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Light Water Reactor Sustainability Program

FY 23 ION-Based Approaches to Address Labor and Knowledge Retention

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FY 23 ION-Based Approaches to Address Labor and Knowledge Retention

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ABSTRACT

This study will seek to outline the current problem facing the nuclear industry related to staffing, training, and retaining the necessary workforce for long-term sustainability. A review of published reports and knowledge gained by working in the nuclear energy sector will form the basis for this scoping study. This study will not seek to draw any conclusions regarding the underlying causes of these personnel issues but will attempt to ask questions and help outline future research. The Integrated Operations for Nuclear business model provides opportunities to partially mitigate some of the current issues facing staffing the nuclear fleet. Upgrading safety and control systems from analog to digital as advocated by the Integrated Operations for Nuclear process allows the nuclear facility to compete for the best and brightest candidates and offers them a broad and sustainable career path where their skills can be valued and utilized in the broader industrial sectors. This study will seek to identify the primary reasons that the nuclear industry is facing this labor crisis and seek to identify possible solutions that will be fully evaluated in future research.

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ACRONYMS

AI	artificial intelligence
AR	augmented reality
DOE	Department of Energy
I&C	instrumentation and control
IAEA	International Atomic Energy Agency
ION	Integrated Operations for Nuclear
ML	machine learning
NPP	nuclear power plant
PTPG	people, technology, process, and governance

FY 23 ION-BASED APPROACHES TO ADDRESS LABOR AND KNOWLEDGE RETENTION

1. PURPOSE OF THIS STUDY

The nuclear industry is faced with a severe resource retention challenge. The large group of personnel originally hired when most of the current nuclear fleet were being built is facing retirement. Their plant operating knowledge needs to be transferred to replacement personnel but hiring, training, and retaining replacements is difficult and time-consuming. This research will identify questions about the incorporation of Integrated Operations for Nuclear (ION)-based approaches to improve labor and knowledge retention which is a critical element in ION Business Model Figure 1.

The ION business model provides opportunities to partially mitigate some of the current issues facing staffing the nuclear fleet. For example, identifying and hiring experienced instrumentation and control (I&C) engineers and technicians has been reported as being very difficult partially because when viable candidates realize that much of their work will be on obsolete and archaic analog systems, they are no longer interested in the position. They see that experience with analog systems currently used in most nuclear plants is a career dead end and select to work in other industries that are using modern digital systems. Upgrading safety and control systems from analog to digital as advocated by the ION process allows the nuclear facility to compete for the best and brightest candidates and offers them a broad and sustainable career path where their skills can be valued and utilized in the broader industrial sectors.

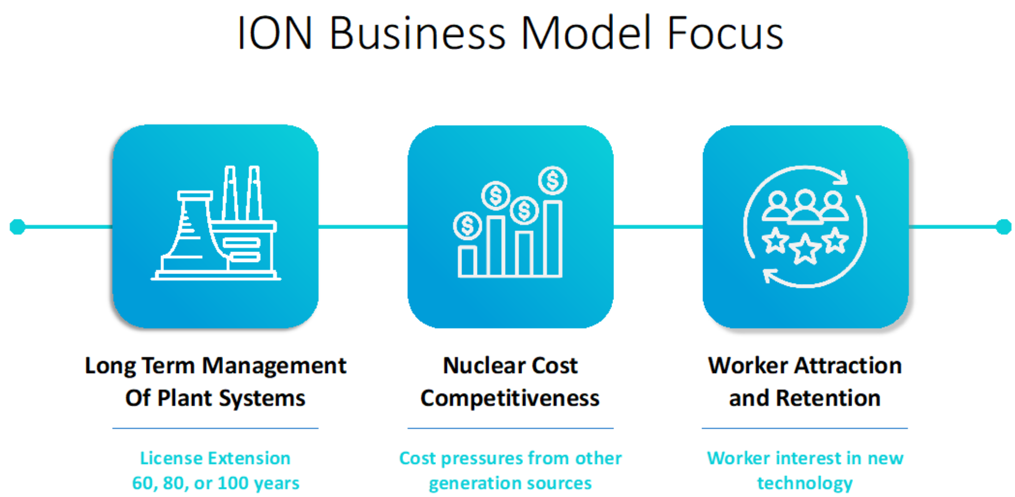


Figure 1. ION business model overview.

This study will seek to identify the primary reasons that the nuclear industry is facing this labor crisis and seek to identify possible solutions that will be fully evaluated in future research. In addition, concerns have been raised regarding the effect that the retirement of experienced personnel may have on the safe and efficient operation of nuclear plants. Many staff that are eligible for retirement have worked in the industry for many decades. They have seen the industry grow and mature and have personally been involved in addressing many of the plant performance issues that plagued the industry in the early years of operation. However, if plant systems and processes can be digitalized and analog equipment replaced with digital systems, much of the base knowledge previously required for the operation and maintenance of these obsolete systems will no longer be required. Modern digital systems require less operator input to function and can self-diagnose system and component faults thereby eliminating difficult and costly troubleshooting activities.

Another benefit of applying digital systems and a digitalized work process is the ability to operate, diagnose and (in some cases) repair systems and equipment remotely. This remote workability will enable bringing the problem to the expert versus bringing the expert to the problem. This capability should enable at least some jobs to be done remotely most of the time and will provide added job flexibility that would be attractive to many potential employees.

Even though the focus of this study is on the current legacy fleet, it is recognized that maintaining a healthy employee attraction and retention program will be vital to the ability to operate and maintain the coming fleet of small modular and advanced reactors. More importantly, defects in the human talent management systems embedded in the current reactor fleet staff will find their way into the next generation of reactors since most of the initial staffing for these plants will come from seasoned employees of the current generation. It is acknowledged that for nuclear power to play a significant role in supplying emission-free energy in the future, a substantial increase in its staff will be required for industry.

1.1 SCOPE OF RESEARCH PROJECT

This study will seek to outline the current problem facing the nuclear industry related to staffing, training and retaining the necessary workforce for long-term sustainability. A review of published reports and knowledge gained by working in the nuclear energy sector will form the basis for this scoping study. This study will not seek to draw any conclusions regarding the underlying causes of these personnel issues but will attempt to ask questions and help outline future research.

This scoping study will not include an analysis of the impact of salary and benefits. It is assumed that these factors will be managed locally according to human resources guidelines.

This research project will be particularly focused on how the application of the ION framework affects the ability of a nuclear plant to sustain a viable and vibrant workforce in the long-term. As shown in Figure 2, the people part of the People, Technology, Process, and Governance (PTPG) equation figures significantly into the overall effectiveness of the ION process. Upgrade programs that do not include every element of the PTPG equation are less likely to succeed compared to integrated upgrades that adopt a holistic and sustainable approach to the entire enterprise.

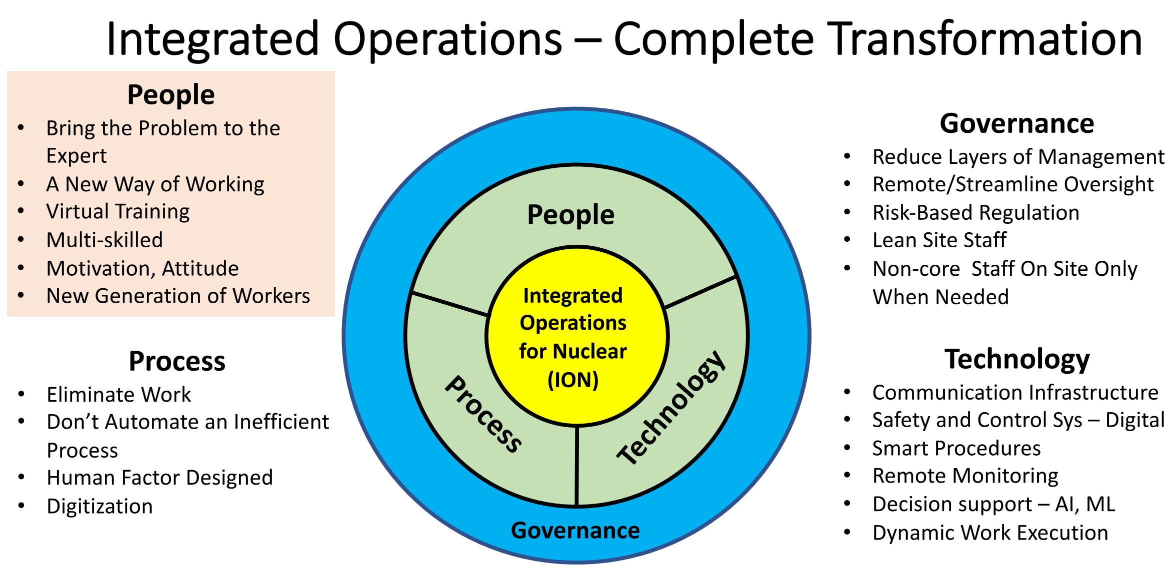


Figure 2. Integrated operations – complete transformation.

2. DESCRIPTION OF INTEGRATED OPERATIONS

As illustrated in Figure 2 the complete transformation to ION is a new way for the nuclear industry to achieve their operational capabilities. Done strategically, a plant's operational capabilities (e.g. deliver power, maintain the plant, ensure safety) can be enhanced by the transformation to integrated operations. To do so requires new supporting capabilities enabled and achieved by the installation of new technologies that can transform the four categories to align them with the characteristics described in Figure 2.

The process of transforming nuclear plant operations takes place over time and across many targeted individual improvements for how work is performed and supported. Nuclear plants have a history of making incremental process improvements to prevent unwanted events from occurring. However, these process improvements typically add complexity or length to a process and do little to reduce the burden on those performing the work. Too often, as these process changes are made, more burden is placed on the employees. The ION framework identifies work processes that are both a cost burden to facilities and have an opportunity to be redesigned using available technology and supporting capabilities to transform the work process.

The key to transforming a work process is the coupling and cooperation of people and technology at a plant that simplifies the processes required to meet the governance that called for the process in the first place. Secondly, the new technologies must be designed to work well not only with its immediate users but also add value to the plant by collecting needed data, transforming data to information or translating information across organizations for other purposes. Capturing, creating, and transmitting information from the total plant environment is part of the transformed nuclear plant envisioned under IONs. However, as stated, this new way to use data and information cannot be achieved until the new technology is designed to work with its users and recipients of the information.

Transforming a process therefore requires an in depth understanding of what is expected of the users as well as what should be expected from the users. Properly designing technology, a work environment, or process that involves a human requires a clear understanding of the strengths and weaknesses of both the system and human. The study of Human Factors has methods for identifying these strengths and weakness and understanding how to develop processes that balance the capabilities of human and technology in a harmonious way. As the nuclear industry faces shifts in the current work force and seeks to attract the next generation of nuclear industry professionals, the processes within the industry must be transformed with an understanding of what skills, knowledge, and abilities should be expected of those performing work in a nuclear plant.

3. HUMAN CHARACTERISTICS AND LIMITATIONS

An early proponent of systems theory, Fitts (1951) wrestled with the challenge of correctly assigning tasks to humans versus machines and created a list ascribing functions to either one. Each task was deemed better performed by a human or machine (Fitts' famous "Humans Are Better At, Machines are Better At" (HABA-MABA) formula), based on characteristics and limitations of both (Figure 3). Although this list is still informative and widely cited some 70 years later, new models of function allocation have since emerged that address degrees of human-machine interactions, in which tasks are completed by a combination of both in concert, and not just one or the other.

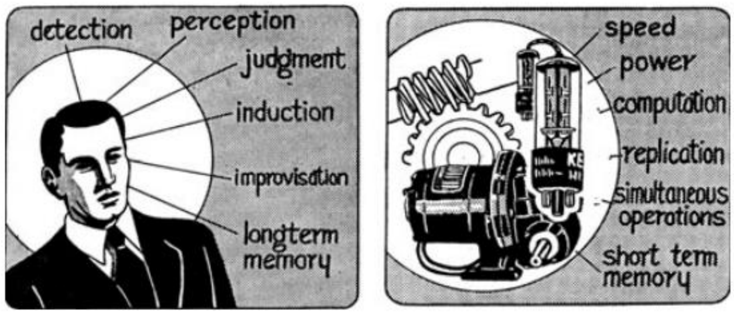


Figure 3. Fitts' (1951) "MABA-MABA" list.

3.1 Description of Human Factors and Function Allocation in the Nuclear Setting

Function Allocation in nuclear has perhaps not deviated as much from the original HABA-MABA classifications. Limited additions of new technological capabilities has stunted much of the transfer of new MABA capabilities and kept humans performing work that could be re-allocated to digital systems quite easily in today's digital world. Kovesdi (2022) has published an overview of function allocation in the nuclear context and summarized some of the more salient critiques of strict use of Fitts' List of which two are particularly relevant here:

1. A false dichotomy: Assigning functions is not as simple as "who does what" but is more often a cooperation between the human and the technology.
2. Overly Simplified: The context in which functions are performed has bearing on how they are allocated and not simply what humans or machines are better at in isolated tests.

These critiques point to the importance of understanding the functions, their purpose, and those who are involved with them to properly integrate the technology into the human-system ecosystem.

Another observation made by Kovesdi, et. al (2021) is that typically function allocation in nuclear has a safety focus and not a production focus. That is, function allocation methods are applied when safety systems are being updated but are more of a cursory exercise when updates are made to secondary systems. However, if ION is going to transform the nuclear industry, then the same level of rigor must be applied to understanding the human-system interaction at all levels and organizations within a plant.

The study of human-system interactions falls under the purview of human factors and engineering (HFE). HFE researchers are trained in psychological science, and nuclear power operations and are tasked with designing user interface technology optimal for humans that promotes safe and efficient operations. Given the rapid increase in digital technology in recent decades, the ways in which nuclear power plants (NPP's) are operated and maintained are also changing, which calls for a different type of workforce, away from mechanical toward digital competencies. Demographic forces are also having an impact on nuclear's future workforce, none more so than the fact that the industry is aging.

4. ADDRESSING THE AGING WORKFORCE

Throughout the 20th century, Western societies added 30 years to their life spans representing an unprecedented longevity gain, and more years added than in all human history combined (National Center for Health Statistics, 2004). In the 21st century, there are no signs of slowing down. Globally, we added almost seven more years to our life expectancy (from 66.8 in 2000 to 73.4 years in 2020; World Health Organization, 2020). This phenomenon has entirely changed the age composition of the world, such that today, the 80+ years age group is growing faster than any other, and in the U.S., by the year 2035 senior citizens will outnumber children for the first time (Vespa, 2018). Unsurprisingly, this has had dramatic and far-reaching ramifications across all aspects of society including the economy, health, and the workforce.

Unlike any time since employment records began, older workers (i.e., the 55+ years age group) in the U.S. now make up the largest sector of industry workers across all age groups (Bureau of Labor Statistics, 2019). This number includes both men and women and will increase further in the coming decades. Consider that only 24 years ago in 1999, the 55 plus age group made up the smallest portion of the labor market and by a margin – a time-tested pattern observed throughout the ages. Historically, younger adults have carried the labor burden. This turnaround is remarkable. There are manifold reasons that older adults delay retirement including rising costs in healthcare and education (Popkin, 2008), and the social benefits that accompany remaining in the workforce (Charness & Czaja, 2006). These unprecedented figures place older workers firmly at the forefront of today's industry and economics, including the energy industry. Today, aging staffers are particularly salient in nuclear power because many career employees were recruited in the 1970s and 1980s when the plants were commissioned. This necessitates close attention be paid by the industrial and government sectors as to how an aging workforce impacts nuclear operations and knowledge management.

Recently, Hall et al., (2022) introduced cognitive aging as a human factor in nuclear operations and outlined several considerations. To begin, performance effects as a function of age must be characterized and examined within the context of experience and expertise. Cognitive development in adulthood is nuanced, and while some skills such as processing speed and working memory decrease with age (McCarrey et al., 2016), other abilities remain stable and yet others demonstrate gains including deductive reasoning and verbal skills (Hartshorne & Germine, 2015). How these gains and reductions are present in the context of expertise accrued over a career must be understood. Hall et al., (2022) show preliminary findings suggesting that performance age effects are mitigated and even reversed by years of on-the-job experience.

In addition, how lifespan changes to cognition will interact with the industry's shift toward digitalization must be understood. This is because more centralized, automated plant control and maintenance will necessitate a workforce skillset different from that currently required. Other work by the Hall research group provides comprehensive methods to empirically test whether there is an interaction effect between age and levels of digitalization/automation (Velasquez et al., 2023). With a shift away from manual communication of operations to coordinating supervision or monitoring, the authors hypothesize that the modest but robust developmental gains in skills such as deductive reasoning, communication, and reduced vulnerability to distractions may prove more beneficial than a younger cognitive toolkit in the modernized control room. In addition, combating cybersecurity threats brought about by digitalization will require individuals with extensive experience and expertise, and who possess a deep knowledge of the systems. Taken together, older generations of talent will become even more relevant as legacy operations digitalize and with the advent of advanced reactor designs.

An important aspect of industry modernization is the introduction of artificial intelligence and machine learning technologies (artificial intelligence (AI)/ML), which are changing the nature of current job functions and how people interact with machines. As mentioned, new and different job descriptions will require augmented and new employee skill sets. In their recent document titled "Future of jobs report 2023", the World Economic Forum estimated that worldwide, 44% of workers' skills will be disrupted in the years leading up to 2027, in part because of AI/ML applications, and 60% will require additional training (Di Battista et al., 2023). According to a global survey of industry leadership, analytics, creative thinking, and understanding of how to use AI / big data are the top-ranking skills-training. Human-machine collaborations will increase for most job descriptions inside NPPs, and while this will create work process efficiencies, the original job description of the employee will be displaced by something else. With the adoption of AI/ML technologies, the nuclear industry will have to be cognizant of creating an environment that ensures the correct skills are being developed in personnel (Agarwal et al., 2023).

Central to industry knowledge preservation is the fact that an aging world has brought about five generations available in the labor market, each with its own distinct characteristics. Broadly defined, Figure 4 illustrates the value systems and motivations for each of the current working generations. While an intergenerational workplace can produce high levels of innovation when fresh ideas from younger minds are skillfully guided by older, experienced minds (Randstad Malaysia, 2018), any breakdown of this cooperation can lead to workplace tension. This requires nuclear stakeholders and leadership to understand the similarities and differences in working styles that each cohort brings into the team mix to minimize conflict, establish effective knowledge pipelines, and develop strategies to best harness the unique abilities that each possesses.

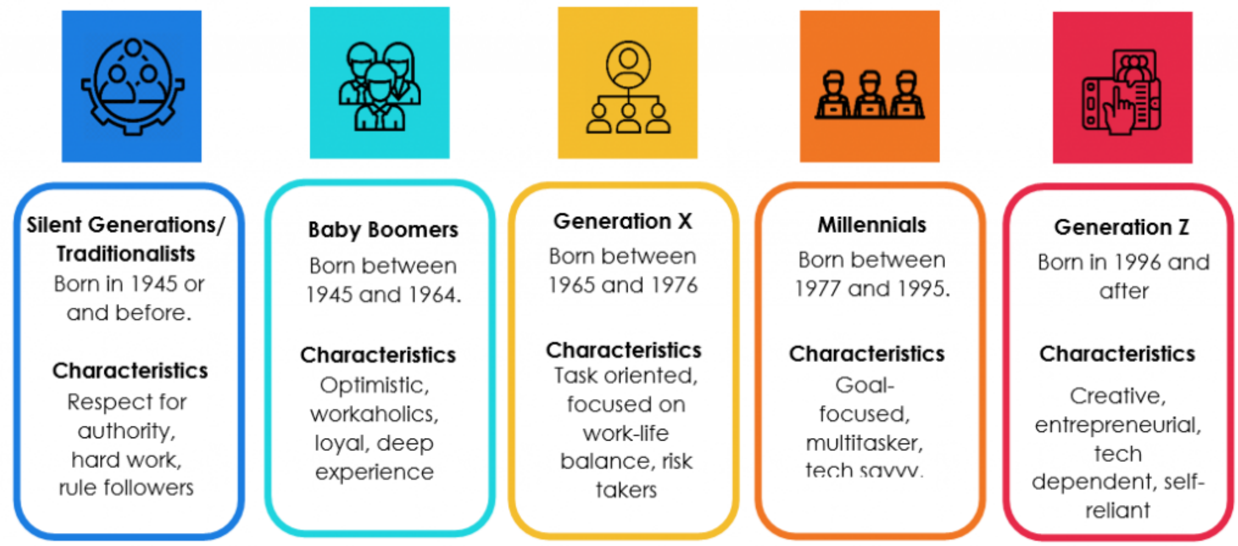


Figure 4. Understanding five generations in the workplace.

Additionally, more so than at any other time in history, the age composition of the current workforce highlights differences in technological competencies and preferences, which are pervasive across generations. Specifically, how humans relate to technology has rapidly changed in recent decades and whereas millennials are classified as tech-savvy, Generation Z is notably tech-dependent.

Beyond technological concerns, the industry must carefully consider talent retention and track with changing career expectations of newer generations of staff. Thus, unlike the traditionalists and baby boomers who typically became career nuclear employees favoring hard work and respect for authority as virtues, younger generations increasingly value a greater work-life balance, creative tasks and greater flexibility in the workday. These traits do not necessarily lend themselves to legacy operations, which are characterized by a highly rule-driven environment, shift work, and mastery of one analog or hybrid plant system only. Recent research by Hall et al., (2023) points towards industry concerns that without a new concept of operations (i.e., digital transformation of a control room), the nuclear power industry might struggle to recruit and retain newer generations of talent. The attractions to a career in nuclear power of yesteryear (i.e., job security and mechanical mastery) no longer apply. Instead, skills portability and self-reliance are now favored. Taken together, developing an ecosystem that not only attracts but grows and retains talent will be critical in strengthening the nuclear human capital base.

Further, the COVID-19 pandemic has unquestionably changed job expectations, with many once-onsite positions reshaped into a work-from-home role, affording employees even greater flexibility in lifestyle and from locations of their choice. Advanced reactors with remote operations capability will be a key factor in an enduring nuclear workforce of the future.

One of the most pressing issues surrounding an aging nuclear workforce is knowledge retention, as long-time employees retire (Stroud, 2015). Since 2004, the International Atomic Energy Agency has produced several documents that identify challenges posed by managing an aging nuclear workforce, and best practices in knowledge preservation. In the main, the guidance depicts lessons learned from industry case studies worldwide, including mentoring and coaching practices. This coincided with the launch of the International Journal of Nuclear Knowledge Management, a publication of “research articles, review papers and technical notes in all domains related to the improvement of the peaceful uses of nuclear energy and the development of nuclear sciences- and technologies-related knowledge”.

The applied psychology literature points to two types of knowledge to be transferred in the workplace:

3. Explicit knowledge – this type of knowledge includes job content and procedures. It can be written down and is relatively easy to pass on.
4. Tacit knowledge, or implicit knowledge – this type of knowledge is more difficult to pass on because it contains information gained from shared experiences and is learned within context. This type of knowledge also contains historical and cultural perspectives of the company, which are essential to employee success.

Different types of knowledge as well as different types of job roles (e.g., supervisor versus craft) will require different transmission approaches. Some examples include knowledge being imparted via training versus experience-based methods. Currently, the industry is filled with highly-skilled and experienced technicians, and with anticipated rapid growth in the energy sector, pipelines must be developed that can establish accelerated knowledge capture and acquisition.

Currently, there are several nuclear power facilities including branches of the DOE-Nuclear Energy complex that are considering future workforce needs and knowledge management. According to International Atomic Energy Agency (IAEA) guidance, knowledge retention for safety-related systems is to be prioritized. At Idaho National Laboratory, the safety scrutiny surrounding radiation has led to thorough and rigorous new hire training, mentorship, and experience for radiation-related tasking. To the extent that other hazardous materials such as those included in chemical and biological laboratories are perceived as less of a threat, there is less likely to be knowledge transfer and mentoring processes in place. Other examples of the link between knowledge retention programs and safety are the initiatives from DOE-Office of Human Capital Development in safeguards knowledge management, and the National Nuclear Security Administration’s Nonproliferation Stewardship Program. An ION-based approach to labor and knowledge retention will complement existing strategies targeting safety-systems already underway in U.S. nuclear power operations and expand out into work processes and business practices.

5. INDUSTRIAL AND NUCLEAR WORKFORCE

Nuclear reactors currently employ around 100,000 people in the United States with each plant employing roughly 400 - 800 personnel (Figure 5) These professions include skilled trades, professional positions, and a range of technicians, engineers, and radiologists. Planned new reactors and keeping existing reactors running will require more jobs than qualified people which could be one of the largest challenges facing the nuclear industry in the coming years.

Figure 5. Jobs in the US Nuclear Sector.

The industrial workforce spans various sectors such as manufacturing, construction, energy, and transportation. As technology advances and global market trends continue to mold the industrial sector, it is essential to grasp the forthcoming employment opportunities and obstacles that the industrial workforce will encounter.

The majority of people who quit their jobs in the past two years are not returning to the industries they left. The mass departure of individuals from their previous industries and their subsequent choices to embark on new career paths reflect a confluence of factors, including involving work values, industry-specific challenges, technological advancements, and the changing dynamics of the job market. This pattern not only changes the course of individual careers but also holds wider consequences for industries in the years ahead. Industrial companies are seeking to adjust their strategies to attract and retain talent within an ever-evolving professional environment.

As stated by David Drury, who leads the Nuclear Knowledge Management Section at the IAEA, nuclear power organizations should be designing human resource requirements to create appealing work environments to bolster their industrial workforce. It is essential to offer a clear path for career growth to potential employees and newcomers to accomplish this objective (Drury, D. 2019).

The industrial workforce is experiencing a growing integration of automation and digital technologies. This shift enhances productivity and efficiency but also necessitates a change in skill requirements. The demand for professionals proficient in robotics, AI, and data analytics is predicted to increase.

Adapting to the evolving requirements of the industrial workforce field requires a consistent focus on reskilling and upskilling the current workforce. Employers will be looking for adaptable employees capable of swiftly acquiring new technologies and methodologies.

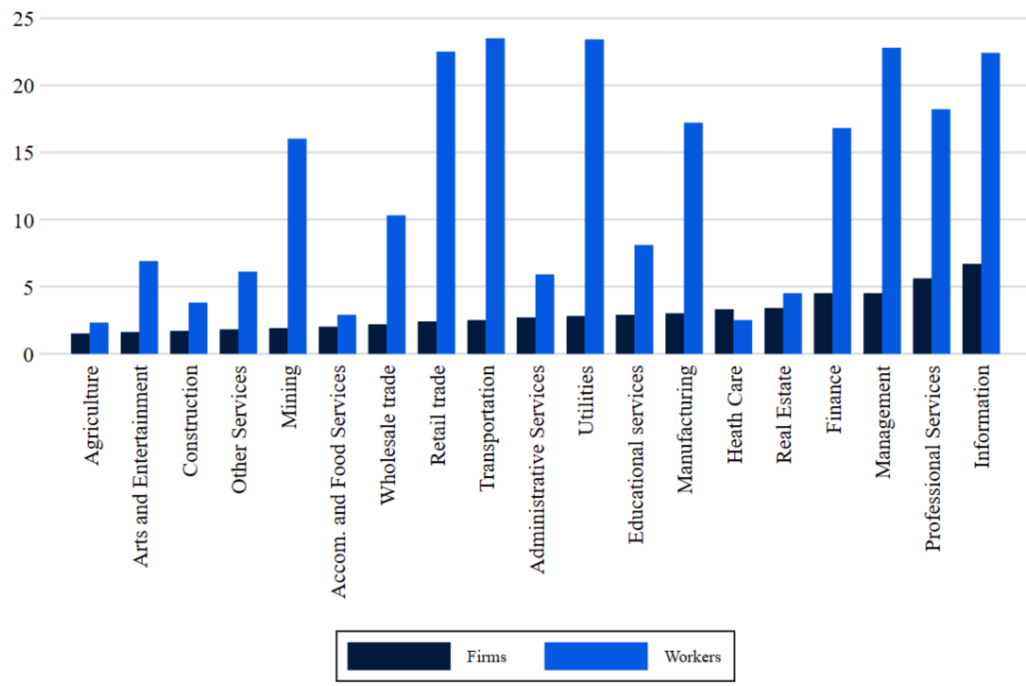
Recent IAEA research meetings emphasized the importance of building knowledge transfer programs with a focus on mentoring and leadership development. Participants suggested utilizing the IAEA's capacity-building mechanisms and exchange platforms to facilitate this process. Representatives from China, France, the Russian Federation, and the United States shared their relevant experiences in this regard (Drury 2019).

A substantial segment of the industrial workforce, aged 55 and older, anticipates continuing work beyond the typical retirement age. As these workers age, they encounter shifts in both physical and cognitive aspects. Research has noted declines in cognitive functions, visual clarity, and physical abilities among older employees. These physiological declines are associated with decreased quality and quantity of work performance, as well as increased variability over time. There comes a threshold where workers may no longer be able to perform their duties effectively, highlighting the importance of understanding the dynamics of industrial workers' functional capabilities (Dimovski, V., et al. 2019). However, other studies as outlined in section 4, indicate that older workers may provide the maturity and decision making abilities necessary for future reactor operation.

The industrial workforce has been encountering notable challenges, particularly tied to changing demographics. An important issue revolves around the aging workforce, potentially resulting in skills shortages. To tackle this concern, it is imperative to proactively inspire younger generations to choose careers within our industry. Moreover, the advent of automation and AI raises ethical questions that warrant attention. It is essential to promote responsible technology implementation and effective workforce management to address the broader societal impact of these technological advancements.

Furthermore, as industries become more digitally interconnected, cybersecurity threats become more prevalent. Prioritizing cybersecurity training and investing in robust measures to protect sensitive information is vital for both industrial workers and companies. This approach helps safeguard valuable data from potential cyberattacks.

With the continuous progress of AI and machine learning (ML) technology, notable transformations are anticipated for the industrial workforce, influencing elements such as employment, productivity, and overall expansion. Reflecting on the history of workplace technology tracing back to the Industrial Revolution, it is evident that each new advancement has prompted alterations in the skill sets required by various industries. The integration of automation and AI is predicted to accelerate these skill shifts even further, surpassing the pace of changes observed in recent times. Automation and AI will accelerate the shift in skills that the workforce needs see Figure 6. (Bughin, J., et al. 2018)



Source: Annual Business Survey 2019; CEA calculations

Figure 6. Jobs in the US Nuclear Sector percentage of firms and workers with some AI adoption. (Source Bughin, J., et al. 2018).

The ongoing incorporation of automation and AI technologies is expected to continually reshape the industrial workforce. As automation replaces routine and repetitive tasks, workers must adapt by acquiring new skills that complement and work in partnership with technology. This may involve developing expertise in managing and maintaining automated systems, data analysis, and programming.

The future industrial workforce will require a strong foundation in digital literacy. Proficiency in digital tools, software, and platforms becoming increasingly important across various job roles. Technologies like virtual collaboration tools, remote monitoring systems, and augmented reality (AR) will enable remote work in industrial settings.

Collaboration between humans and machines will be key in the future of work, with automation and AI technologies augmenting human capabilities rather than replacing humans. Skills in managing and collaborating with intelligent machines, along with creativity, problem-solving, critical thinking, and emotional intelligence, will be essential for workers.

Sustainability and environmental responsibility are gaining importance in industrial sectors, and the future workforce will need to be aware of sustainable practices, energy efficiency, and green technologies. There will be a growing demand for professionals who can design, implement, and manage environmentally friendly solutions in industrial operations.

6. ECONOMIC IMPLICATIONS OF WORKFORCE ISSUES

Globally, the COVID pandemic disrupted a lot of lives and a lot of things, not the least of which was the U.S. labor market. Faced with mandates to "stay home," employees were forced to figure out how to effectively work-from-home, find themselves laid off, or find employment where work-from-home was a suitable alternative. These, among other relevant drivers, brought on what has been coined "The Great

Resignation" in the U.S. labor force (Giggleman 2022). The U.S. Bureau of Labor Statistics collects data on the rate at which people voluntarily leave current employment (BLS 2023). Before the pandemic, that rate ranged from 1.5% to 2%. This means that 'on average,' an employer could expect 1.5% to 2% of their workforce to turnover each year. At the height of the pandemic, the quite rate peaked at 3%. Although in practice this does not sound like a large change, in real terms, that is double the number of people voluntarily separating from employment, that is a lot of people. Today the quite rate has returned to a relatively normal level of 2.4%, which is consistent with the long-term average of 2.2%.

During this period (2020 – 2022) when people were leaving current employment, the energy sector added new workers. Energy sector jobs grew by roughly 4% during the same period when other sectors were losing people (U.S. DOE 2022). Prior to the pandemic, energy sector job growth was one of the fastest-growing sectors of the economy, and that momentum may have sustained much of the growth during the pandemic. And while employment in the nuclear industry grew, it did not keep pace with the energy sector more broadly. Employment in the nuclear industry grew by just over 2% during the same period.

Recent research provides an informative view of the extent of labor market challenges in the nuclear industry. A recent survey by the North American Young Generation in Nuclear (NAYGN) found that the two biggest drivers of young professionals leaving the industry were low morale and increasing workloads (Smyth et al. 2022). It also found that job satisfaction among their members was decreasing, leading to a finding that nearly half of the surveyed members were job hunting at the time of the survey. And more compelling, over a quarter of the surveyed members were seeking to leave the nuclear industry altogether. When questioned about why they want to leave, the top four answers included 1) issues related to work-life balance, 2) higher compensation and better benefits elsewhere, 3) corporate culture, and 4) lack of advancement opportunities. These findings are consistent with other surveys. GETI (2023) found that 81% of survey respondents were job hunting for better proximity to family and focused more on work-life balance.

These insights from the employee perspective are consistent with recent survey analysis from the supplier perspective. A recent study from the Gateway for Accelerated Innovation in Nuclear (GAIN) conducted a survey of nuclear supply chain vendors to assess capacity to ramp production to meet projected industry growth (Lohse et al. 2023). When the respondents were asked about their issues of concern, workforce availability and work force experience resoundingly rose to the top. Workforce challenges are well-documented from both employee and employer perspectives. These findings do not get into the issue of an aging workforce in the industry, which is a whole other issue of workforce economics not touched on here.

A recent conversation, although anecdotal, may shed some light on what may be contributing to trends surveys are capturing. At a social event, a young welder, who is also a pipefitter and business owner was asked, "Do you anticipate submitting bids for nuclear work to be performed at a local nuclear facility?" The young welder's response was an emphatic, "No way!" When prompted for more detail, the welder responded that he could make more money in less time in food processing and manufacturing than in nuclear welding because of "all the red tape" in nuclear. Hardly a general result, but the welder's response is worth thinking about how his insight may apply more broadly to the gaps identified in the nuclear workforce.

An economic consequence of workforce issues is that of employee turnover; specifically, how much does employee turnover cost the industry each year, or each utility? Although the BLS collects data on the quit rate, it does not collect it specifically for the nuclear industry. However the BLS data show that from 2013 to the present, the average quit rate across the U.S. labor force is 2.2% (BLS 2023). A recent DOE estimate of energy sector employment finds that at the end of 2019, there were approximately 100,000 people employed in the nuclear industry (U.S. DOE 2019). As for the per-employee cost of turnover, estimates range from 33% to a factor of 4 times the separating employee's salary (Heyman 2023; Shuster

2022). Taken together, these statistics and a median average wage in the nuclear industry of $41.32 (ScottMadden 2021) can be applied to obtain a "back-of-the-envelope" calculation of the cost of employee turnover in the nuclear industry. More specifically, the equation to obtain this result follows.

Cost = #employees * median wage * turnover cost * quit rate

Parameterizing this equation with the data in the preceding paragraph and normalizing by MW yields the following table of results.

Table 1. Rough-order estimate of the cost of annual employee turnover in the nuclear industry

	Turnover cost 33% of separating employee salary	Turnover cost 4× that of separating employee salary
$/MW	594	7,920
Industry (95 GW)	56,724,096	756,321,280
Nuclear Power Plant (1000 MW)	594,000	7,920,258

Table 1 shows a rough-order approximation, but the data provide a sense of the magnitude of workforce economics in the nuclear industry. Given that today the nuclear workforce is about 100 thousand people, and that labor force needs to be projected into the future in the DOE Liftoff reports is over 300 thousand people (Kozeracki et al. 2023), issues of workforce retention and attraction will need to be addressed.

The survey data shows show that work-life balance and compensation are key drivers of workforce retention. Understanding what this means across the staffing at a nuclear power plant is an important area of future investigation. Especially, important, estimating the wage delta needed to attract qualified candidates who now appear to be migrating to other energy sector employment. Finally, investigating more formally what 'red tape' issues mean for the potential workforce and how to mitigate these is needed.

7. FUTURE RESEARCH NEEDS

The central purpose of this research task was to formulate questions related to labor availability and worker retention along with knowledge transfer to incoming workers. In addition, this report investigated in a summary manner how utilizing the ION approach to plant operation and maintenance could impact future labor requirements for existing and new reactors. Many other reports that were reviewed for this research were more focused on the classic worker attraction and retention issues including pay, benefits, and work life balance. However, none of them evaluated how the use of advanced technology, modern management strategies and multi-skilled labor categories could help address this looming labor problem. Future research should address the ION related issues while not ignoring the more classical human resource issues.

The output of this research suggests that the next step to take in understanding and then helping create helpful solutions would be to assess the state of labor utilization and capability retention across the nuclear industry. This future study could evaluate the application of advanced digital technology and business process transformation to improve labor utilization and capability retention while maximizing efficiency and cost savings. Working with industry leaders including Xcel Energy and Dominion Energy the following project could include:

- Determine how implementation of ION can mitigate labor utilization issues
- Determine the most critical priorities between retention, hiring, attrition and knowledge transfer

- Survey advanced collaboration and remote workers technologies
- Evaluate solutions that can best mitigate labor utilization and knowledge retention issues in the ION business model context.

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APPENDIX A

ION-BASED APPROACHES TO ADDRESS LABOR AND KNOWLEDGE RETENTION

Appendix A
ION-Based Approaches to Address Labor and Knowledge Retention

Briefing Paper

Authors:
Jason Remer, Anna Hall, Zachary Spielman, Jason Hansen, Jodi Vollmer

August 2023

LWRS LIGHT WATER REACTOR SUSTAINABILITY

ION-BASED APPROACHES TO ADDRESS LABOR AND KNOWLEDGE RETENTION

Context of Research

The nuclear industry is faced with a severe resource retention challenge. The large group of personnel originally hired when most of the current nuclear fleet were being built is facing retirement. Their plant operating knowledge needs to be transferred to replacement personnel but hiring, training, and retaining replacements is difficult and time-consuming. This research will identify questions about the incorporation of Integrated Operations for Nuclear (ION)-based approaches to improve labor and knowledge retention which is a critical element in ION Business Model Figure 1. The ION business model provides opportunities to partially mitigate some of the current issues facing staffing the nuclear fleet.

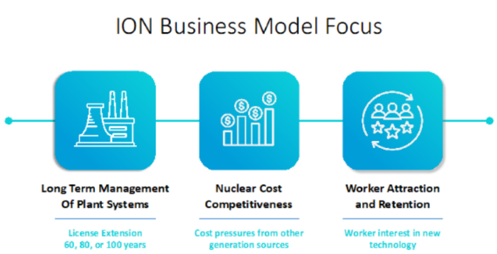

Figure 1. ION Business Model

Summary of Research Efforts Results

The central purpose of this research task was to formulate questions related to labor availability and worker retention along with knowledge transfer to incoming workers. In addition, this report investigated in a summary manner how utilizing the ION approach to plant operation and maintenance could impact future labor requirements for existing and new reactors. Many other reports that were reviewed for this research were more focused on the classic worker attraction and retention issues including pay, benefits, and work life balance. However, none of them evaluated how the use of advanced technology, modern management strategies and multi-skilled labor categories could help address this looming labor problem.

Central to industry knowledge preservation is the fact that an aging world has brought about five generations available in the labor market, each with its own distinct characteristics. Broadly defined, Figure 2 illustrates the value systems and motivations for each of the current working generations. While an intergenerational workplace can produce high levels of innovation when fresh ideas from younger minds are skillfully guided by older, experienced minds (Randstad Malaysia, 2018), any breakdown of this cooperation can lead to workplace tension. This requires nuclear stakeholders and leadership to understand the similarities and differences in working styles that each cohort brings into the team mix to minimize conflict, establish effective knowledge pipelines, and develop strategies to best harness the unique abilities that each possesses.

U.S. DEPARTMENT OF ENERGY

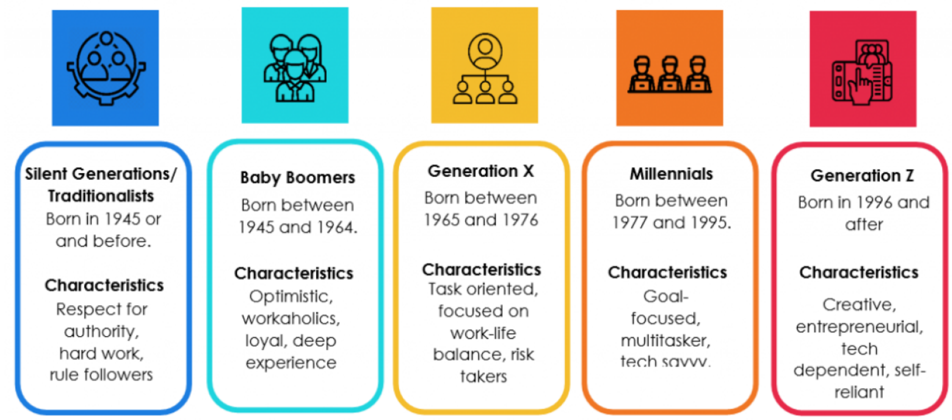

Figure 2. Understanding five generations in the workplace.

Next Steps

The output of this research suggests that the next step to take in understanding and then helping create helpful solutions would be to assess the state of labor utilization and capability retention across the nuclear industry. This future study could evaluate the application of advanced digital technology and business process transformation to improve labor utilization and capability retention while maximizing efficiency and cost savings. Working with industry leaders including Xcel Energy and Dominion Energy the following project could include:

- Determine how implementation of ION can mitigate labor utilization issues
- Determine the most critical priorities between retention, hiring, attrition and knowledge transfer
- Survey advanced collaboration and remote workers technologies
- Evaluate solutions that can best mitigate labor utilization and knowledge retention issues in the ION business model context

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More on the LWRS Program: https://lwrs.inl.gov/

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