doi.org/10.15392/2319-0612.2024.2691
2024, 12(4B) | 01-21 | e2691
Submitted: 2024-08-30
Accepted: 2024-12-23

A Study on Application of SPAR-H Method for Human Reliability Analysis of an Electric-electronic System of a Mechanism for Moving a Nuclear Fuel Irradiation Capsule

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Abstract: The "Centro de Desenvolvimento da Tecnologia Nuclear" (CDTN) is developing the prototype of a computer-controlled mechanism for moving a nuclear fuel irradiation capsule, called "Dispositivo de Movimentação da Cápsula" (DMC). This mechanism will be installed in the "Reator Multipropósito Brasileiro" (RMB), which is a Brazilian research reactor currently under construction, and will be used to carry out fuel qualification tests, such as power ramp tests. In addition to the engineering design of the mechanical system, CDTN is also developing the engineering design of the DMC electric-electronic system including a control and data acquisition software. In the context of nuclear facilities, human factors play an important role in safety and reliability assessments. Many techniques are suitable for modeling and analyzing human reliability and, among these, can be highlighted "Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H)". In this work, the applicability of this technique to predict human error probabilities (HEPs) is illustrated as an example of a quantitative study to improve the safety and reliability of the DMC electric-electronic system through acting on human factors issues.

Keywords: human reliability assessment, electric-electronic system, capsule movement device, nuclear fuel qualification.

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Estudo da Aplicação do Método de Análise de Confiabilidade Humana SPAR-H em um Sistema Eletroeletrônico de um Mecanismo para Movimentação de uma Cápsula de Irradiação de Combustíveis Nucleares

Resumo: O Centro de Desenvolvimento da Tecnologia Nuclear (CDTN) está desenvolvendo o protótipo de um mecanismo controlado por computador para a movimentação de uma cápsula de irradiação de combustíveis nucleares, chamado de Dispositivo de Movimentação da Cápsula (DMC). Esse dispositivo será instalado no Reator Multipropósito Brasileiro (RMB), que atualmente está em construção, e será utilizado na realização de testes para qualificação de combustíveis nucleares, como os testes de rampa de potência. Além do projeto de engenharia do sistema mecânico, o CDTN também está desenvolvendo o projeto de engenharia do sistema eletroeletrônico do DMC, incluindo um software de controle e aquisição de dados. No contexto das instalações nucleares, os fatores humanos desempenham um papel importante nas avaliações de segurança e confiabilidade. Muitas técnicas são utilizadas para modelar e analisar a confiabilidade humana e, dentre elas, pode-se destacar a técnica "Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H)". Neste trabalho, a aplicabilidade desta técnica para predizer as probabilidades de erro humano (HEPs) é ilustrada em um exemplo de um estudo quantitativo objetivando melhorar a segurança e a confiabilidade do sistema eletroeletrônico DMC por meio da atuação em questões relacionadas a fatores humanos.

Palavras-chave: análise de confiabilidade humana, sistema eletroeletrônico, dispositivo de movimentação de cápsula, qualificação de combustível nuclear.

1. INTRODUCTION

Nuclear research reactors are important scientific experimental tools for the nuclear area. They are used in basic and technological research in several areas, mainly nuclear physics, materials science, power generation and nuclear medicine [1]. According to the International Atomic Energy Agency (IAEA), there are currently 226 research reactors in operation in 54 countries in the world [2]. Brazil has four research reactors in operation and one research reactor under construction, called "Reator Multipropósito Brasileiro" (RMB). The RMB will be an open pool-type reactor with a maximum power of 30 MW and will use low enriched uranium fuel [3, 4]. One of the relevant purposes of the RMB is the development of nuclear fuel elements for national reactors. Nuclear fuels must be experimentally tested and qualified in research reactors using experimental facilities known as irradiation circuits, which consist of an irradiation capsule and operational and instrumentation systems [5, 6].

Centro de Desenvolvimento da Tecnologia Nuclear (CDTN) is carrying out the technological development of a mechanism for moving an irradiation capsule inside the RMB core, called "Dispositivo de Movimentação da Cápsula" (DMC). This mechanism will be used to carry out in pile tests known as "power ramp tests" that assess fuel performance during anticipated power changes. The main purpose of such tests is to establish operational limits for fuel safe use specifying the "technological limit" which, if not exceeded, will guarantee fuel cladding leak tightness [7, 8]. DMC will perform precise and cyclical approaching and moving away movements between the irradiation capsule and the reactor core. These movements make it possible to vary the intensity of neutrons flux, which irradiates the fuel. This position variation exposes the fuel to a higher or lower flux of neutrons causing a greater or lesser fuel burnup. Neutronic and thermohydraulic calculations are being performed to ensure that test conditions and safety requirements are met [9]. In addition to engineering design of the mechanical system, CDTN is also developing the engineering design of the DMC electric-electronic system. A control and data acquisition software developed in LabVIEW® programming language is part of this system [10].

In the context of nuclear facilities, human factors play an important role in safety and reliability assessments. Human reliability can be defined as the probability that some set of human actions is performed successfully under the specified condition in a specified time or opportunity [11]. Many techniques are suitable for modeling and analyzing human reliability [12, 13]. Among these can be highlighted "Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H)" that was developed by the Idaho National Laboratory in collaboration with the U.S. Nuclear Regulatory Commission (USNRC) [14].

In this work, the applicability of this technique to predict Human Error Probabilities (HEPs) is illustrated as an example of a quantitative study to improve the safety and reliability of the DMC electric-electronic system through acting on human factors issues.

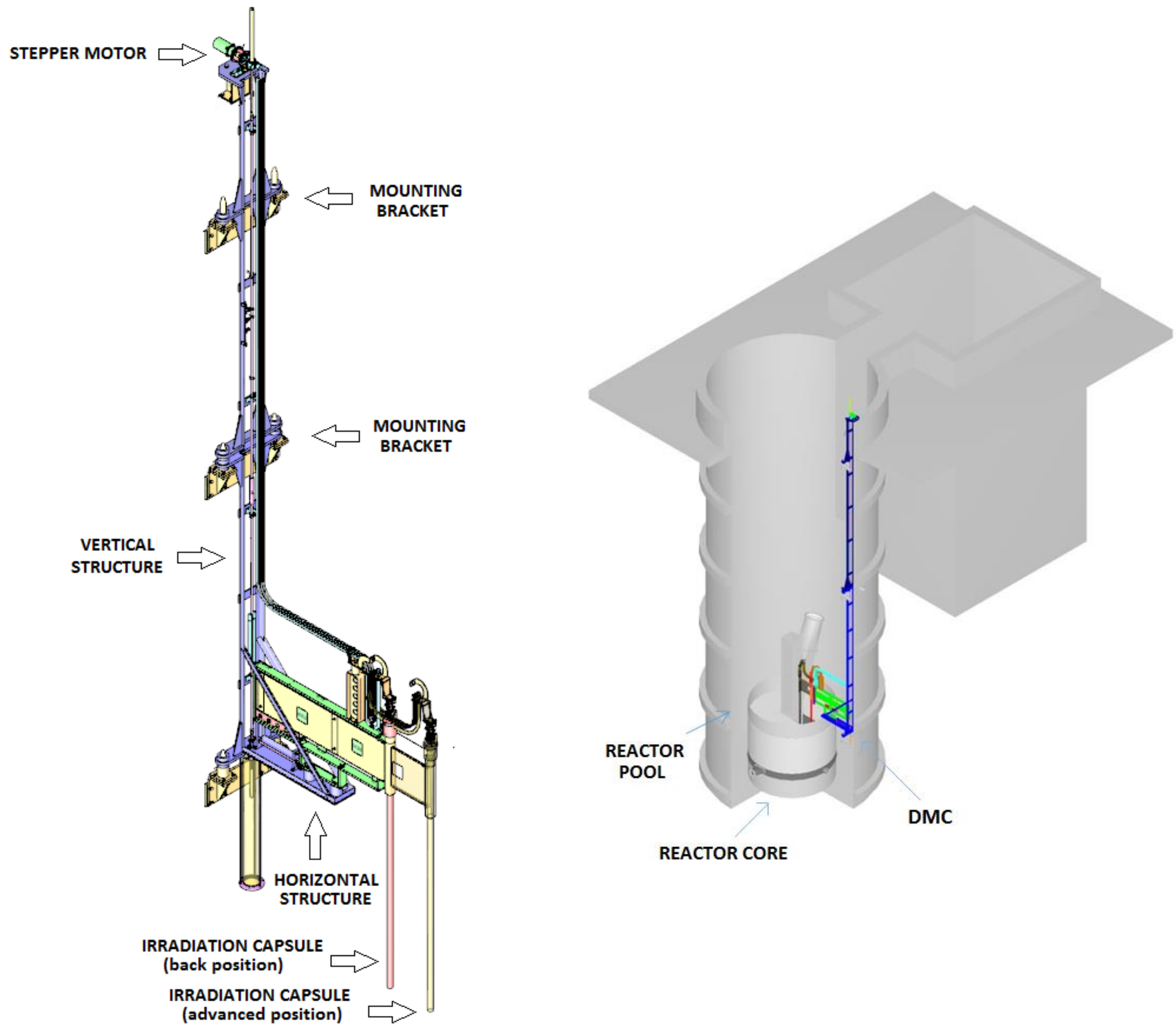
2. METHODOLOGY

2.1. DMC: The mechanism for moving an irradiation capsule inside RMB core

DMC is a systematic arrangement of mechanical, electric and electronic components whose purpose is to perform the precise and controlled movement of a nuclear fuel irradiation capsule inside the RMB research reactor core. The components are organized into two systems – the Mechanical System and the Electric-electronic System. Figure 1 shows the DMC Mechanical System and the planned installation position for it within the RMB.

In the Mechanical System, a rigid metallic structure, with an "L" shaped profile, is the basis for assembling the DMC's fixed and mobile components – stepper motor, gear motor, electromagnetic clutch, bevel gears, rack and pinion pairs, prismatic guides, bearings, fixing shafts, supports and a main drive shaft, among others components. These components form a movement transmission mechanism that is driven by the stepper motor, which results in the movements of the irradiation capsule.

Figure 1: DMC. (a) Some of the main components of the Mechanical System. (b) Planned installation position for the DMC Mechanical System within the RMB.

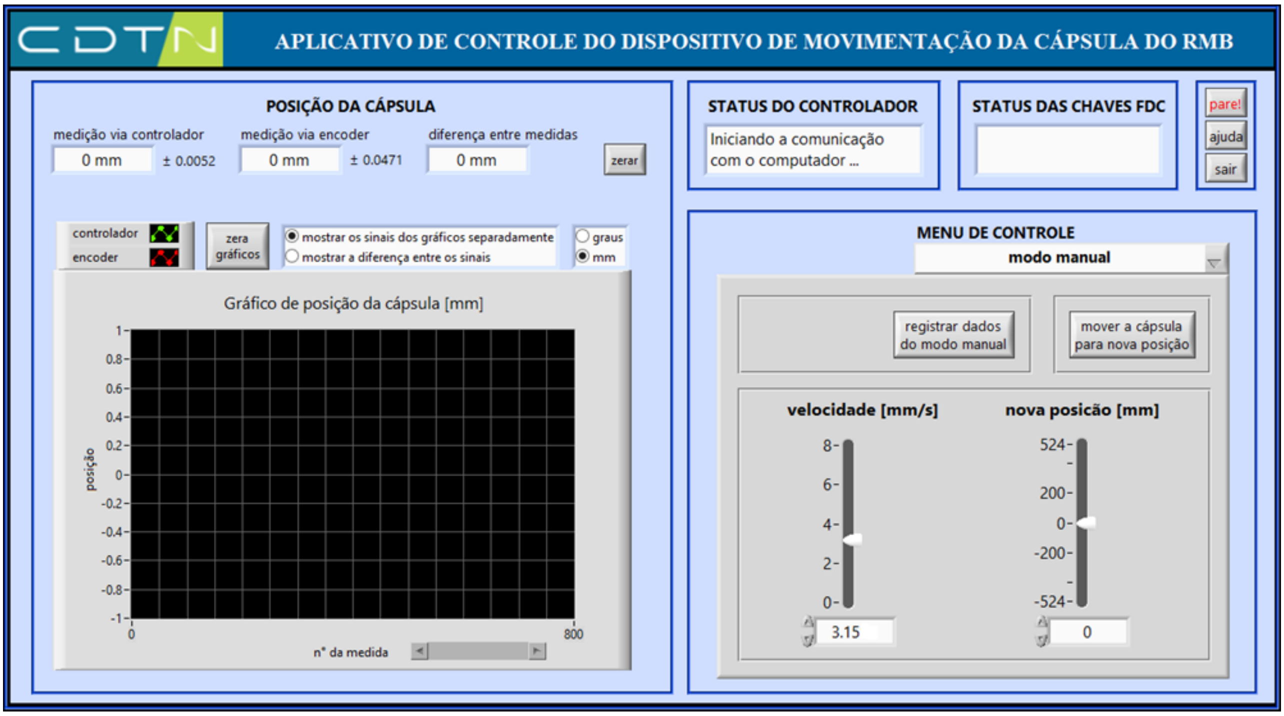


(a) (b)

Source: Edson Ribeiro (CDTN).

In addition to the mechanical components, the DMC also has electric and electronic components that form a set of hardware and software system called the DMC Electric-Electronic System. This system is responsible for carrying out the control, data acquisition and protection tasks of the DMC. The software, whose tag name is “APLICATIVO DE CONTROLE DO DISPOSITIVO DE MOVIMENTAÇÃO DA CÁPSULA DO DMC”, was developed in the LabVIEW® programming language [10]. The software has two parts: a front panel, which is usually the user interface, and a block diagram panel, which contains the program's source code. On the front panel are positioned virtual graphic components that represent panel meters, graphic recorders, lamps, switches, selector buttons and other electric-electronic components commonly used in electrical panels. Each front panel element is associated with one or more block diagram components that are linked to define the data flow. Figure 2 shows the main user interface of DMC Control and Data Acquisition Software.

Figure 2: Main graphical interface of DMC Control and Data Acquisition Software.



Source: Authors.

The main functions performed by the DMC Control and Acquisition Software are:

● Remote configuration and programming of the stepper motor controller to run the irradiation capsule movements defined by the power ramp tests.

● Monitoring and data logging of system parameters: irradiation capsule position and status of operating and safety instrumentation parameters.

● Remote actuation of the protection system responsible for preventing capsule movements that could cause incidents.

2.2. The SPAR-H Method

Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) is a technique used in Human Reliability Analysis (HRA) for human failure events quantification. Initially developed for the nuclear industry, SPAR-H is also used in many other industry areas like pharmaceutical, petroleum (gas and oil), transportation (air, maritime and rail), among others industries [15, 16, 17].

The basic SPAR-H framework is the following [14, 18]:

● SPAR-H categorizes tasks into two main groups – action tasks and diagnostic tasks. Action tasks include operating equipment, performing line-ups, starting pumps, conducting calibration or testing and other activities performed during the course of following plant procedures or work orders. Diagnostic tasks consist of reliance on knowledge and experience to understand existing conditions, planning and prioritizing activities and determining appropriate courses of action.

● Assigns a baseline human error probability, called Nominal Human Error Probability (NHEP), for each type of task based on general human performance data. NHEP takes a value of 0.01 for diagnostic tasks and 0.001 for action tasks [14].

● Make use of Performance Shaping Factors (PSFs) - environmental, personal, or task-oriented factors that influence the probability of human error. The eight PSFs used in the SPAR-H technique are [14]:

(1) Available time: Refers to the amount of time that an operator or a crew has to diagnose and act upon an abnormal event.

(2) Stress and stressors: Refers to the level of undesirable conditions and circumstances that impede the operator from easily completing a task. Stress can include mental stress, excessive workload, or physical stress (such as that imposed by difficult environmental factors).

(3) Complexity: Refers to how difficult the task is to perform in the given context. Complexity considers both the task and the environment in which it is to be performed. The more difficult the task is to perform, the greater the chance for human error. Similarly, the more ambiguous the task is, the greater the chance for human error.

(4) Experience and training: Refers to the experience and training of the operator(s) involved in the task. Included in this consideration are years of experience of the individual or crew, and whether or not the operator/crew has been trained on the type of accident, the amount of time passed since training, and the systems involved in the task and scenario. Another consideration is whether the scenario is novel or unique (i.e., whether or not the crew or individual has been involved in a similar scenario, in either a training or an operational setting).

(5) Procedures: Refers to the existence and use of formal operating procedures for the tasks under consideration. Common problems seen in event investigations for procedures include situations where procedures give wrong or inadequate information regarding a particular control sequence. Other common problems are the ambiguous or missing steps.

(6) Ergonomics/HMI: Refers to the equipment, displays and controls, layout, quality and quantity of information available from instrumentation, and the interaction of the operator/crew with the equipment to carry out tasks. Aspects of human machine interaction (HMI) are included in this category. Software usability is also included in this PSF.

(7) Fitness for duty: Refers to whether or not the individual performing the task is physically and mentally fit to perform the task at the available time. Things that may affect fitness include fatigue, sickness, drug use (legal or illegal), overconfidence, personal problems, and distractions. Fitness for duty includes factors associated with individuals, but not related to training, experience, or stress.

(8) Work process: Refer to aspects of doing work, including inter-organizational, safety culture, work planning, communication, and management support and policies. How work is planned, communicated, and executed can affect individual and crew performance.

PSFs have different levels and, for each level, there is an associated multiplier. Table 1, based on NUREG/CR 6883 [14], shows the PSF multipliers for diagnostic tasks (DM) and for action tasks (AM). PSF levels are used to adjust the nominal human error probability (NHEP) for a task, with multipliers applied to reflect the impact of the factor. PSFs multipliers lesser than one have a positive effect as multiplying NHEP by this fractional value leads to a decrease in the resulting human error probability. PSFs multipliers greater than one have a negative effect as multiplying NHEP by this value leads to an increase in the resulting human error probability. For example, in a situation with barely adequate time to perform a diagnostic task, the PSF multiplier Available Time might increase the human error probability by a factor of 10, while high experience and training might decrease it by a factor of 0.5.

Table 1: The PSF multipliers for diagnostic tasks (DM) and action tasks (AM).

PSFs	PSF Levels	Description	DM	AM
Available Time	Inadequate time	Problem not diagnosed in the available time / Appropriate action not taken in the available time	HEP = 1	HEP = 1
	Barely adequate time	Available time is about 2/3 of required time	10	N/A
	Time available is equal to the time required	There is just enough time to execute the appropriate action	N/A	10
	Nominal time	Sufficient time to diagnose the problem / There is some extra time above what is minimally required to execute the appropriate action	1	1
	Extra time	Time available is between one to two times greater than the nominal time required, and is also greater than 30 minutes	0.1	N/A
	Time available ≥ 5x time required	There is an extra amount of time to execute the appropriate action	N/A	0.1
	Expansive time	Time greater than twice the nominal time and greater than 30 minutes	0.01	N/A
	Time available ≥ 50x time required	There is an expansive amount of time to execute the appropriate action	N/A	0.01
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1
Stress and Stressors	Extreme	Most people's performance will deteriorate dramatically	5	5
	High	Stress level higher than nominal level	2	2
	Nominal	Stress level conducive to good performance	1	1
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1
Complexity	High complex	Very difficult to perform	5	5
	Moderately complex	Somewhat difficult to perform	2	2
	Nominal	Not difficult to perform	1	1
	Obvious diagnosis	Diagnosis becomes greatly simplified. Validating and/or convergent information becomes available to the operator	0.1	N/A
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1

PSFs	PSF Levels	Description	DM	AM
Experience and Training	Low	Less than six months of experience and/or training, not providing the knowledge necessary to perform the tasks properly	10	3
	Nominal	More than six months of experience and/or training, enabling adequate learning	1	1
	High	Extensive experience, providing the operator with extensive knowledge and practice in a wide range of scenarios	0.5	0.5
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1
Procedures	Not available	Procedure required for a specific task is not available	50	50
	Incomplete	Required information is not contained in the procedure (sections or instructions are missing)	20	20
	Available, but poor	A procedure is available, but is difficult to use due to formatting issues, ambiguity, or inconsistency	5	5
	Nominal	Procedure available and improves performance	1	1
	Diagnosis / symptom oriented	Diagnostic procedures assist the operator in correctly diagnosing the event. Symptom-oriented procedures provide the means to maintain critical safety functions without having to diagnose exactly what the event is and what needs to be done to mitigate it.	0.5	N/A
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1
Ergonomics / HMI	Missing / Misleading	Instrumentation fails to support diagnosis or is inaccurate	50	50
	Poor	Plant design negatively impacts task performance	10	10
	Nominal	The plant design supports correct performance, but does not improve performance or make tasks easier to perform.	1	1
	Good	Plant design positively affects performance by providing necessary information and the ability to perform tasks in a way that reduces errors.	0.5	0.5
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1

PSFs	PSF Levels	Description	DM	AM
Fitness for Duty	Unfit	The individual cannot perform the required tasks due to illness or other physical or mental incapacitation	HEP = 1	HEP = 1
	Degraded fitness	The individual is able to perform tasks, although performance is negatively affected	5	5
	Nominal	The individual is able to perform tasks	1	1
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1
Work Processes	Poor	Performance is negatively affected by the work process	2	5
	Nominal	Performance is not significantly affected by the work process or the work process do not appear to play an important role in performance	1	1
	Good	Work process improves performance, leading to a more successful outcome than would be the case if it were not well implemented.	0.8	0.5
	Insufficient information	Lack of sufficient information to choose between other alternatives	1	1

N/A: Not applicable for this type of task (diagnostic or action).

- The basic steps in SPAR-H process are the following:

(1) Define the task to be analyzed. This includes identify the task type (diagnostic or action task) and understanding the context in which the task is performed and the potential consequences of errors.

(2) Assign appropriate multipliers for each of the eight PSF according to the task context (using Table 1).

(3) Calculate the human error probability (HEP) according to the following equations:

$$HEP_{diagnostic\ task} = NHEP_{diagnostic\ tasks} * \prod PSF_{diagnostic\ task} \quad (1)$$

$$HEP_{action\ task} = NHEP_{action\ tasks} * \prod PSF_{action\ task} \quad (2)$$

$$HEP_{total} = HEP_{diagnostic\ task} + HEP_{action\ task} \quad (3)$$

where:

$NHEP_{diagnostic\ tasks}$: Nominal human error probability for diagnostic tasks, defined in SPAR-H to be equal to 0.01;

$NHEP_{action\ tasks}$: Nominal human error probability for action tasks, defined in SPAR-H to be equal to 0.001;

$PSF_{diagnostic\ task}$: Multiplier assigned to the PSF under analysis according to the context of the diagnostic task. Possible values are defined in Table 1;

$PSF_{action\ task}$: Multiplier assigned to the PSF under analysis according to the context of the action task. Possible values are defined in Table 1;

$HEP_{diagnostic\ task}$: Human error probability for diagnostic task;

$HEP_{action\ task}$: Human error probability for action task;

HEP_{total}: Total human error probability for the task under analysis.

When calculating the human error probabilities for the diagnostic and action tasks, if three or more PSF multipliers have a value greater than 1, there is a possibility that the resulting calculated values could be greater than 1. In this case, equations (1) and (2) should be replaced by equations (4) and (5):

$$HEP_{diagnostic\ task} = \frac{NHEP_{diagnostic\ tasks} * \prod PSF_{diagnostic\ task}}{NHEP_{diagnostic\ tasks} * (\prod PSF_{diagnostic\ task} - 1) + 1} \quad (4)$$

$$HEP_{action\ task} = \frac{NHEP_{action\ tasks} * \prod PSF_{action\ task}}{NHEP_{action\ tasks} * (\prod PSF_{action\ task} - 1) + 1} \quad (5)$$

In all cases, if HEP_{total} approaches or exceeds the value of 1, equation (6) should be used instead of equation (3):

$$HEP_{total} = HEP_{diagnostic\ task} + HEP_{action\ task} - (HEP_{diagnostic\ task} * HEP_{action\ task}) \quad (6)$$

3. RESULTS AND DISCUSSIONS

The methodology discussed in the preceding section was applied to an event of loss of electrical power that occurred during a power ramp test performed by DMC. After analyzing the event, the DMC's technical staff decided to resume the interrupted test. Under these circumstances, the data file used by the control and data acquisition software to perform the automatic positioning of the irradiation capsule must be modified based on the information of the interrupted test. This particular task falls under the researcher's responsibility for the test. The DMC operator, on the other hand, is tasked with examining the file during software setup to identify any data inconsistencies that could affect the facility safe operation.

The DMC's operator tasks to be analyzed in this scenario were divided in two groups:

Group 1: Electric-electronic system restart including the control and data acquisition software. The main tasks to be performed are:

● Power up the stepper motor controller: Press the "on" button in the electric panel and check if all the fault indicators leds are lit in green, signaling that there are no hardware components faults.

● Power up the electromagnetic clutch: Press the "on" button in the electric panel and check if the clutch's indicator light has turned on.

● Power up the computer and start the control and data acquisition software: Press the computer "on" button, perform user login and start the control and data acquisition software. Check the software's graphical interface for any operation inconsistences such as communication failures between the software and the stepper motor, as well as any DMC's sensors faults.

Group 2: Configuration of control and data acquisition software. The main tasks to be performed are:

● Reestablish the irradiation capsule to “zero coordinate position” which is an essential reference for the control and data acquisition software: Using the manual mode functionality in the software, move the capsule until the zero position sensor is activated. Then reset the DMC position coordinate indicators to 0 mm.

● Configuration of the automatic capsule positioning mode using the modified data file to resume the test: Load the software with the modified data file and check the software’s graphical interface to ensure that the planned movements do not pose any risk to the safe operation of DMC.

Table 2 and Table 3 show the PSF assessments for operator tasks. Instead of analyzing the tasks individually, both the tasks in Group 1 and those in Group 2 were analyzed collectively, according to Table 1.

Table 2: Group 1 operator tasks assessment.

PSFs	PSF Levels		PSF Multipliers	
	Diagnosis	**Action**	**Diagnosis**	**Action**
Available Time	Extra time	Time available ≥ 5x the time required	0.1	0.1
Stress and Stressors	Nominal	Nominal	1	1
Complexity	Obvious diagnosis	Nominal	0.1	1
Experience and Training	High	High	0.5	0.5
Procedures	Diagnosis / symptom oriented	Nominal	0.5	1
Ergonomics/HMI	Good	Good	0.5	0.5
Fitness for Duty	Nominal	Nominal	1	1
Work Process	Good	Good	0.8	0.5

Table 3: Group 2 operator tasks assessment.

PSFs	PSF Levels		PSF Multipliers	
	Diagnosis	**Action**	**Diagnosis**	**Action**
Available Time	Nominal	Nominal	1	1
Stress and Stressors	High	Nominal	2	1
Complexity	Nominal	Nominal	1	1

PSFs	PSF Levels		PSF Multipliers	
	Diagnosis	**Action**	**Diagnosis**	**Action**
Experience and Training	High	High	0.5	0.5
Procedures	Diagnosis / symptom oriented	Nominal	0.5	1
Ergonomics/HMI	Good	Good	0.5	0.5
Fitness for Duty	Nominal	Nominal	1	1
Work Process	Good	Good	0.8	0.5

Human error probability in the Group 1 tasks are:

$$HEP_{diagnostic\ task} = 0.01 * 0.1 * 1 * 0.1 * 0.5 * 0.5 * 0.5 * 1 * 0.8 = 1.0 * 10^{-5} \quad (7)$$

$$HEP_{action\ task} = 0.001 * 0.1 * 1 * 1 * 0.5 * 1 * 0.5 * 1 * 0.5 = 1.25 * 10^{-5} \quad (8)$$

$$HEP_{total} = 1.0 * 10^{-5} + 1.25 * 10^{-5} = 2.25 * 10^{-5} \quad (9)$$

Human error probability in the Group 2 tasks are:

$$HEP_{diagnostic\ task} = 0.01 * 1 * 2 * 1 * 0.5 * 0.5 * 0.5 * 1 * 0.8 = 2.0 * 10^{-3} \quad (10)$$

$$HEP_{action\ task} = 0.001 * 1 * 1 * 1 * 0.5 * 1 * 0.5 * 1 * 0.5 = 1.25 * 10^{-4} \quad (11)$$

$$HEP_{total} = 2.0 * 10^{-3} + 1.25 * 10^{-5} = 2.13 * 10^{-3} \quad (12)$$

The results show that the total human error probability (HEP_{total}) was higher in Group 2 tasks than in Group 1 tasks, as Group 2 PSF factors Available Time (diagnostic and action tasks), Stress and Stressors (diagnostic tasks) and Complexity (diagnostic tasks) had higher level classification (more negative). Among these three PSF factors, the one that had the highest negative impact on human error probability was the PSF Stress and Stressors, whose PSF level multiplier for diagnostic tasks was 2.

In the context of DMC operation, Group 1 diagnostic and action tasks are simpler than Group 2 tasks. Group 1 tasks are similar to the routine day-to-day operation tasks of the DMC, which are less prone to human failure. Group 2 tasks are more critical in terms of the safe operation of the DMC because they are those that are directly related to the irradiation tests where the capsule is in motion. In addition, a human error that occurs when the control and data acquisition software is being set may result in a failure during the test. In long-term tests, software and hardware failures that compromise the continuity of the experiments can result in significant losses of information, time and invested financial resources. This type of situation may induce considerable stress and could potentially affect adversely the operator performance.

The PSF factors Experience and Training, Procedures, Ergonomics/HMI, Fitness for Duty and Work Process had the same level classification for both Group 1 and 2 tasks. Furthermore, all these five PSF factors had the lowest level rating within the range of possible values in Group 1 and 2 tasks assessments. In this case, there was a positive effect of PSF multiplier values contributing to the reduction of the HEP in diagnostic and action tasks of both groups. Situations may also occur where the negative effects of these PSFs significantly affect HEP results. In [19], Oliveira applied the SPAR-H technique to perform a human reliability analysis of Argonauta nuclear research reactor in different operational scenarios. The human error probability values obtained in the study were strongly negatively impacted by the PSF factors Procedures (available, but poor) and Ergonomics/HMI (poor), whose PSF level multipliers are relatively high when compared to the level multipliers of the other PSFs.

In the present study, some measures could be taken to reduce the human error probability, mainly in Group 2 tasks. Relating to the PSF Available Time, one of the key measures would be to redesign processes to allow more time for decision-making and task execution. By giving operators sufficient time, the probability of erroneous decisions can be minimized. Another approach could involve automating certain tasks to reduce the cognitive load and the time required for their execution, allowing operators to focus on critical aspects of their duties without feeling overwhelmed by time constraints. When addressing PSF Stress and Stressors, a key measure would be to prepare operators for high-pressure environments through simulation-based training that mimics stressful scenarios. This would help them develop the resilience and skills needed to perform well under pressure. Finally, related to PSF Complexity, a measure could be restructuring tasks to make them more straightforward and eliminating unnecessary steps, wherever possible. Providing support tools, such as automation, could significantly improve task execution. In addition, ensuring that operators are well-trained to handle complex operations could help to minimize the probability of errors.

4. CONCLUSIONS

The applicability of the SPAR-H technique to predict Human Error Probabilities (HEPs) was illustrated as an example of a quantitative study to improve the safety and reliability of the DMC electric-electronic system through acting on human factors issues.

The DMC's operator tasks were analyzed in an event of loss of electrical power occurred during a power ramp test. Tasks were divided in two groups and the results showed that Group 2 tasks had a higher human error probability. To reduce the human error probability, some measures directly related to the PSFs that had the greatest negative impact on the results were suggested.

ACKNOWLEDGMENT

We thank Comissão Nacional de Energia Nuclear (CNEN) and Financiadora de Inovação e Pesquisa (FINEP) for the financial support of the research carried out.

FUNDING

This research was made possible thanks to CNEN and FINEP funding.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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