 Challenges in Existing Methodologies

The distinctive features of SMRs expose limitations in existing FA methodologies. Accordingly, a new ConOps has been developed to reflect higher level of automation and expanded use of passive and inherent safety systems. Because agent interactions in SMRs are more complex than in conventional large NPPs, clearer role definition is necessary. Under this framework, clearer delineation of roles and responsibilities among agents is required, given the more complex interactions in SMRs compared to conventional large NPPs.

Current FA approaches have difficulty in accommodating passive and inherent safety functions, as they traditionally allocate functions only to humans or automation. However, SMRs assign safety functions to additional agents, necessitating an FA methodology capable of reflecting these expanded allocations.

Moreover, conventional FA methodologies do not clearly identify human roles related to the monitoring and backup of automation. With higher level of automation in SMRs, direct manual actions decrease while oversight and contingency roles become more critical. Therefore, FA for SMRs should explicitly account for monitoring and backup functions so that the roles then can be analyzed through task analysis (TA) and reflected in subsequent HFE processes.

3. Methods and Results

In this study, to address the challenges outlined in Section 2.2, a new FA methodology for SMRs is proposed. The approach is based on NUREC/CR-3331 [3] and includes the development of a worksheet to organize allocation outcomes.

3.1 Proposed FA Methodology for SMRs

The proposed methodology comprises two stages. In the first stage, functions identified through FRA are initially allocated to human, automation, passive systems, or inherent safety characteristics based on a set of evaluation questions. In the second stage, this preliminary allocation is refined to determine the final assignment and to define the detailed roles of each agent.

Fig. 2 illustrates the stage 1 procedure for establishing the initial allocation. In the figure, labels A through D denote allocation to inherent safety characteristics, automation, passive system, and human, respectively. These designations represent stage 1 outcomes and provide the linkage to stage 2. Stage 1 consists of 13 steps as shown in Table II that support the preliminary allocation decision. Steps 1, 2, 6, and 13 are added or modified from the methodology described in NUREG/CR-3331.

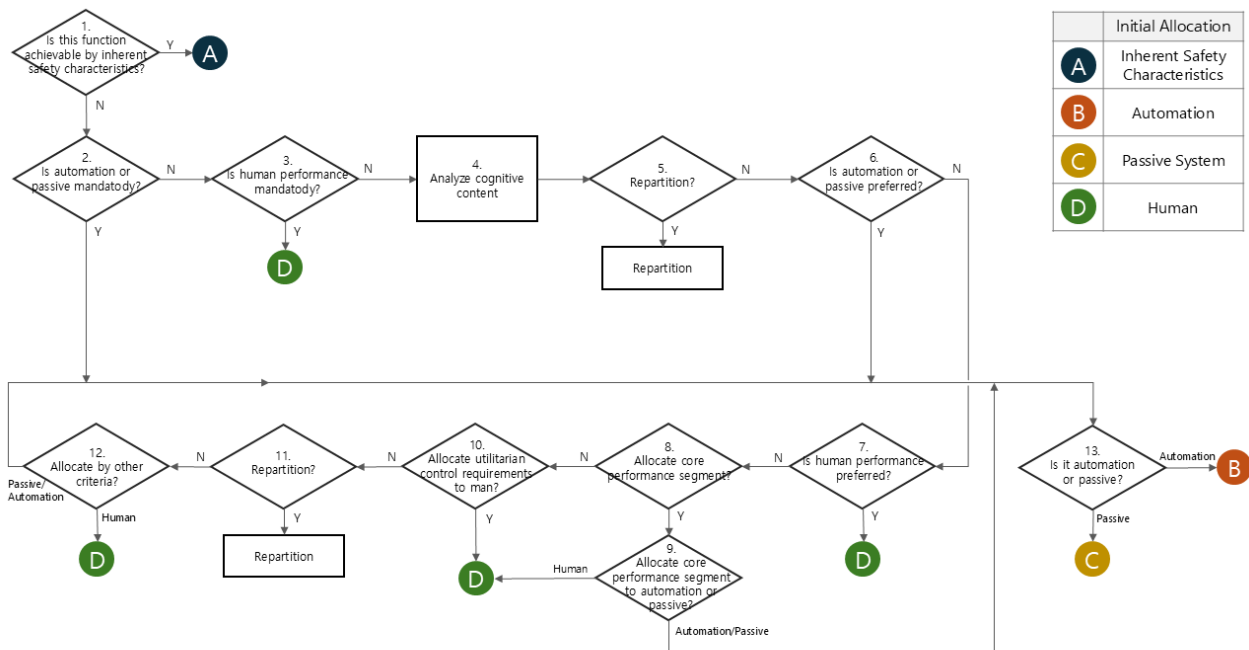


Fig. 2. Function allocation methodology – stage 1

Table II: Steps in Stage 1

Step	Description
1	Is this function achievable by inherent safety characteristics? (This step is to determine if the function can be accomplished by inherent safety characteristics. If yes, the function is further reviewed whether human role is required or not in stage 2.)
2	Is automation or passive mandatory? (This step identifies whether automation or passive is mandatory to accomplish the function.)
3	Is human performance mandatory?
4	Analyze cognitive content
5	Repartition?
6	Is automation or passive preferred? (If the function does not satisfy any steps 1 through 5, preference is then reviewed. This step determines if all included tasks are preferred to be performed by automation or passive system)
7	Is human performance preferred?
8	Allocate core performance segment?
9	Allocate core performance segment to automation or passive?
10	Allocate utilitarian control requirements to man?
11	Repartition?
12	Allocate by other criteria?
13	Is it automation or passive? (This step examines whether the function is to be performed by automation or by a passive system.)

Fig. 3 illustrates the decision procedures involved in stage 2. The initial allocation established in stage 1 feeds into the corresponding parallel pathways of stage 2. Designers perform a series of steps to assess the technical feasibility of the preliminary allocation and to define the detailed roles of each agent. Stage 2 mainly

consists of five steps. The questions related to technical feasibility and processes for specifying residual role of men and auto support are largely consistent with NUREG/CR-3331. However, the proposed methodology further refines and elaborates on the existing approach. Each of the five steps are described below.

- Verification of technical feasibility  
This step examines the technical feasibility of the initially allocated agent. If it is not feasible, the function must be repartitioned, redefined, or assigned a new engineering solution.
- Specification of roles of the responsible agent (Gray boxes)  
If the agent is technically feasible, in this step, the roles of the agent are specified.
- Specification of residual roles of human and type of human role (Yellow boxes)  
This step specifies residual roles of human and identifies type of each human role: primary, monitoring, and backup. Primary refers to essential functions that required to be performed to accomplish the function. Monitoring represents monitoring performance of automation and passive systems, as well as status parameters. Backup indicates actions taken by human if other agents are not functioning as designed.
- Specification of residual roles of automated support (Blue boxes)  
This step specifies residual automated support to assist human performance. Types of automated support are also classified into primary role support, monitoring role support, backup role support

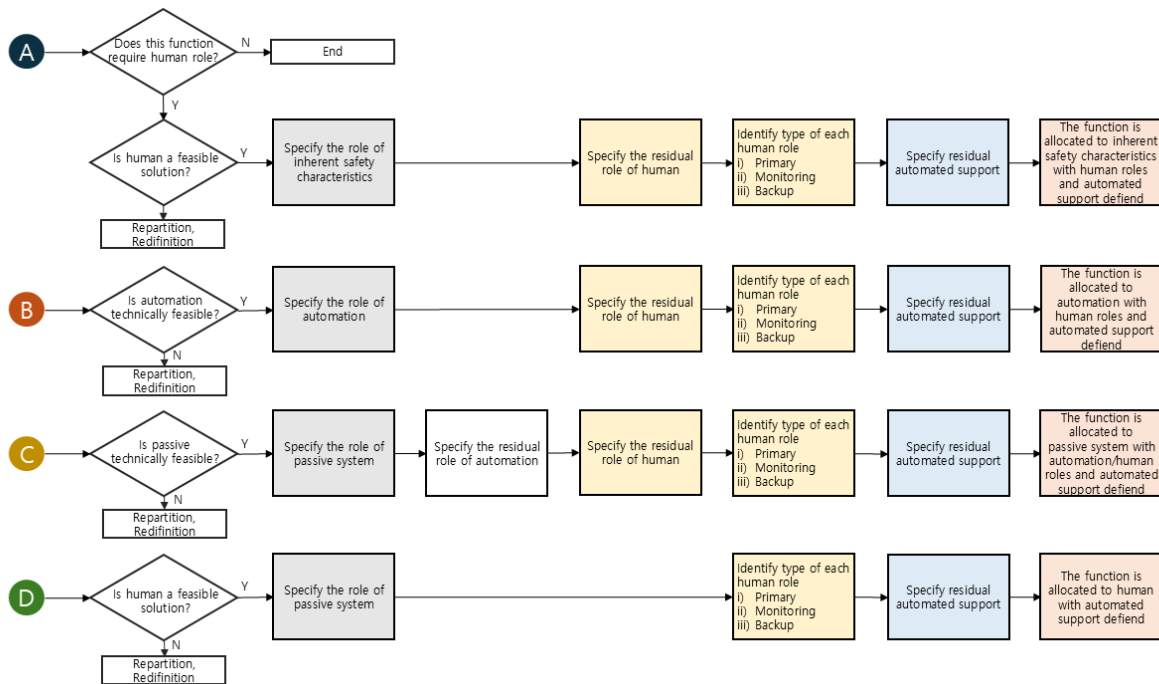


Fig. 3. Function allocation methodology – stage 2

- Final allocation decision with residual roles of other agents (Pink boxes)  
Final function allocation decisions are made by specifying each agent's roles, as well as the associated automated support.

### 3.2 Proposed FA Worksheet

The documentation of allocation results enables a structured representation of allocation decisions. This study proposes an FA worksheet developed based on NUREG/CR-3331, designed to capture all results generated through the proposed FA methodology. The developed worksheet is presented in Table III.

Table III: FA Worksheet

1. Function	
2. Subsystem	
3. Plant State	
4. Basis	
5. Level of Automation	
6. Control Requirement	7. Automation / Passive System / Inherent Safety Characteristics Role
8. Operator Role	9. Automated Support Role
(i) Primary Role	(i) Primary Role Support
(ii) Monitoring Role	(ii) Monitoring Role Support
(iii) Backup Role	(iii) Backup Role Support

The worksheet consists of nine parts described as follows:

- Function*: functions identified from FRA
- Subsystem*: systems and components related to the function accomplishment
- Plant State*: plant states that the function is applied
- Basis*: the allocation-determined path from FA methodology
- Level of Automation*: level of automation derived from FA
- Control Requirement*: conditions required to satisfy the function
- Automation / Passive System / Inherent Safety Characteristics Role*: Roles assigned to automation, passive system, or inherent safety characteristics
- Operator Role*: roles assigned to operators, categorized by primary, monitoring, and backup
- Automated Support Role*: roles of automated support to assist operator's role

## 4. Discussion and Conclusion

Previous studies on function allocation (FA) methodologies have primarily focused on assigning control functions to either humans or automation, which restricts the consideration of passive systems and inherent safety features as allocation agents. Moreover, in small modular reactors (SMRs), operators' supervisory responsibilities, such as overseeing automation performance and providing backup, are becoming increasingly important. However, existing FA methodologies show limitations in clearly defining and describing these roles.

This study proposes an FA methodology that classifies agents into four categories (human, automation, passive systems, and inherent safety characteristics), enabling the clear differentiation of functions from the FA stage in SMRs, where interactions among agents are more complex than large NPPs. In addition, by distinguishing human roles, such as monitoring and backup, in highly automated environments at the FA stage, detailed operator's tasks can be identified through subsequent tasks analysis (TA). These outcomes can then be incorporated into later human factors engineering (HFE) processes, including staffing plan, procedures and training development, and human-system interface (HSI) design. Furthermore, it specifies the roles of operator support systems under different situations associated with each type of human role. A worksheet is provided to clearly summarize and organize the allocation results.

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