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# Human Performance Considerations for Nuclear Operations and Inspections: Cross-cutting Issues in Nuclear Safety and International Safeguards

Cooperative Monitoring Center (CMC)

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# OVERVIEW

About the VRS (Visiting Research Scholar)

Research Conducted at IPEN (USP) and the Brazilian Nuclear Program

The VRS Project

Human Performance, Human Error and Notable Events

The Future and the Nuclear Technology

Current Context – a case study

Results from the VRS Program

Conclusions

Potential Further Research and Applications

Acknowledgements



## ABOUT THE VRS (VISITING RESEARCH SCHOLAR)

Nuclear Technology Graduate Student at University of Sao Paulo, Brazil (2021-present)

National School on Nuclear Security Cooperation between IAEA x IPEN USP (2022)

Psychosomatics Specialist (2021)

Nuclear Energy Project Management at University of Sao Paulo's Polytechnic School (2017)

Amazul employee (2011-present)

Psychotherapist (2015-2022)

B.S. Psychology (2014)

### Honors and awards:

IAEA Marie Sklodowska Curie Fellowship (2021-present)

Honorary Submariner (2020) issued by Comando da Força de Submarinos – Brazilian Navy

# RESEARCH CONDUCTED AT IPEN (USP) AND THE BRAZILIAN NUCLEAR PROGRAM

“The importance of human performance analysis to nuclear safety”



## RESEARCH CONDUCTED AT IPEN (USP)

- Systematic literature review on human performance – enable access to this knowledge in Portuguese and serve as a guide to implement, develop and expand related programs in the Brazilian nuclear facilities.
- 15 interviews conducted so far with nuclear operators; more are upcoming in different types of facilities.
- Some preliminary results from the interviews indicate known aspects in the literature that influences the performance in operations such as workload, sleep deprivation, communication with others.



# BRAZILIAN NUCLEAR PROGRAM



Photo: IAEA

**IPEN's Research Reactor**

- 30 Nuclear Facilities
- 3000 Radioactive Facilities

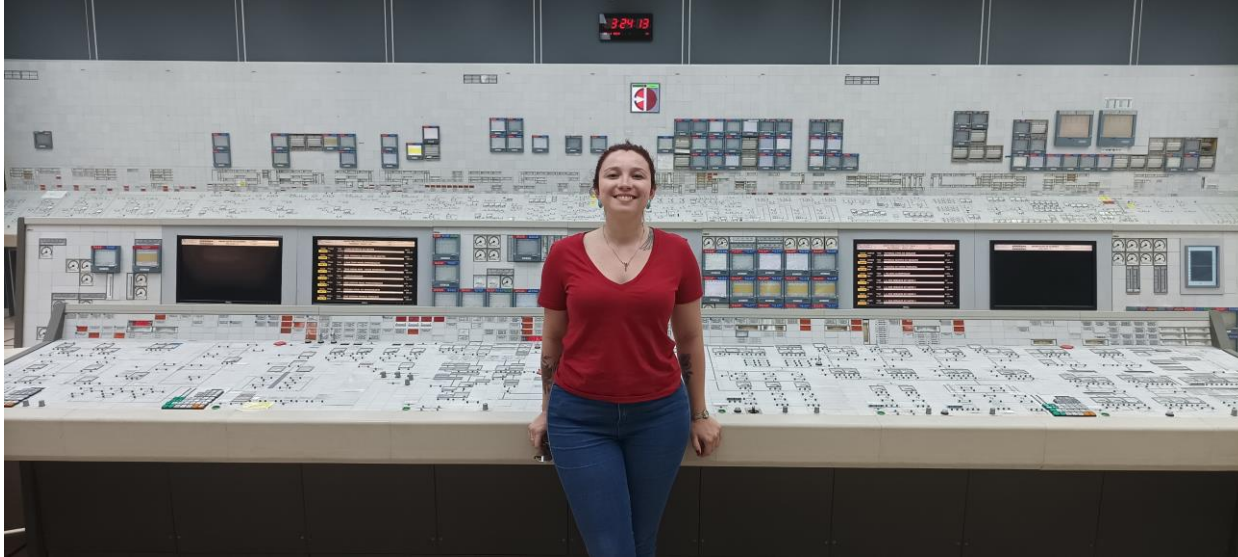


Photo: Eletronuclear

**ANGRA NPP**

- 30 Mining Sites
- 15 Reject Deposits

# BRAZILIAN NUCLEAR PROGRAM



**ANGRA 2 Control Room Simulator**

Photo: Personal collection



**ANGRA 2**

Photo: Personal collection





# BRAZILIAN NUCLEAR PROGRAM



Photo: IAEA

**ARAMAR Navy Technological Center**



Photo: IPEN

**Radiopharmacy Center at IPEN**



# THE VRS PROJECT

Cross-cutting Issues in Nuclear Safety and International Safeguards



## GOALS

- 1) Raise awareness in the international community about the importance and impact of human performance in nuclear safety and safeguards;
- 2) Help start developing training materials for initial human performance assessments for nuclear operators and inspectors; and
- 3) Develop new research on common knowledge and lessons for human factors between nuclear safety and international safeguards.

## METHOD

Literature review on existent research and regulatory bodies' recommendations, and a comparison was conducted between the activities executed in nuclear operations and inspections.

Further than that, several meetings with the Sandia staff from different but related fields (human factors engineering, risk management, systems engineering, cognitive science, psychology, international affairs) were possible, enabling rich discussions and identification of applications to other contexts.

**HUMAN  
PERFORMANCE,  
HUMAN ERROR  
AND NOTABLE  
EVENTS**





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2009	"Human performance tools for individuals, work teams, and management" - DOE Standards, DOE-HDBK-1028[11]
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Author: Pavao & Conti, 2023.



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Image: REUTERS

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Photo: Igor Kostin

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Photo: CNEN

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*After notable human-caused accidents, greater importance was given to the development of methods and tools to enhance nuclear safety in this regard.*

Author: Pavao & Conti, 2023.



*In the case of **safeguards inspections**, there is no public documentation of impacts of human errors. Human error for safeguards is treated theoretically in this research, based on hypothesized consequences.*

# THE FUTURE AND NUCLEAR TECHNOLOGY



# THE FUTURE AND NUCLEAR TECHNOLOGY

- Climate change and the goal of role of reaching net zero global CO2 emissions by 2050 has led to renewed momentum for nuclear power. The use of nuclear power has avoided about 70 gigatonnes of CO2 emissions over the past 50 years.



Image: NOAA

- According to the World Nuclear Association, about 30 countries are considering, planning, or starting nuclear power programs. These range from sophisticated economies to developing nations. Among them are Bangladesh, Egypt and Turkey who are building their very first nuclear power plants.

# THE FUTURE AND NUCLEAR TECHNOLOGY

- New technologies such as SMRs will support the expansion of the nuclear industry, but they will also raise new challenges for human performance and human-machine integration systems.
- With this new context within in the nuclear industry, existing regulations will have to be reviewed, strengthened and modified for both operation and inspection activities.

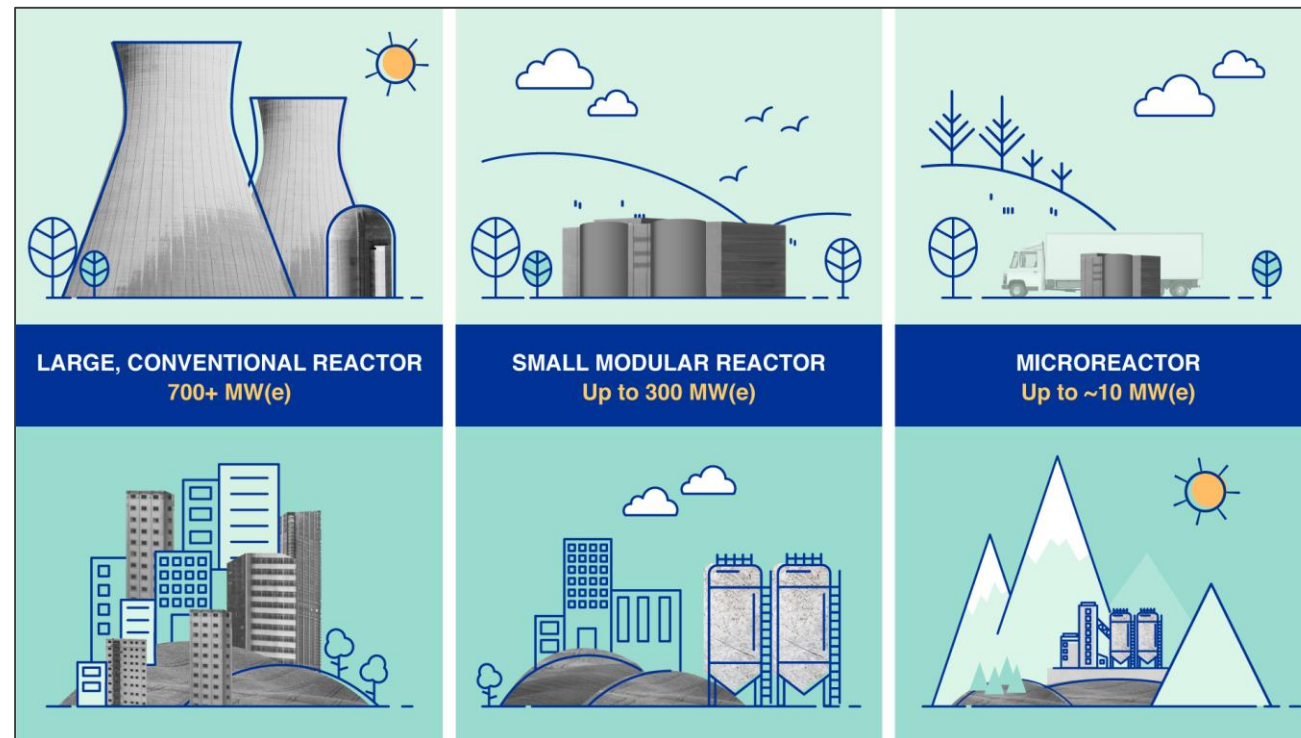


Image: A. Vargas/IAEA

# CURRENT CONTEXT- A CASE STUDY



## CASE STUDY - THE CONFLICT BETWEEN RUSSIA AND UKRAINE

The conflict between Russia and Ukraine brought back the discussion on human performance in safety operations (and inspections) once again.

Workers in Ukraine's nuclear facilities have faced extreme challenges that are known to impact human performance.

*Statements of the IAEA on the situation shows the challenges faced:*



Photo: Alexander Ermochenko

# CASE STUDY - THE CONFLICT BETWEEN RUSSIA AND UKRAINE

## OPERATION SAFETY:

Update 8 – 03Mar2022: *“Ukraine has informed the International Atomic Energy Agency (IAEA) that staff who have been kept at the Chornobyl Nuclear Power Plant (NPP) since Russian military forces took control of the site a week ago were **facing “psychological pressure and moral exhaustion”**, Director General Rafael Mariano Grossi said, stressing that they must be **allowed to rest and rotate so that their crucial work can be carried out safely and Securely”**.*

Oral Report to the Board of Governors  
09JUN2022:

*“Every day it continues; every day that vital maintenance work is delayed; every day that supply chain interruptions cause a break in the delivery of vital equipment; **every day the decision-making ability of Ukrainian staff is compromised**; every day the independent work and assessments of Ukraine’s regulator are undermined; the risk of an accident or a security breach increases”.*



## OPERATION SAFETY:

Update 153 – 13APR2023:

*"The staffing situation at ZNPP remains complex and challenging. Over one-third of the original **staff have left the area**, some of those remaining have signed work contracts under a newly formed Russian operating organization and some remain employed by Energoatom. A significant number of the latter are now on-call, with the rest - mainly key operating staff - still working at the ZNPP, under the direction of Russian appointed management. In recognition of the staff shortages, **operators from Russian NPPs have been receiving simulator and on the job training at the ZNPP**. Once trained, they may be asked to come to work at ZNPP in case of staff shortages".*

*"**the site staff** who are required **to live on site in two-week shifts** as a result of the conflict, are facing difficulties travelling to and from the nearby city of Slavutych, where most of them live. One bridge across the River Uzh has been damaged and a temporary bridge has been submerged due to spring flooding. Despite these difficulties, a planned 8 April rotation of work shifts was carried out successfully".*

# SAFEGUARDS INSPECTIONS

Oral Report to the Board of Governors 09JUN2022:

*"The teams of inspectors of the IAEA also **had to stay longer at the NPP**. Separately, staff members of the IAEA Department of Safeguards:*

- Verified declared nuclear material and activities at facilities selected by the IAEA, and*
- Checked the functioning of the remote safeguards data transmission from the Chornobyl NPP to IAEA headquarters which was re-established at the end of April after two months of interruption.*

*[...] As I said in my opening statement to the Board, one clear line of Ukrainian operational control and responsibility is vital, not only for the safety and security of Zaporizhzhya NPP, but **also so that IAEA inspectors are able to continue to fulfil their regular, indispensable verification activities**. There can be no delay in this. The transmission of safeguards information between Zaporizhzhya NPP and the IAEA has now been interrupted for more than a week."*

## SAFEGUARDS INSPECTIONS

*"At Zaporizhzhya NPP we have reached the point where **the presence of inspectors is essential**. Though our safeguards systems are designed for data to be stored locally even when they are not being transmitted, the ongoing break in data reaching the IAEA is insupportable. Without the data, and without the in-person inspections that must occur in regular intervals, **the IAEA cannot assure the nuclear material at Zaporizhzhya NPP is safeguarded**".*



Photo: Andriy Andriyenko

The example of the current conflict highlights the close relationship between nuclear safety and safeguards, and the importance of factors that impact human performance for both types of activities. Further than that, the situation illustrates also the difficulties of executing essential activities throughout wartime. It is an example of human performance under extreme circumstances and can provide lessons for supporting operators and inspectors in other situations (accidents, natural disasters).

# RESULTS FROM VRS PROGRAM



# NUCLEAR SAFETY – OPERATION SAFETY

Operators are exhaustively trained and credentialled to work in the nuclear field. It takes a lot of effort, time and investment. But mistakes still might happen.

Common themes in the research on human performance in nuclear safety include:

- Impacts of operating in a high risk facility:
  - Stress from the responsibility for overall operation and operation of related subsystems
  - In commercial facilities – making sure the production reaches profit goals
  - Shift rotation and appropriate shift handoffs are essential for adequate cognitive function and decision making in case of any emergency.
- Humans are a huge part of the system and therefore, their actions can result in excellent, good and bad outcomes.
- Treating the humans as if they are outside of the system weakens the strength and safety of the system, making it more vulnerable.
- Several regulations on operation safety (following procedures and training related to the system operation specifically) are published, but there's a gap on how to adequately measure performance and use it to support the operators to improve their performance rather than as an evaluation to “finding someone to blame”.

# NUCLEAR SAFETY – OPERATION SAFETY

Some of the aspects that influence human performance in nuclear operations safety, according to the literature are:

- Workload (fatigue)
- Stress
- Time pressure
- Following many procedures
- Selective attention
- Sleep deprivation
- Multitasking

# NUCLEAR INSPECTIONS – INTERNATIONAL SAFEGUARDS

International safeguards inspectors play an essential role on the ongoing development of nuclear technology for peaceful uses. The inspector, in the field, performs a variety of verification activities such as: nuclear material accountancy, design information verification, environmental sampling, containment and surveillance techniques and others.

Some important aspects of human performance in this domain include:

- **Training** – Inspectors are screened, trained and go through a probationary period, executing tasks related until they can be in the field.
- **Attention to detail** - They have to fill up different documents with many details in a short amount of time.
- **Situational awareness** - Beyond the checklists, inspectors must be aware of subtle details and many times go further in the analytical investigation to make sure the facility is complying with the agreements in force.





# NUCLEAR INSPECTIONS – INTERNATIONAL SAFEGUARDS

Prior work at Sandia on cognition-informed safeguards presents the aspects that most affect these inspectors:

- Attention and inattention
- Cognitive biases
- Cognitive off-loading (taking notes to reduce mental processing)
- Prevalence effects (search for rare events of objects)
- Sleep deprivation (Jet lag)
- Stress
- Task switching and multi tasking
- Wayfinding (sense of direction in the plant)
- Communication (working in a multilingual environment)

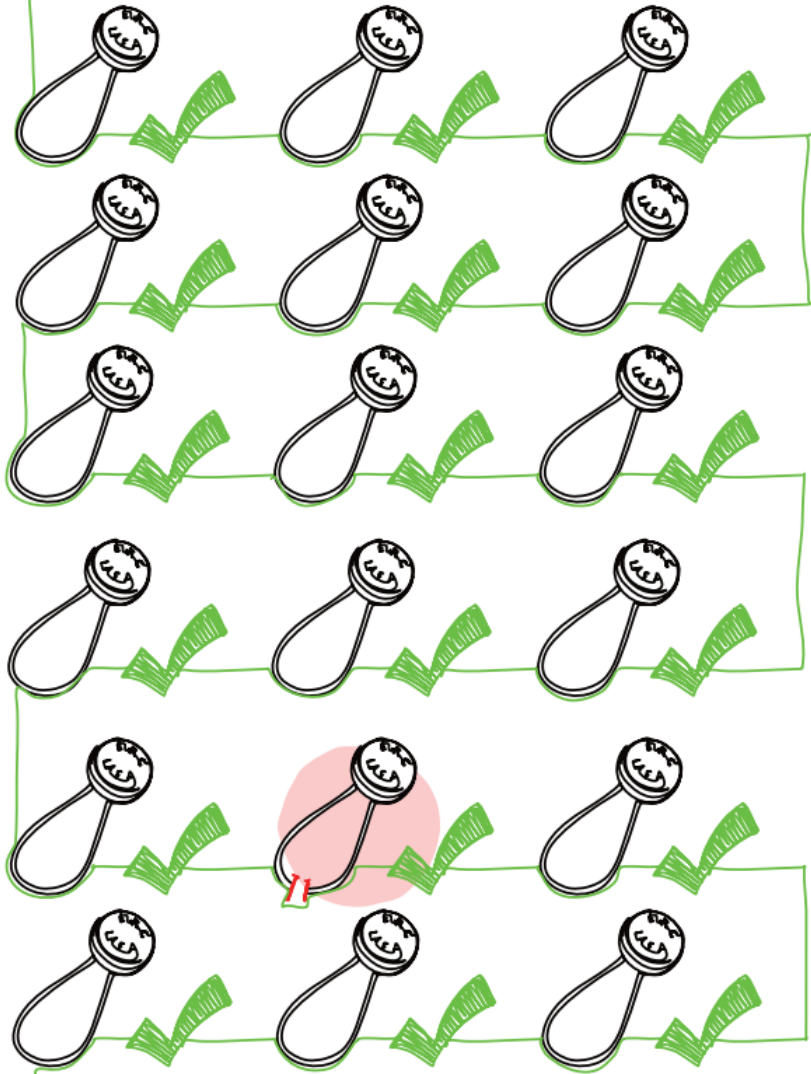
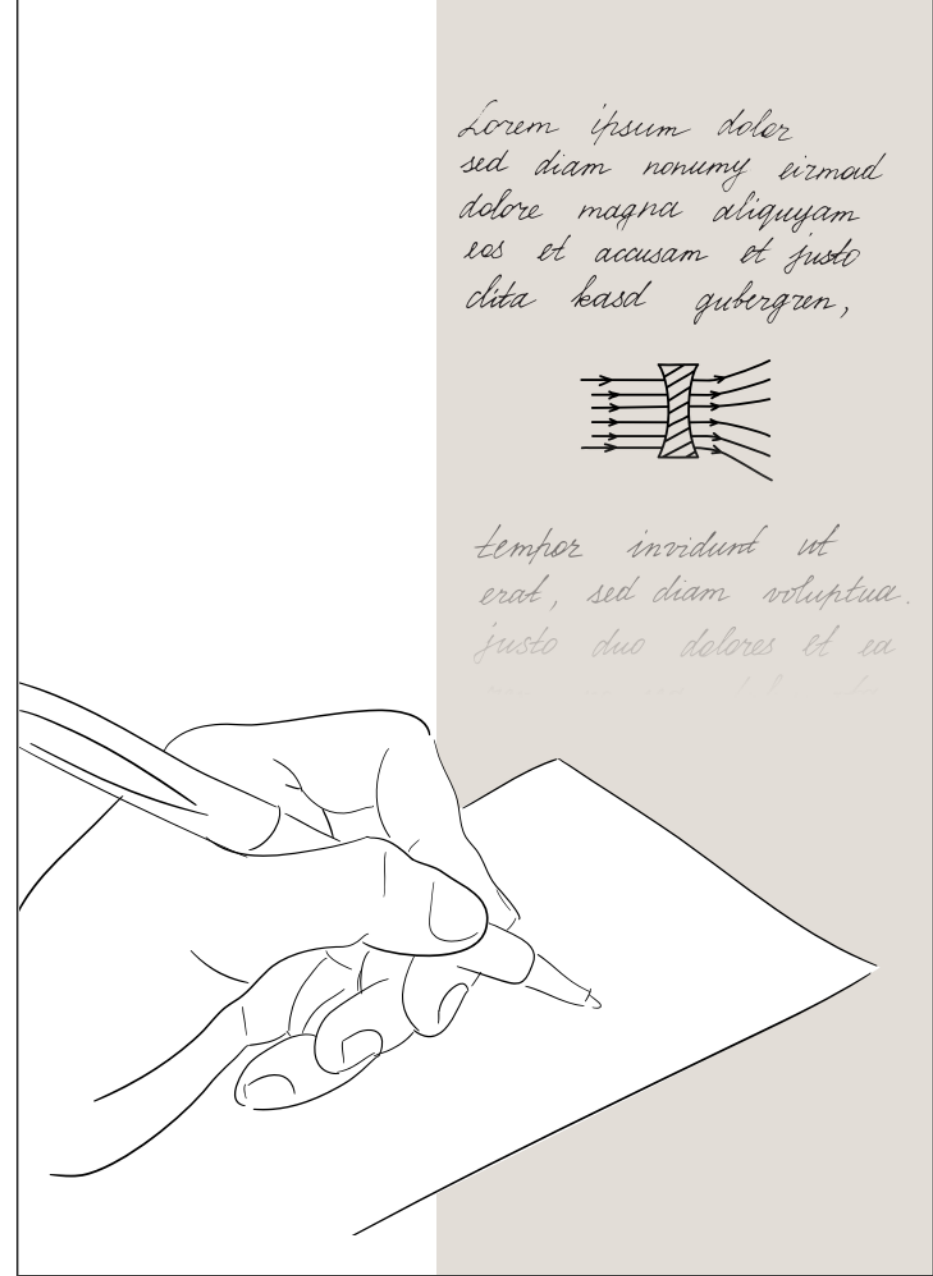


Image: SNL's Booklet on Cognitive-informed Safeguards

Example of a Prevalence Effect



Lorem ipsum dolor  
 sed diam nonumy eirmod  
 dolore magna aliquyam  
 eos et accusam et justo  
 clita kasd gubergren,



Tempor invidunt ut  
 erat, sed diam voluptua.  
 justo duo dolores et ea

Image: SNL's Booklet on Cognitive-informed Safeguards

Example of Cognitive Off-Loading



## Regulations and Recommendations

- For both operation safety and inspections safety (at a National level) the regulatory bodies suggest human factors/human performance approaches to ensure secure activities;
- It was not found among the literature of Regulatory Bodies (CNEN, NRC and ONR) specific regulations on how to assess human performance from a cognitive perspective;
- The approach on human factors analysis differ from country to country;
- From the perspective of the IAEA documents, also are *recommendations* on having human performance programs in the nuclear facilities.

# NUCLEAR SAFETY AND INTERNATIONAL SAFEGUARDS

- Between the two activities, many aspects are similar regarding their influence on human performance;
- Differences appear based on the type of activity and the associated risks;
- Individual differences in cognition should be addressed in both domains and how they can affect performance factors, such as attention, decision making and teamwork;
- Same regarding aspects of culture in decision making and cognitive biases;
- Operations: the presence of experts in the facilities could help to identify and assess those aspects and proceed with analysis and investigation towards performance improvement;
- Inspections: developing assessments on a National Inspection level (regulatory bodies) can provide data to better comprehend the international safeguards inspections necessities in a cognitive and psychological matter.

# CONCLUSIONS



## CONCLUSIONS

- This project provided cross-cutting aspects between nuclear operation safety and human international safeguards, indicating a potential new area for research with current demand;
- The continued development of this subject can help to improve the existing nuclear programs and help States new to nuclear technology to implement robust human performance programs;
- R&D in the area can help provide the IAEA valuable data for international safeguards inspections training improvement and assessment;

## CONCLUSIONS

- This subject can help support international cooperation by emphasizing aspects of human performance that impact both nuclear safety and international safeguards;
- The available publications are *recommendations* on having this type of analysis in the nuclear field, but as a recommendation, this subject can be taken for granted many times – the discussion and research development may lead to a more assertive approach to the creation of regulations in this area;
- Human performance approach can help national inspectors and operators to collaborate with overall national safeguards and safety, enhancing nuclear security as well.

**POTENTIAL  
FURTHER RESEARCH  
AND APPLICATIONS**





## POTENTIAL FURTHER RESEARCH

- For operations, continued assessments on monitoring human performance, such as workload, stress, attention awareness, following procedures, can lead to improvements in the system's overall performance;
- Collaboration on training to support evaluation of National inspectors performance in order to help training for international safeguards inspections. This would raise awareness of human performance issues in both domains, which could benefit both.
- Additional research and data collection focusing on human performance and human-machine interface design can also provide guidelines for new incoming technologies.
- This type of research can support further applications to nuclear security as well, as helping identifying threats, prevent errors in nuclear material accounting activities and also help enhance training materials in the field.

## TECHNICAL GROUP: FUTURE COOPERATION

- The cooperation between the US and Brazil, the experience with operation from the first and inspection from the second, can help nourish the state of art in these areas and foster collaborations with other States as well;
- As a follow up, the suggestion is to prepare a workshop in Brazil on *Human Performance – operations and inspections*, having among the presenters experts of different areas related to human performance such as human factors, safeguards, cognitive science, systems engineering, and others. The presenters from NNSA/DOE, IPEN, ABAAC could exchange experiences and raise the discussion on the importance of the field to the industry;
- Also should be considered the establishment of a permanent multi institutional group, as a suggestion to the IAEA in order to provide training/ guidance in human performance matters to new incoming States in the nuclear field (LAC, Africa and SE Asia).

# ACKNOWLEDGEMENTS





## ACKNOWLEDGEMENTS

Being able to work in the research in person made possible a great exchange with a wide range of experts from different and relatable fields, all of them highly contributed to the results presented.

So, thank you United States Department of Energy for supporting this project and the opportunity to work on such an important subject. Thank you Dr. Amir Mohagheghi, Director of CMC Program, my brilliant and kind hosts Zoe Gastelum and Laura Matzen, and all the staff that contributed for this to happen. Thanks to all Sandians that I had the pleasure to meet and discuss from different points of view the research.

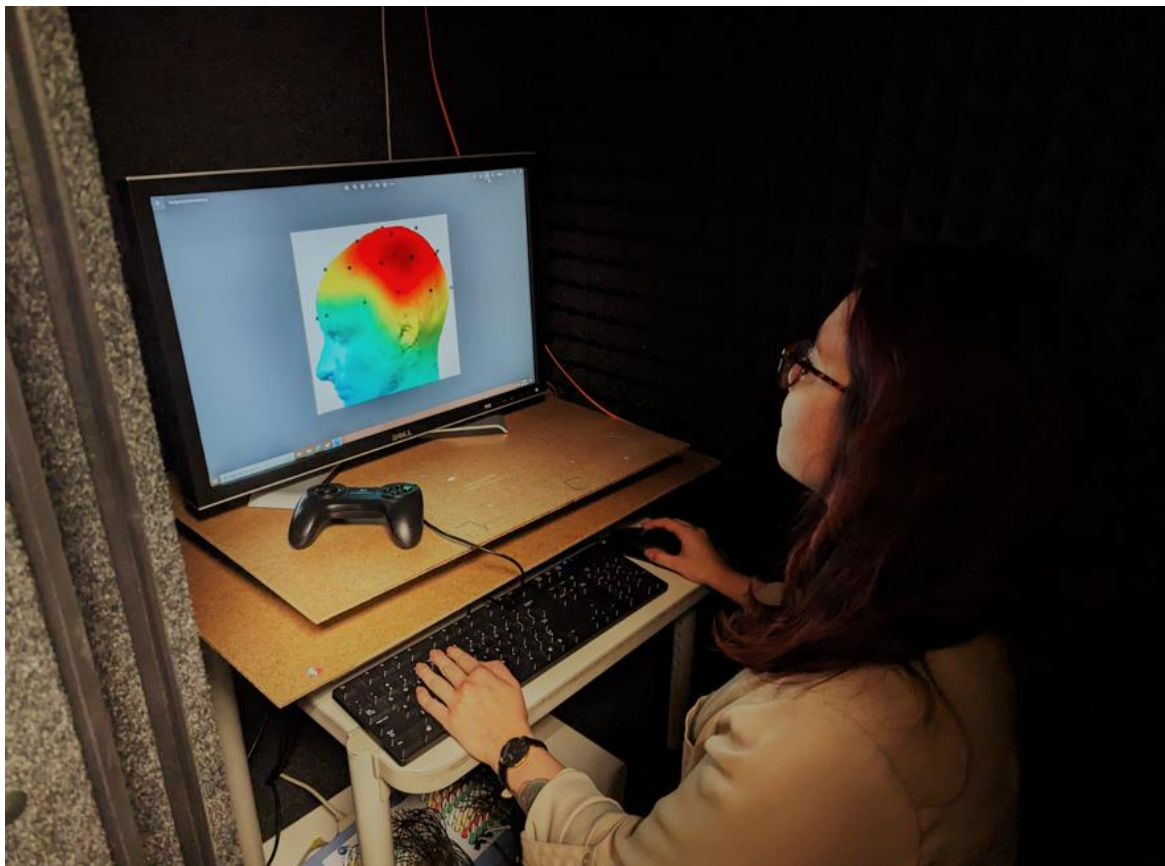
Thanks also to NRC Human Factors and AWE UK staff for providing great insights and references that enriched the work and took to another level of understanding the subject.



# THE TEAM



# IN THE LAB



**THANK YOU!  
OBRIGADA!**

