Human Factors & AI In Nuclear: Regulatory Consensus As the Trust Bucket

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SUMMARY

In 2024, both the inaugural UK AI awards and Nobel Peace Prize for Physics in AI took place. This further intensified the mainstream publicity given to AI both in human automation and machine self-learning. In contrast, the uptake of AI in more industrial and specialist settings has been noticeably measured, especially away from simple automation. For example, in the nuclear industry, Human and Organisational Factors (HOF) have yet to benefit from AI en masse. This is at great odds with the potential that AI presents in mitigating nuclear harm, itself the main concern when scaling nuclear power plants. However, change is afoot.

In the last two years, important international nuclear regulatory guidelines for adopting AI in nuclear HOF have been published. This is a major step change for what is a decidedly risk-averse industry as it encourages the development of AI. But the message remains clear. AI must engender 'top-down' trust in the technology's deterministic predictability. Leading up to the published guidance, two world-leading 'sandbox' trials were conducted under regulatory auspices. Below, I discuss one in detail to show that nuclear can provide HOF practitioners with much-needed empirical data on the potential of AI. As, if nuclear can utilise AI then a vibrant case exists for other fields.

KEYWORDS

Nuclear, AI, Regulations

Introduction

Since the 'Turing Test' of 1950 intelligent technology has been reshaping the human-machine relationship. Despite this test being as old as nuclear technology itself, nuclear Human Factors practitioners have yet to adopt AI without circumspect. This is in part due to rigorous regulatory regimes that exist to mitigate the risks a nuclear facility poses to environment and societies. Key to this mitigation is the crucial role of the human. For example, the Level 7 accident at Chernobyl in 1986 was worsened by safety measures being ignored. Due to such accidents, the Atomic Act of 1946 established international regulations and co-operation that have only strengthened through international political order changes.

Another reason for the slower adoption of AI has been what Grote (2023) refers to as the 'reticence' of HOF practitioners to use newer technology. This has been due to the lack of clarity of how empirical evidence is produced leading up to classical HOF analysis. However, changes on both the transparency and the deployment of AI devices in nuclear is taking place. Its success has the potential to significantly change how HOF practitioners can support human welfare and performance outcomes far beyond nuclear surrounds.

Presenting the work as an independent academic, I briefly list opportunities for AI in nuclear HOF before presenting the challenges. This is much as Kirwan (2024) describes for the aviation industry.

Next, I foreground two case studies the UK regulator, the Office for Nuclear Regulation (ONR), is doing to encourage research into AI. Of these, I detail the HOF critique on one that has led to improved guidance by the regulator in adopting AI in nuclear. I argue that this dialogical process between HOF experts and the regulator has created a 'trust bucket' in the veracity of AI from design to deployment and beyond. This offers a signpost that AI and HOF can benefit human welfare and performance. The business-as-usual deployment of the robotic AI product (RrOBO) at Sellafield Ltd developed during these trials evidences this.

In all this, the measured and symbiotic nature of AI adoption by the regulator has been key to creating trust in this newer technology. A 'top-down' approach to AI development offers us a more classical analytical route over that seen in consumer electronics. This is important in nuclear as the consequences of an unpredictable event is morally and commercially critical. Hence, trust in this technology will be earned in drops as it can be lost in buckets.

This research is independent of the ONR and Sellafield Ltd, they remained informed parties.

Humans and Machines in Nuclear

Thorough License Conditions underpin the role of the human within the complex nuclear sociotechnical control system. As these are built on decades-long learning of human capabilities and vulnerabilities, they do not currently exist for AI Therefore, theory rather than practice has been the main beneficiary of research. Especially when discussing nuclear controls that ensure the safe, ethical, and beneficial use of AI in nuclear HOF. It should be noted that this is very much the status quo in outside of nuclear. For instance, as Salmon et al (2024) show for unmanned aerial vehicles.

All the same, the ONR states that AI in nuclear has clear benefits in safety, security, and safeguarding. Examples include the analysis of large volumes of data to better manage risks and improve efficiency; to accomplish tasks in hazardous areas in order to decrease the risk to workers; and potentially reduce error (ONR, 5th Sept 2024). In more specific research, Abdulrahman et al. (2024) have demonstrated that AI software can reduce the frequency of license event reports as correlated both to the number of vacant staff jobs and the ratio of contract employees to regular employees. Meenu at al. (2022) discuss this specifically for human factor errors in US nuclear power plants. So, in theory, there are significant gains to adopting AI in nuclear HOF. But only if safety and security is consistently demonstrable. This is why the role of the regulator is so vital in encouraging the safe testing of newer technology.

UK Regulator / Licensee Case Studies

In 2024, the ONR published two papers on AI, itself an uncommon occurrence in this industry. The second of these was notable as it set out considerations for the use of AI in HOF based on the 'sandbox' testing of two pre-deployment projects in 2023 (ONR, 8th Nov. 2023). One on structural integrity and the other on handling radioactive material. To exhibit the value of AI and HOF, I detail the latter as it involved human-retained automation of a previously labour-intensive human-machine interface glovebox function. This is used to handle highly radioactive material at Sellafield in difficult spatial and atmospheric conditions. Following observations and analysis by an industry-representative team, including HOF experts, it was concluded that assessed numerical claims on reliability could not be placed on the AI component. However, there was enough integrity in the trial process to encourage continued testing, resulting in deployment in 2024/2025.

As a result, the research and 'business as usual' use of AI in nuclear HOF continues apace at Sellafield Ltd. This has resulted in removing significant numbers of people from harm's way; a faster and more remote way of decommissioning hard to reach areas and finally; overall hazard and risk reduction in working conditions (ONR, 8th Nov. 2024). This is much the same as Sellafield

Ltd.'s everyday use of Spot the mobile robot 'dog' which was only deployed after trials successfully satisfied the strict License Condition 22: Modification or Experiment on Existing Plant.

The RrOBO Trial: Risk-reduction Of glovebox Operations Trial at Sellafield Ltd.

The ONR workshopped and tested the use of AI in a process where highly radioactive material is processed in a challenging operational environment. The objective for HOF practitioners here has always been to minimise human exposure to time spent with radioactive waste. The goal in inviting HOF experts was to substantiate safety claims that moving the human to a supervisory rather than operator mode would decrease the level of threat and incident.

The Risk-reduction Of glovebox Operations (RrOBO) mechanical system details are as follows: the baseline system for active deployment consists of a Kinova robotic arm protected by a containment sleeve and equipped with a parallel jaw gripper as the end effector. It is compatible with future tooling and mobile stands. Cameras are inbuilt to allow for remote viewing and remote operator control of the robotic arm via a haptic controller with force feedback.

The supply chain demonstrations included fitting the containment sleeve, inserting the robotic arm into a glovebox and describing the selection of additional tools and capabilities that would become available through COTS (Commercial-Off-The-Shelf) items. These tools and capabilities include applying decontamination gel, swabbing, LiDAR (Light Detection and Ranging) laser scans, radiometric sensors, and many more. (Source: Sellafield Annual Research and Development Review, p. 26). Below in Fig. 1 are some images from Sellafield Ltd.

Fig. 1: Demonstration of the Kinova robotic arm in a nuclear glovebox; inactive trials of the Kinova robotic arm in a nuclear glovebox; Kinova robotic arm control room. (Source: Sellafield Annual Research and Development Review, p. 26).

Table 1 below summarises some of the topics and outcomes of the pre-trial workshop as commented by the assembled team, including HOF practitioners and researchers. A clear pattern of unpredictability emerges.

Table 1: Pilot of a regulatory sandbox on Artificial Intelligence in the nuclear sector

Topics	Outcomes
The possibility of placing a numerical claim on the AI component itself;	The group did not consider it possible at present and attributing reliability numbers to an AI system could drive the wrong behaviours.
Design of the whole system, including wraparounds and other systems to support the safety, security and environmental case;	It is likely to be difficult to substantiate AI software due to their complexity, inaccessibility to code to understanding the machine learning algorithms.
Human/AI coworking, managing handovers from AI to humans, recovery from faults and defining a safe state; and	The group noted that 'the human' cannot be removed from the system altogether.
Modifications and future behaviour, maintenance procedures and through-life behaviours.	Subtle changes in the AI operational environment have the potential to change the performance significantly. The sandboxing revealed that there may be a gap in the availability of good practice for the examination, maintenance, inspection and testing of AI systems.
Conclusion	
It was recommended that AI algorithms should be locked down and arrangements put in place to control modifications. Deep, continuously learning systems could be used as a non-safety aid but are unlikely to be justifiable for use in any safe operation. It was considered that self-learning systems may challenge current guidance for Licence Conditions.	

Source: Regulators' Pioneer Fund (Department for Science, Innovation and Technology): Pilot of a regulatory sandbox on artificial intelligence in the nuclear sector.

Analysis and Commentary

It is clear from the above that HOF experts were unanimous in being unable to substantiate safety claims on the deployment of AI robotics in this particular setting. This is not uncommon for this discipline and for the state of AI in other critical safety industries. However, since the sandbox trial of 2023, the RrOBO devices are now scheduled for active deployment into several gloveboxes on site. It was approved at the Remediation portfolio board to be delivered in 2024/25 (Sellafield Annual Research and Development Review, p. 26). It is notable that significant contribution has been made by HOF practitioners in this achievement toward reducing the risks to humans whilst improving productivity.

As a simplistic example of HOF contribution, in Table 2 is a comparison of the original definition of this AI application to a robotic glovebox task and then the revised problem/opportunity statement. The imprint of HOF conceptualisation and pre-design expertise is clear.

Table 2: Comparison of approach statements

Original	Revised
AI for real-time application to inform operations to optimise robotic movements.	The robotic glovebox will process a highly radioactive material that needs to be processed in a challenging operational environment where minimising human exposure is critical/important. This is currently done manually by technicians and is very labour intensive.

	Main hazards are leakage into environment (generating large amounts of radioactive waste) and danger to the operator. There are multiple possible deployment modes –from full mission-based automation, to acting as a supervisor for a human controlling the robot. The focus of this work will be on the case both for the supervisory robot (where the arms are teleoperated by a human, but the AI system provides haptic feedback to prevent collisions or other dangerous behaviour) and autonomous mission-based modes (with a human supervising the operation remotely). The arms could be handling tools during operation.

The above formed the pre-cursor objective before the sandbox trials were undertaken and the commentary in Table 1 developed. As such, it would not have been possible to develop a critique on the safety claims without a thorough problem/opportunity statement. This itself would not have been possible without the input of HOF academics and practitioners. So, whilst HOF might show some reticence towards the role of AI, in fact development in the nuclear industry show that the measured and symbiotic development of AI has only been made possible through HOF practices and research.

Further to this, what ought to give HOF, robotics and AI encouragement is the measured and collaborative process undertaken by the UK regulator. Also, the list of collaborators and contributors is comprehensive enough to account for expertise amongst academics, commercial interests to execute, international regulatory bodies and nuclear power plant licensees.

Conclusion

AI in nuclear HOF is undergoing significant research globally, with the UK 'sandbox' trial the first of its kind anywhere in the world. This, coupled with significant literature output from collaborating international regulators shows that the role of the human in the nuclear industry could be set to change. Whilst HOF has been slower to adopt AI into traditional assessment methodology, the collaborative and measure pace of change in nuclear seems to suit the way HOF has approached safety claims and human/machine task allocation. In many ways, both nuclear workers and HOF practitioners appear to understand that it is this calculated change of pace that will create the all-important trust bucket for AI predictability. In nuclear, it is very well understood that, should it tip over it will empty very quickly.

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