INL/CON-24-79887-Revision-0

Digitalized procedures in nuclear power operations

July 2024

Anna Hall

Changing the World's Energy Future

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/CON-24-79887-Revision-0

Digitalized procedures in nuclear power operations

Anna Hall

July 2024

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517


DATAGLANCE
CX2024
Users Conference &
Functional Training
Drury Plaza Hotel – *Disney Springs®*
July 29 – August 1, 2024
DATAGLANCE
CX2024 Users Conference & Functional Training

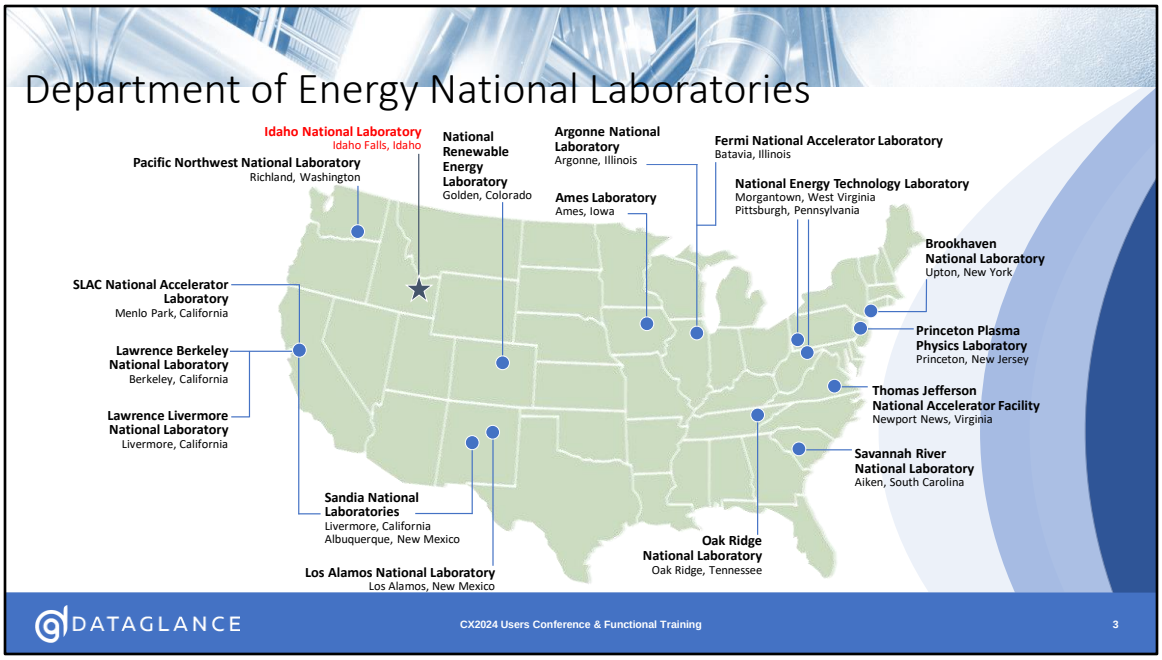
Anna Hall, PhD

Senior Scientist, Human Factors and Reliability
Idaho National Laboratory

Digitalized procedures in nuclear power operations

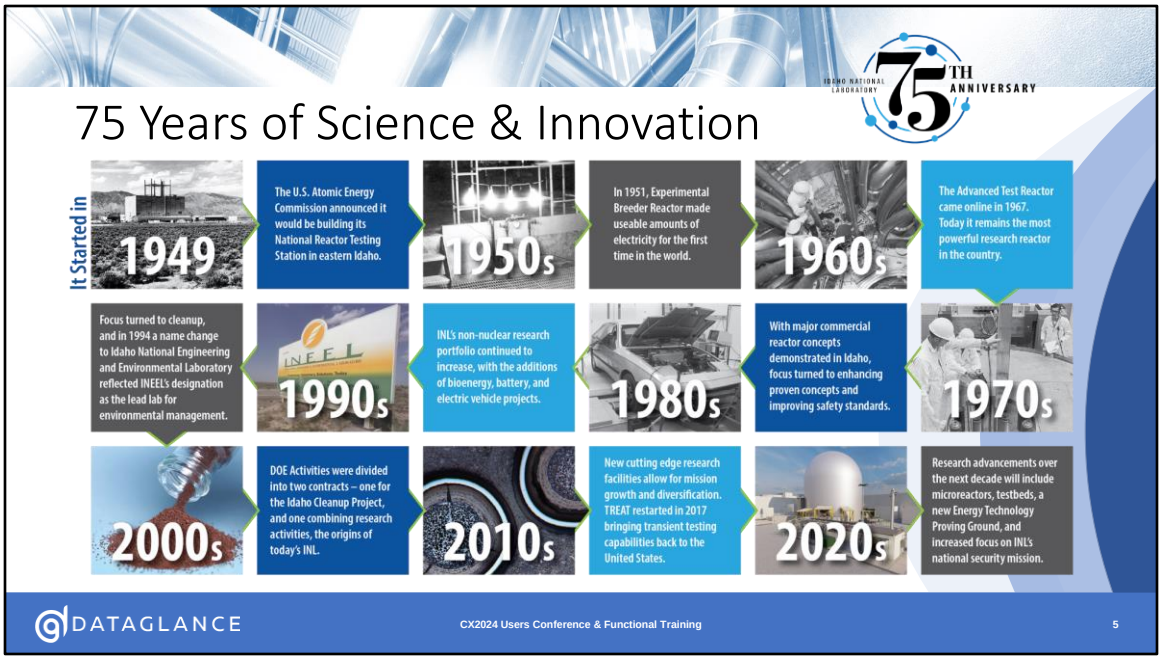
Idaho National Laboratory

& Functional Training



Together, the 17 DOE laboratories comprise a preeminent federal research system,

INL spans 890-square-mile area in southeastern Idaho we have unique strategic scientific and technological capabilities. The desert site is 35 miles from Idaho Falls. We have been growing and we're currently at around 6000 employees.



National Reactor Testing Station

On Feb. 18, 1949, the U.S. Atomic Energy Commission announced it would be building its National Reactor Testing Station on the Naval Proving Ground in eastern Idaho. The Idaho site was chosen over a more remote site in Montana based on socio-economic factors, namely nearby towns that could absorb new population.

The National Reactor Testing Station drove nuclear innovation in the U.S. and around the world.

World's first nuclear power plant, first U.S. city to be powered by nuclear energy (1951 – four light bulbs - Argonne's Experimental Breeder Reactor No. 1), first Submarine reactor tested; first Mobile nuclear power plant for the army.

1953 Submarine Thermal Reactor marked the birth of America's nuclear navy

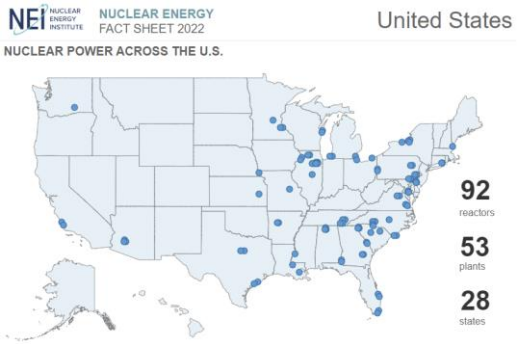
1955 Arco, Idaho has proudly claimed the title of "First City Lit By Atomic Power."

- **https://www.axis.com/blog/secure-insights/critical-infrastructure-cyberattacks/**. *Use as a talking point to discuss INL's cybersecurity efforts.*
- **Hydrogen Production Facility**
- **Nuclear Aircraft Carrier and Submarine** – A U.S. fast-attack submarine steams ahead of the aircraft carrier USS Ronald Reagan
- **Plant Vogtle:**
- **Curiosity Rover** –currently roaming Mars. The rover's space battery (radioisotope thermoelectric generator) was assembled at MFC and transported to the Kennedy Space Center prior to launch.
- **Abrams Tank** –

U.S. nuclear industry recognizes the demand for new nuclear

Utilities recently identify the need to add 100 gigawatts of nuclear power by 2050, more than doubling current capacity.

Today, 92 reactors provide nearly 20% of the electricity produced for our power grid and more than half of our carbon-free electricity – more than solar, wind, hydro, and geothermal combined.



- Utilities are prepared to invest in nuclear energy because it is a proven non-carbon-emitting solution
- New reactor designs are simpler, more versatile, and more economical at scale
- Utilities are evaluating reusing retired coal plant sites to leverage existing infrastructure and workforce

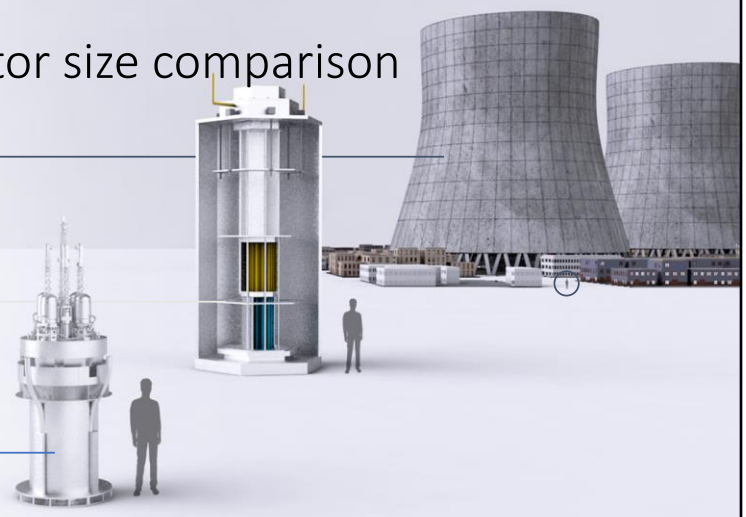
In March 2023, Chief Nuclear Officers at Nuclear Energy Institute member utilities identify the need to add 100 gigawatts of nuclear power by 2050, more than doubling current capacity.

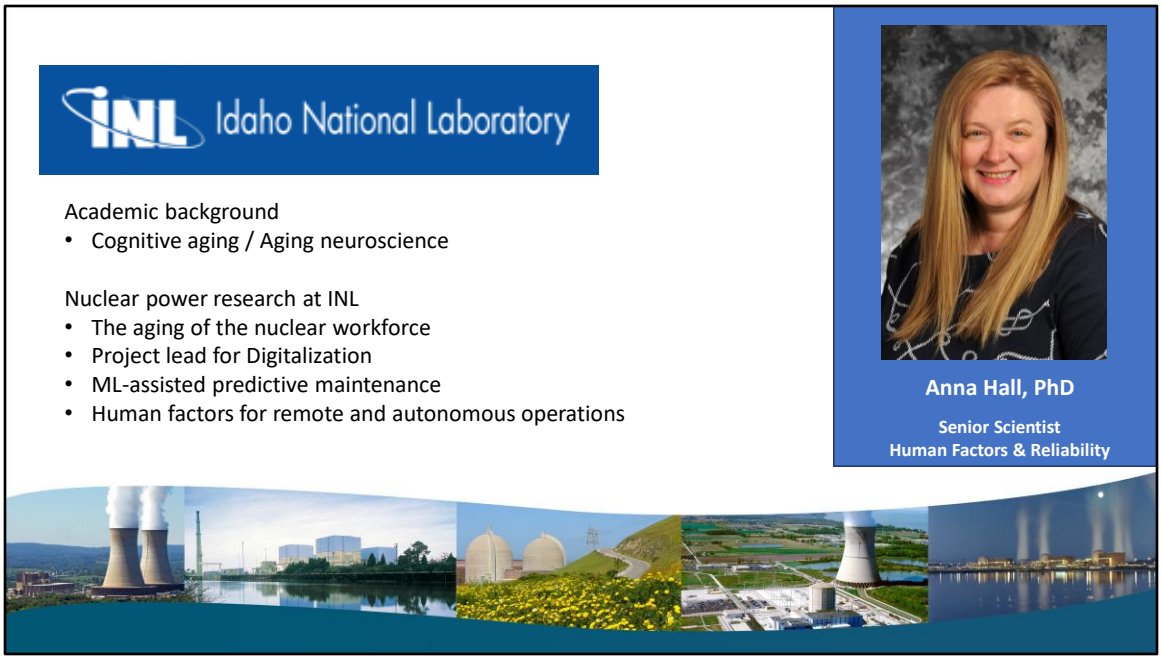
Advanced reactor size comparison

Large-Scale Reactor
300 MW – 1,000+ MW
1,500 ACRES

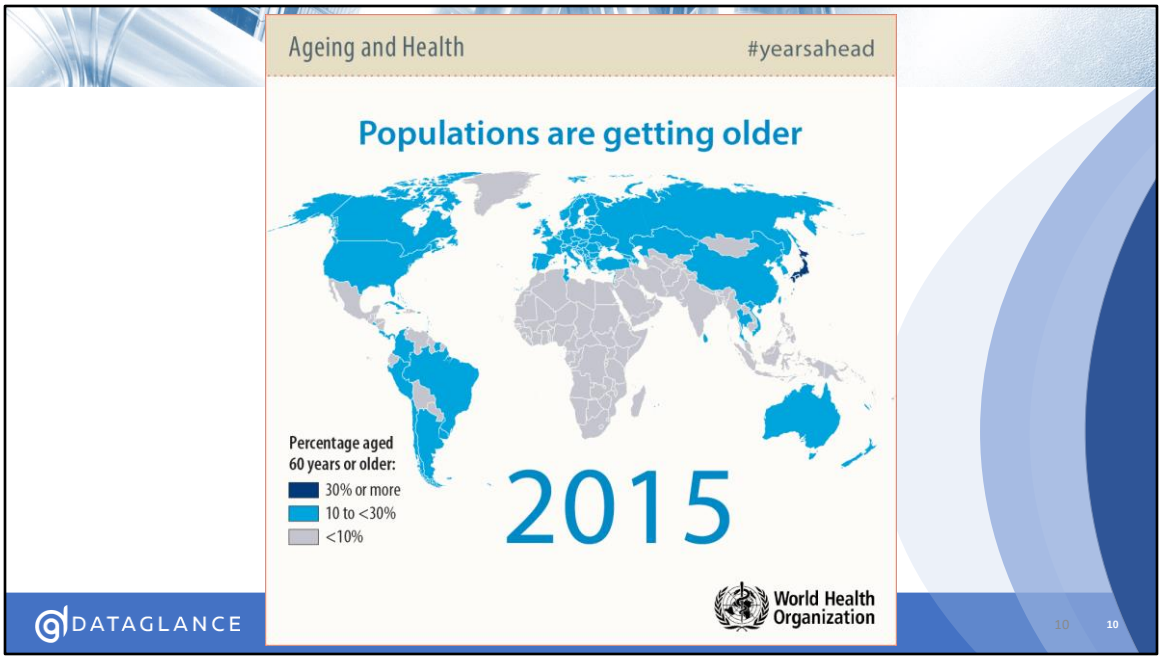
Small Modular Reactor
20 MW – 300 MW
50 ACRES

Microreactor
1 MW – 20 MW
LESS THAN AN ACRE



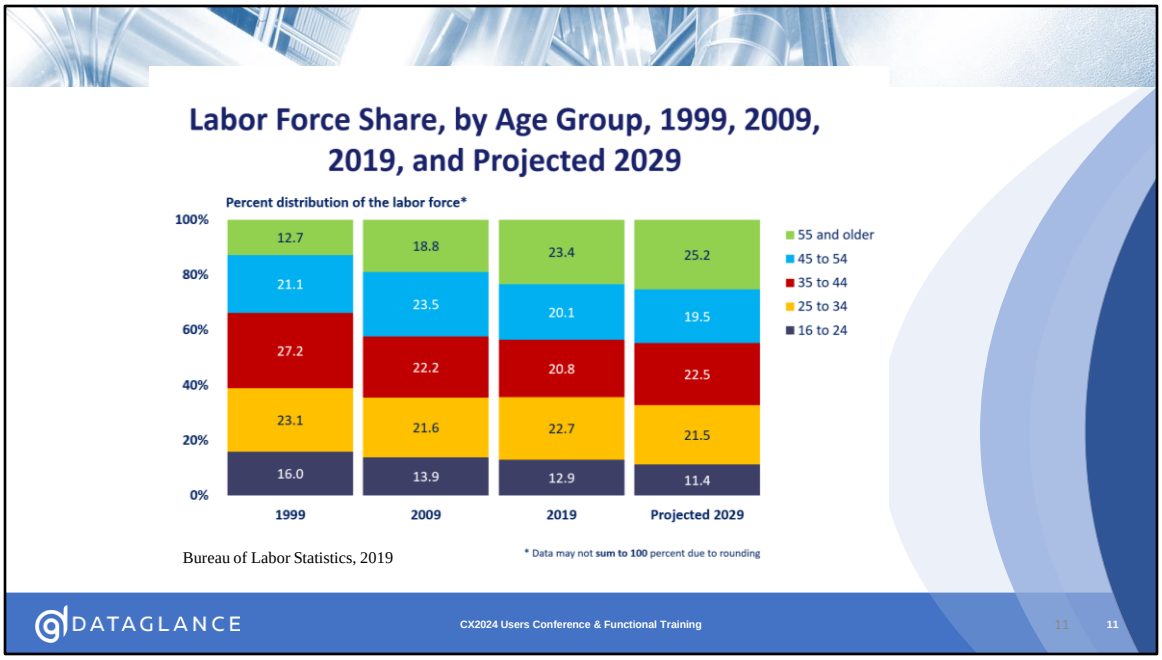


I'm currently spearheading research efforts that examine the aging nuclear workforce. You'll be aware that the world is aging and so is the workforce, and nuclear is no exception. So I'm able to bring my aging expertise to bear on topics such as industry knowledge retention across a multi- generational workforce, potential age effects in technology adoption, and we're actually running an experiment looking at perception and performance effects in digitalized technologies that might differ across age of user.
Knowledge retention / attracting new talent



Populations are getting older. Globally, the world's population of people 60+ years of age has doubled since 1980 and we're on course to double again by 2050 reaching 2 billion making people aged 60 years and older the fastest growing age group.

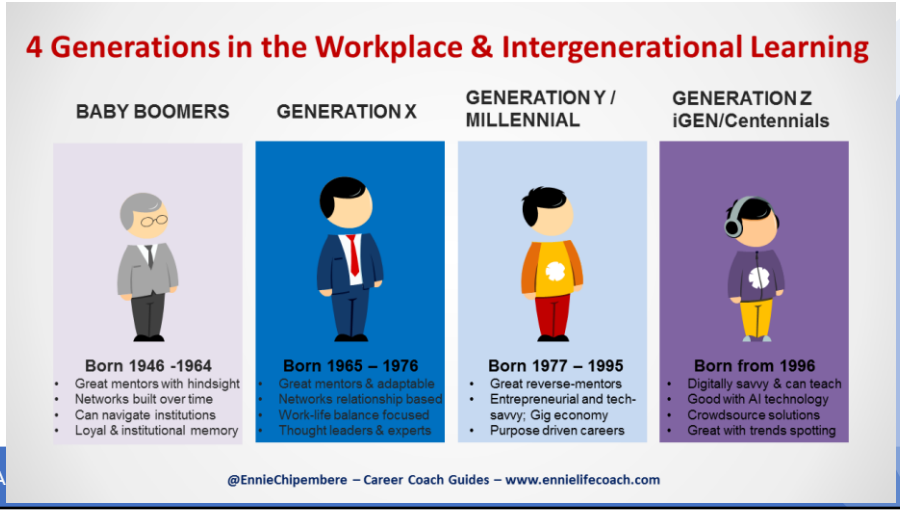
Did you know that in 2035, older adults are **projected to outnumber kids** for the first time in U.S. history?



The workforce is aging. What I want you to pay attention to here, is the share that the oldest workers hold: you can see that in 1999 they made up the smallest share but in 2019 they made up the largest share. And that's only going to grow. This is quite remarkable – for the first time in human history, older adults compose the largest share of the workforce.

As a result, the ways in which aging is associated with performance in the workplace has gained attention in recent decades [7, 8]. With that said, developmental aging effects begin to manifest much earlier than reaching older adulthood, and understanding differences and changes across life stages is necessary to optimize performance in the workplace. Of that 25.2%, about 8% will be 65+

Intergenerational workplace

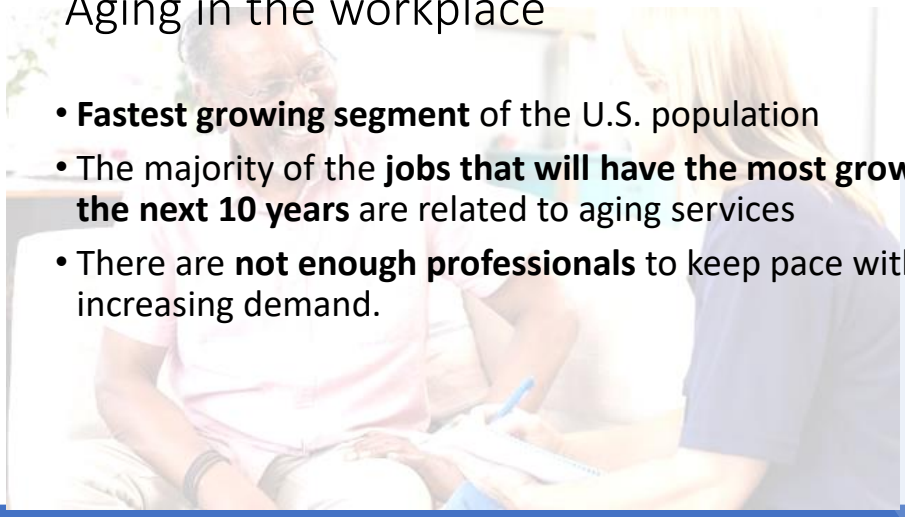


Moving towards a top-heavy society means the workplace, including energy operations, are seeing an increase in intergenerational staff. What this means is that training and management now must have an understanding of the abilities, motivations and values differences across generations, in order to elicit best performance.

There's a law that the president cannot be <35 years

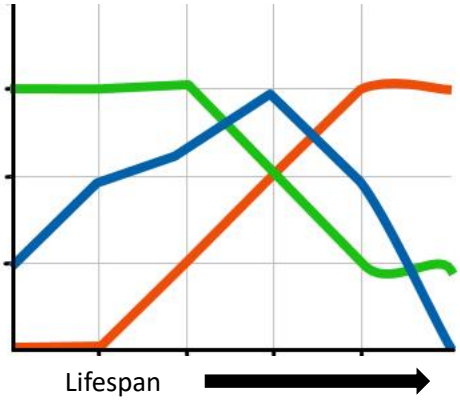
$350 million additional funding to the NIA to fund Alzheimers in the years 2016 and 2017

Aging in the workplace



- **Fastest growing segment** of the U.S. population
- The majority of the **jobs that will have the most growth in the next 10 years** are related to aging services
- There are **not enough professionals** to keep pace with the increasing demand.

Cognitive Aging 101



Cognitive abilities peak and crest at different times throughout the lifespan

Cognitive aging = Developmental effects the natural aging process has on cognitive function

Cognitive functions peak at different times across the adult lifespan

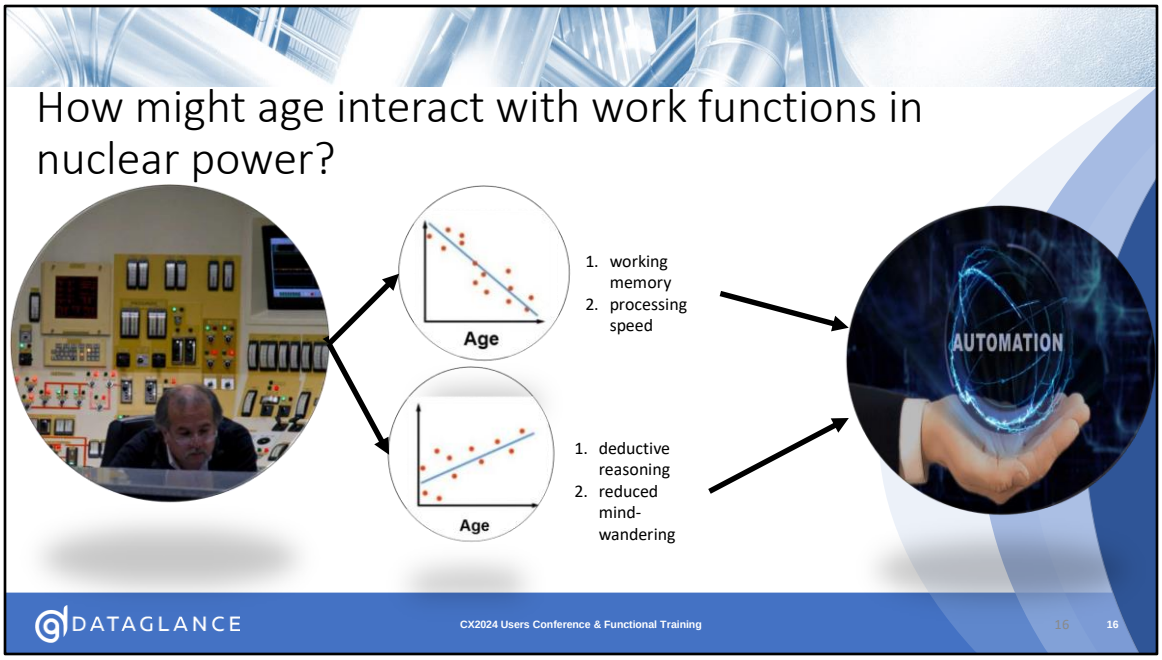
- Color vision in early 20s
- Face learning ability in early 30s
- Language accumulate across a lifetime

INL CAES

- 2020 Summer Visiting Faculty Program
- Title: “Cognitive aging and human performance in a nuclear power plant control room”

CAES
Center for Advanced Energy Studies

I became really interested in nuclear human factors research about four years ago, when I applied for and won a small grant from CAES to develop the premise that cognitive aging is something that we should be paying attention to in nuclear operations.

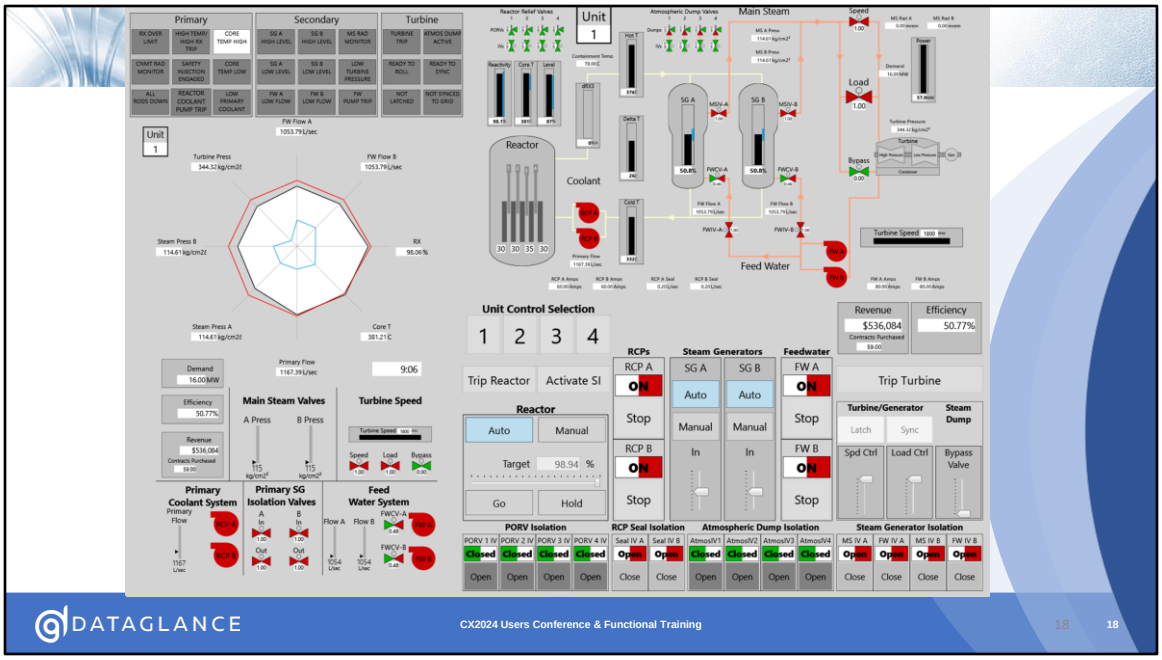


So what might it look like? Let's now consider two cognitive functions that are implicated in safe and efficient NPP operations: working memory (the ability to hold and manipulate information in mind for short durations [50]) and prevalence of task-unrelated thoughts, or mind-wandering. Interestingly, although young adults typically outperform older adults on most tasks of working memory [51, 52], they are also more susceptible to task-unrelated thoughts [53–55]. Taken together, given that optimal human performance in the NPP control room relies on a multitude of skills that peak and crest at different times throughout the lifespan, how aging interacts with these specific cognitive skillsets will be vital for realizing age-differentiated work design [57], as well as new age-sensitive HMI designs and guidance tools for modernization.

Do we know anything about cognitive aging in nuclear?

- Preliminary results of performance data

- N=15 nuclear industry workers
  - Age range = 22-65 years, 2 females



Rancor is a simplified simulator that mimics both everyday operations and emergency situations performed in an NPP. It was developed at INL and the University of Idaho (Ulrich et al., 2017) by human factors scientists and contains essential NPP components and systems such as the reactor core, control rods, reactor cooling and feedwater pumps, bypass and load valves, steam generators, and turbine. Static screens

The interface consists of three areas:

Importantly, Rancor allows both operations experts and novices without operations experience to effectively monitor and control a simulated NPP to a proficient level.

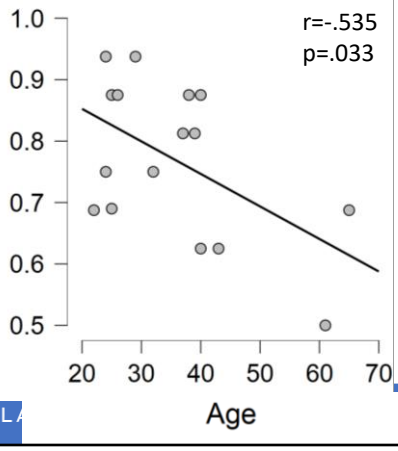
Answer questions about a HMI display

We asked them state, range, digital and position questions. So, for example, one of the range questions was “Is the Power at full capacity”. An example of a position question was “What are the positions of the control rods in the Reactor”?

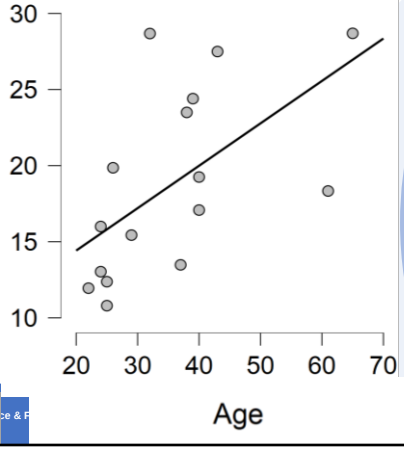
They answered 16 questions in total, and I examined how performance and reaction time scores varied by age.

Results: Age is linked to lower and slower performance

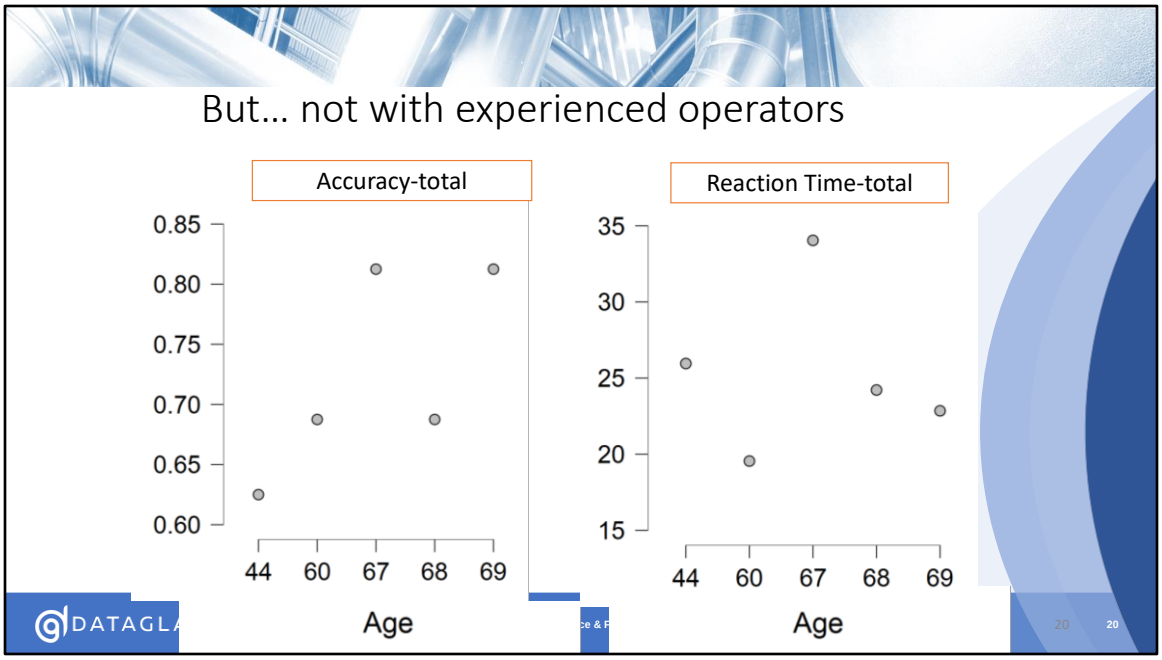
Accuracy



Reaction Time



19



Expertise mitigates cognitive aging effects. Software compensates for hardware

Summary of aging in nuclear

1. Advancing years is linked to lower and slower HMI performance in nuclear industry staffers
   - But this isn't the case with experienced operators

   - Design implications
   - Safety performance implications
   - Time-critical actions

2. What about new generations of 'digital natives' on legacy nuclear plants?

Points to aging versus expertise.

The public appears to be generally favorable to older operators with expertise, but may have safety concerns

Cognitive aging research in nuclear may help reassure the public

So up until now we've been considering how aging minds interact with technology and CR modernization, but equally crucial question for the nuclear industry is the effect of new generations of 'digital natives'

Taylor & Francis

Nuclear Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/unct20

Cognitive Aging as a Human Factor: Effects of Age on Human Performance

Anna Hall, Ronald L. Boring & Tina M. Miyake

To cite this article: Anna Hall, Ronald L. Boring & Tina M. Miyake (2023) Cognitive Aging as a Human Factor: Effects of Age on Human Performance, Nuclear Technology, 209:3, 261-275, DOI: 10.1080/00295450.2022.2073951

To link to this article: https://doi.org/10.1080/00295450.2022.2073951

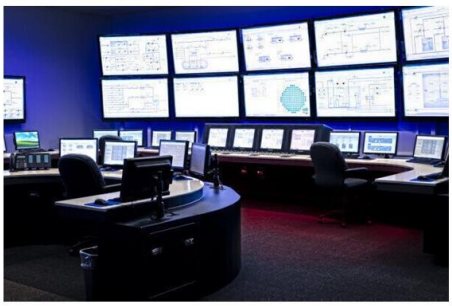
Digitalization research at INL

DATAGLANCE

CX2024

IDAHO NATIONAL LABORATORY

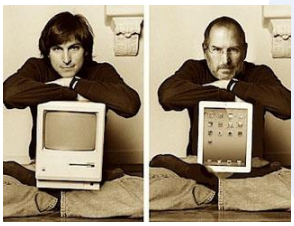
Nuclear power modernization



- **Have perspectives on Control Room Modernization changed in the last 10 years?**

Perspectives on control room modernization

- ❑ The purpose of collecting the survey data was to help identify current industry thinking with regard the opportunities and challenges inherent in CRM.
- ❑ Recent findings were compared with answers to the same questions 10 years ago.



Survey Overview

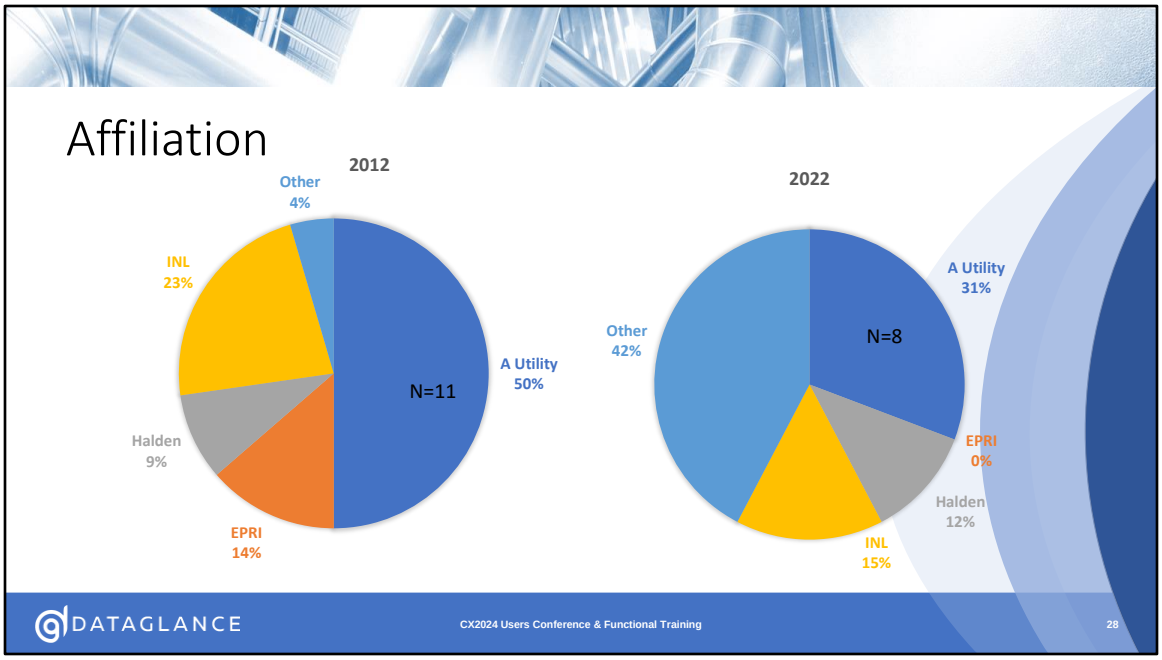
2012

- Issued at the 2012 Winter LWRS Utility Working Group Meeting
  - Real-time audience polling technology
  - Forced-choice, no open responses
  - 11 U.S. utilities and 10 individuals from industry

2022

- Issued online via email
  - Open from May 4 through June 7, 2022
  - Forced-choice + open responses
  - 26 / 64 response rate
    - 8 U.S. utilities and 16 individuals from industry

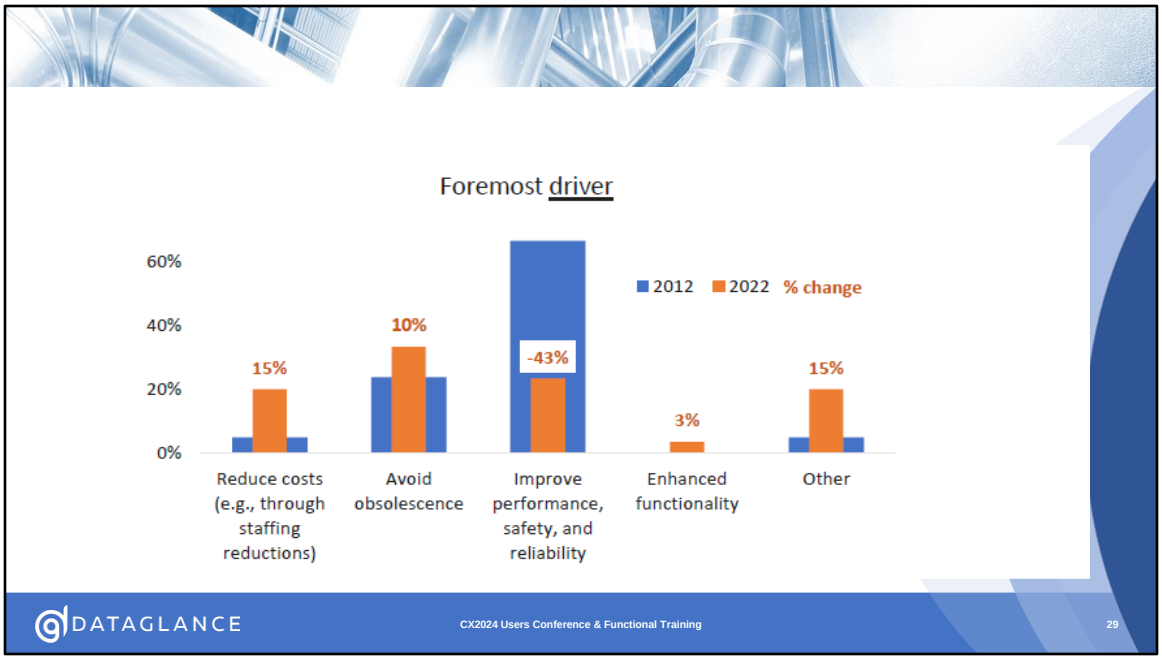
- Drivers of and barriers to modernization
- Use of new technologies in their MCR modernization efforts
- Concepts of operation
- Approaches to modernization
- Effects on maintenance, qualifications, and training
- Timeframe for modernization efforts
- Use of guidelines



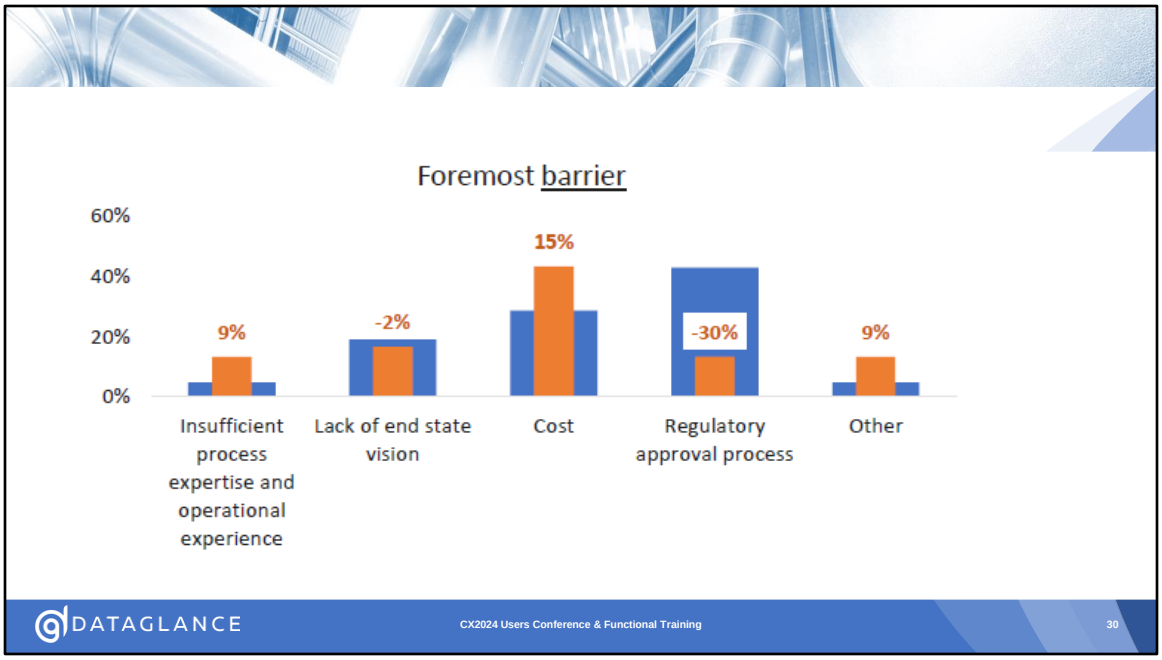
Key points:

1) whereas most non-utility were from nuclear research institutes in 2012, in 2022, the majority were not from research institutes and instead from industry.
2) In 2022 at least, all respondents were males (N=1 preferred not to say) / Mean age = 57 years; Range 34-68 years

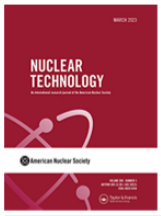
1. *ScottMadden*
2. *MPR Associates*
3. *Mitusbishi*
4. *Sargent & Lundy*



Qualitative responses for the "other" category included a desire to create an MCR that can be used by younger generations, extending plant life, and several comments regarding obsolescence concerns. Notably, avoiding obsolescence was the modal response in 2022.



Qualitative responses for the "other" category included perceptions of high risk, a lack of examples of project delivery success, and different barriers for safety- and non-safety systems.



Nuclear Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/unct20

NUCLEAR TECHNOLOGY

DOI: https://doi.org/10.1080/00295450.2024.2380228

Check for updates

Utility and Industry Perceptions of Control Room Modernization Over the Last 10 Years

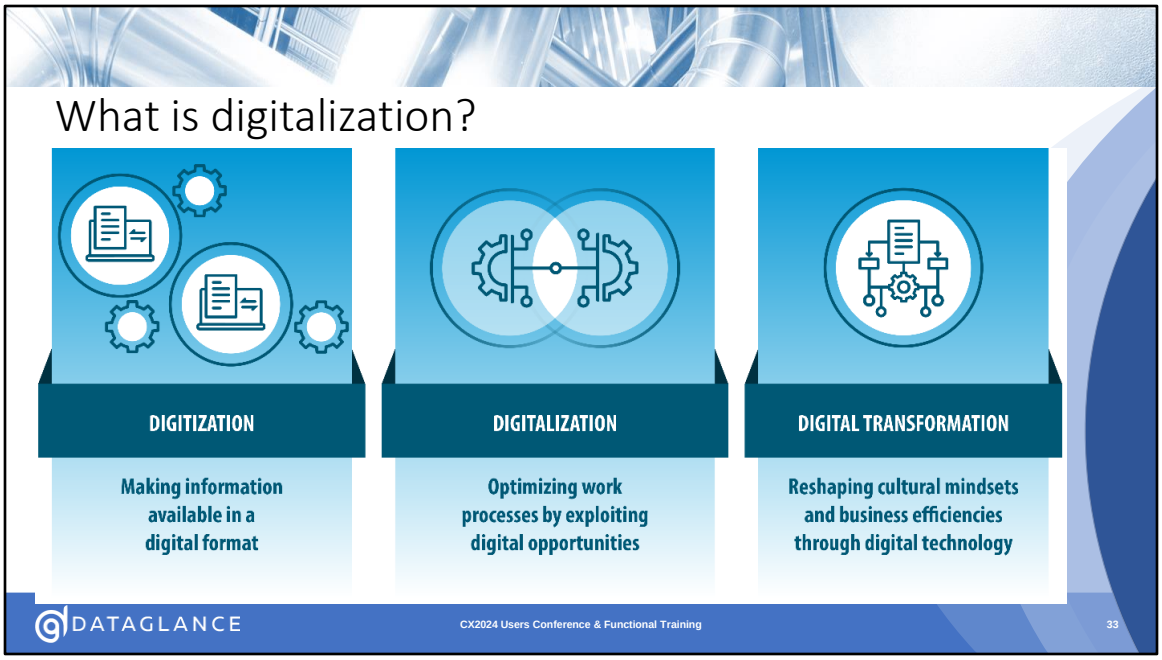
Q1 Anna Hall* and Jeffrey C. Joe

Idaho National Laboratory, Human Factors & Reliability Department, Idaho Falls, Idaho

5 Received November 15, 2023
Accepted for Publication July 8, 2024

Digitalization research at INL

- the use of digital technologies to change a business model and provide new revenue and value-producing opportunities
- it is the process of moving to a digital business.



Been described different ways. For example, digitalization is the use of digital technology to transform processes.

Digitalization means optimizing work processes by exploiting digital opportunities. We believe Digitalization is essential to keep nuclear power plants financially competitive.

Digitalized Procedures

A Rancor Microworld Study

Rancor is a simplified simulator, but very importantly, Rancor allows both operations experts and novices without operations experience to effectively monitor and control a simulated NPP to a proficient level. They can be trained quickly, just about 1hr. The cool thing about Rancor is that It monitors and records the status of all plant parameters as well as any actions taken by participants in each step of a procedure.

Nuclear power modernization

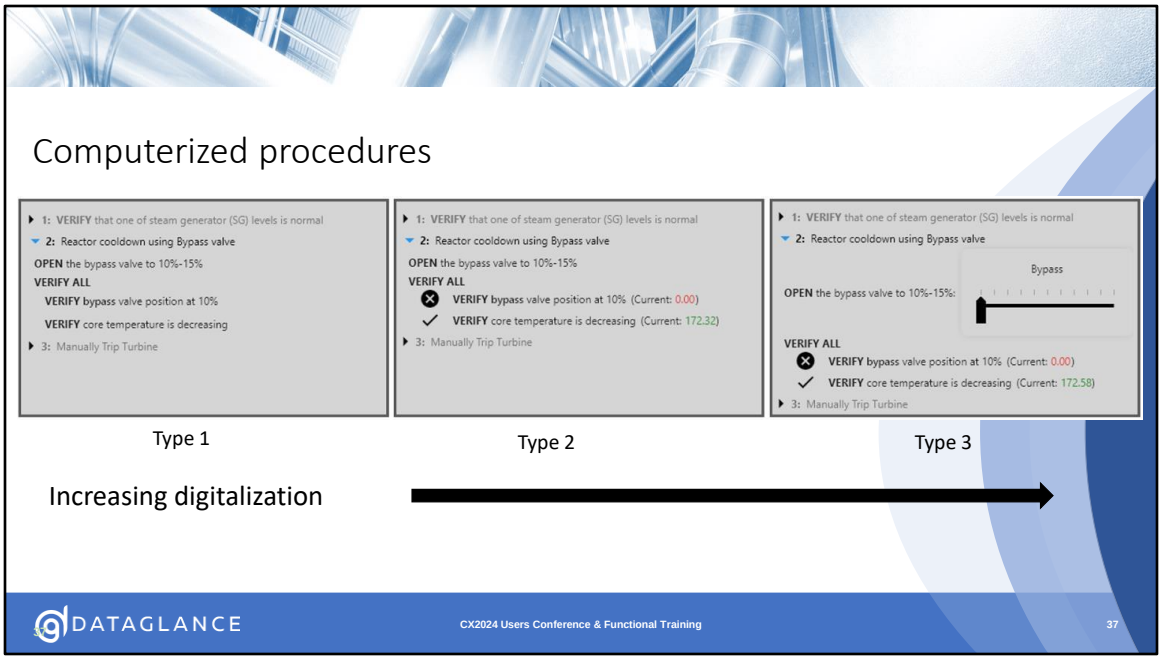
Digitization	Digitalization	Automation
Turning analog information into digital	Enhancing analog information with digital processes	Augmenting human monitoring and control with machines

digital representation | digital functionality | digital control

This slide to demonstrate that we maintain a focus on the human factors considerations with digitalization, automation and AI applications.

Paper procedures

- A procedure guides operators through a particular task, such as maneuvering the plant.
- Problems following paper-based procedures contributed to most reportable events:
  - trouble identifying the correct procedure to follow
  - stress involved with following multiple nested procedures in emergency scenarios
  - issues with divided attention.



In a recent study, three different types of simulated computerized procedures (with increasing digital functionality)

- Guide operators through various tasks
- Three types:
  - Type 1: digitized versions of paper procedures / displays only the instructions
  - Type 2: displays instructions along with embedded plant indicators
  - Type 3: digitized versions with added embedded indicators and soft controls alongside instructions

as specified by Institute of Electrical and Electronics Engineers (IEEE) Standard 1786 were presented to student operators. The computerized procedure types were: 1) digitized versions of paper procedures, 2) digitized versions with added embedded indicators, and 3) digitized versions with added embedded indicators and soft controls

Hypothesis

- Type 1 favored the least, demonstrate lower usability compared to types with greater digitalization

Rancor Microworld Simulator

Process overview / alarm bank

Piping & Instrumentation

Control panel

DATAGLANCE

CX2024 User

39

Importantly, Rancor allows both operations experts and novices without operations experience to effectively monitor and control a simulated NPP to a proficient level.

Method

- Participants: N = 27 (19 M, 8 F), $Mean_{age}$ = 27.85, *SD* = 1.41 years

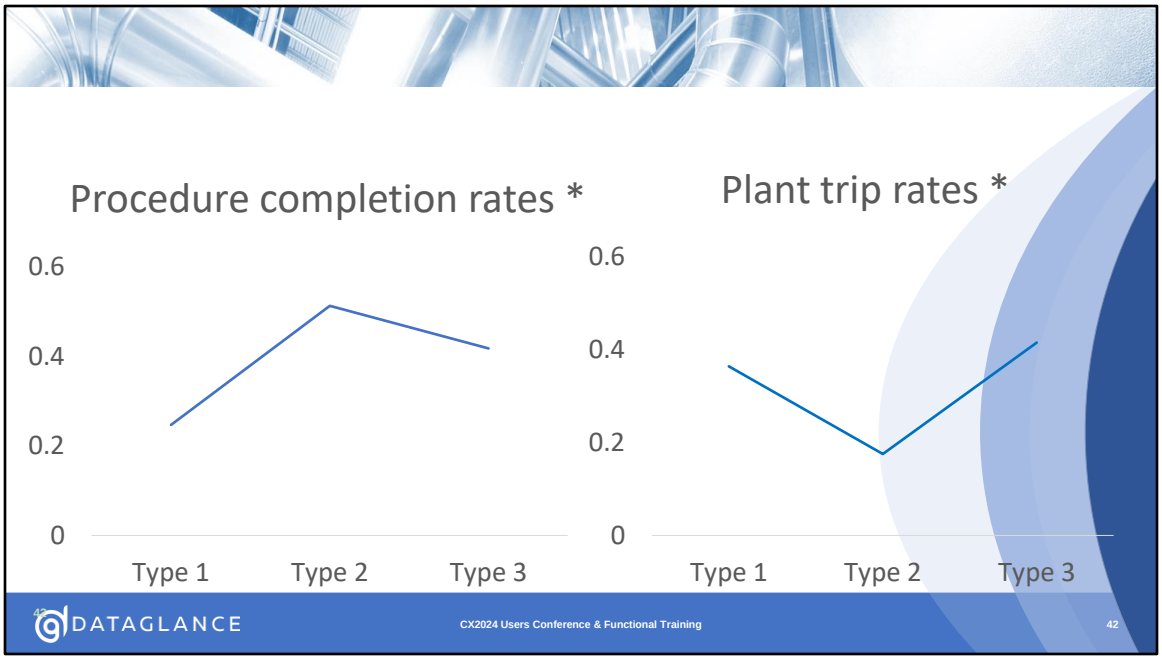
- Scenarios
  - Start up
  - Loss of feedwater

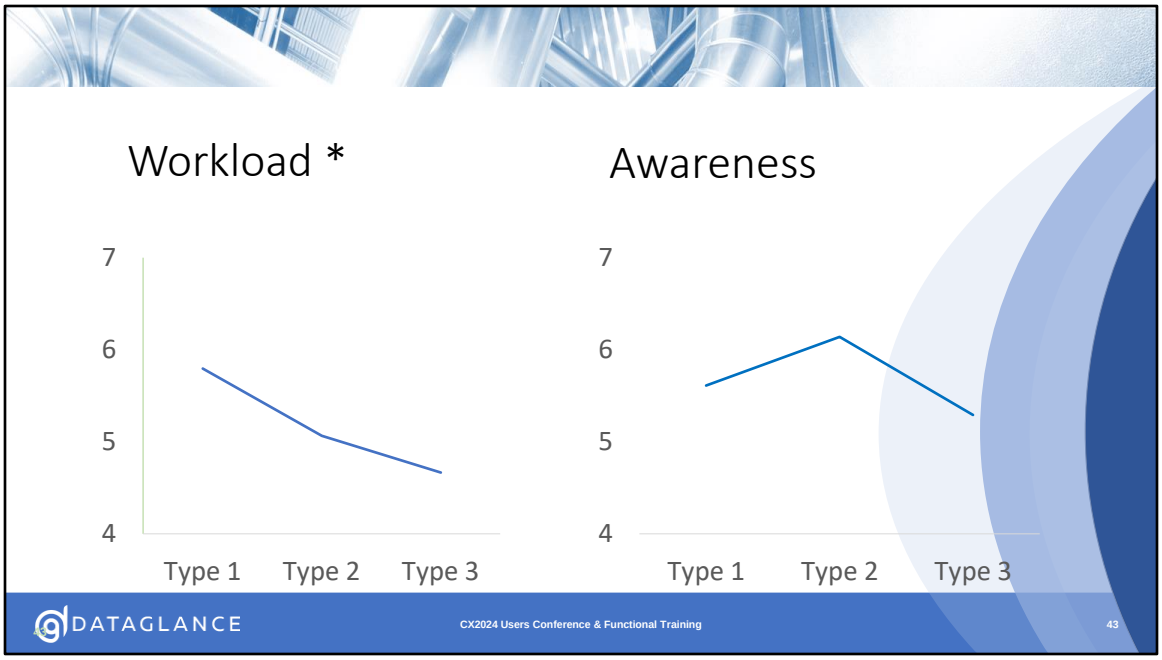
- Metrics
  - Completion / Trip rates
  - Actions performed
  - Task Load (NASA-TLX)
  - Situation Awareness (3D SART)
  - Helpfulness / liking of procedures

NASA-TLX – mental workload, effort, time pressures
SART – attentional resources, understanding of the situation

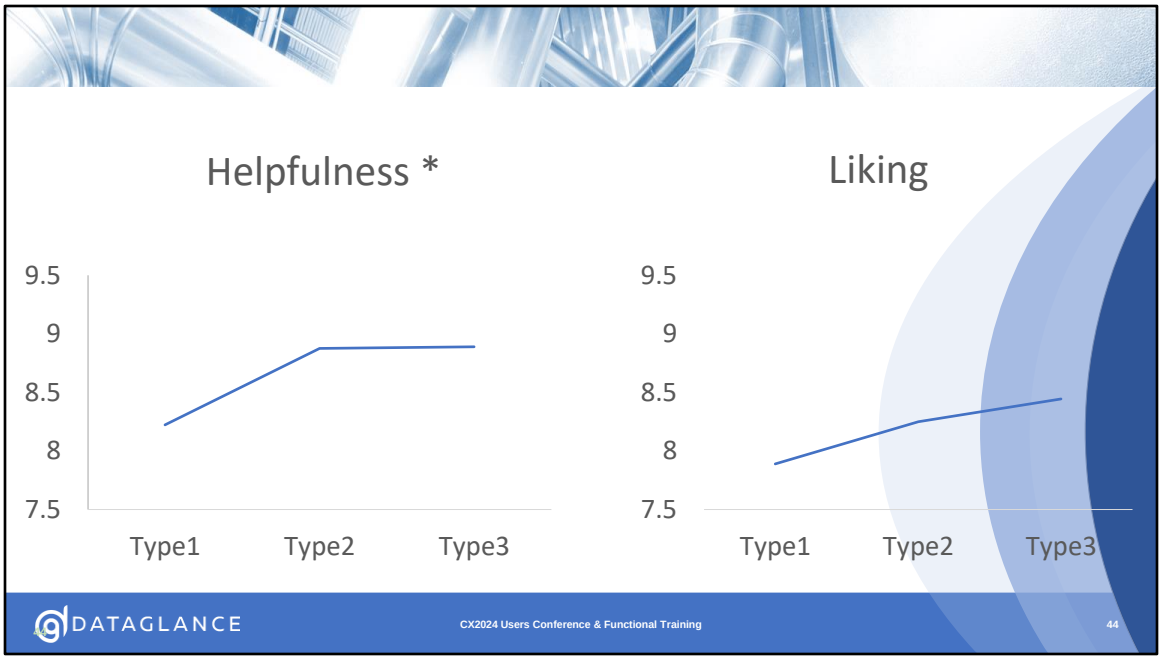
Perception and performance metrics

Results


Procedure completion rates *
0.6
0.4
0.2
0
Type 1
Type 2
Type 3
Plant trip rates *
0.6
0.4
0.2
0
Type 1
Type 2
Type 3
DATAGLANCE
CX2024 Users Conference & Functional Training
42

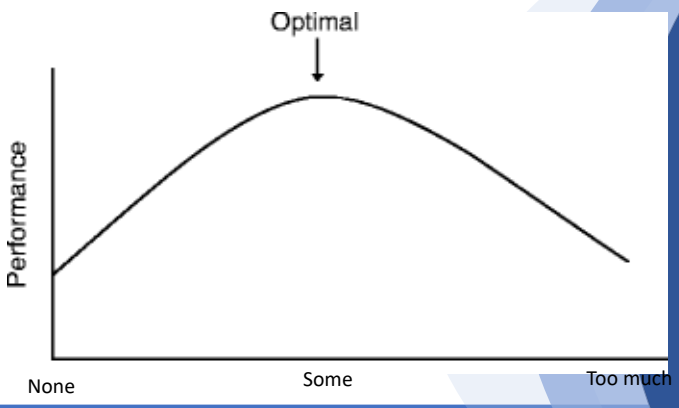


For SART, significant difference within startup only



Taken together, these data suggest that Type II procedures, absent embedded soft controls as with Type III, but with the addition of plant process indicators and step logic compared to Type I, may represent the ‘sweet spot’ of computerized procedures, at least for control room operations.

- Type 2 may represent the ‘sweet spot’ of computerized procedures
- Optimal = manual / digital balance
- Levels of digitalization matter



We see this phenomenom in psychology quite a bit. For example, it is well documented that exposure to some amounts of stress facilities performance in domains such as organizational tasking, work productivity, and many types of cognitive function. This has also been demonstrated in animal research e.g., rats in a maze. Too much or too little stress intensity results in a performance decline.

User experience was generally positive.

We need to balance what we know about performance and how the end user buys in to the usefulness. Preference versus performance.

Proceedings of the Human Factors and Ergonomics Society Annual Meeting

HFES

JOURNAL HOMEPAGE

Free access | Research article | First published online November 22, 2023

A Comparison of Three Types of Computer-Based Procedures: An Experiment Using the Rancor Microworld Simulator

Anna Hall, Ronald L. Boring, [...], and Georgios Michail Makrakis +5 View all authors and affiliations

Volume 67, Issue 1 | https://doi.org/10.1177/21695067231205507

Contents | PDF / ePub | Cite article | Share options | Information, rights and permissions | Metrics and citations

Next steps,,

- Older > younger adults
  - Reduced mind wandering
  - Reduced distractions

Hypothesize: Older adults will have less favorable impressions of highest digitalized procedures, but Type 3 will perform the best with this population


DATAGLANCE
Anna.Hall@INL.gov
THANK YOU!
DATAGLANCE
CX2024 Users Conference & Functional Training
CX2024 Users Conference & Functional Training
48