Nye driftsformer i kjernekraft:

Small Modular Reactors, Generation III+ and IV

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The future of nuclear power?

Worldwide:

- **434** Nuclear Power Reactors in operation
- **11,3 %** World electricity production
- **70** Reactors under construction
- **150** Reactors in planning stage

Georgia Power - Southern Company, USA

Vogtle1,2 in operation, 2 under construction, Vogtle 3,4 (2017)

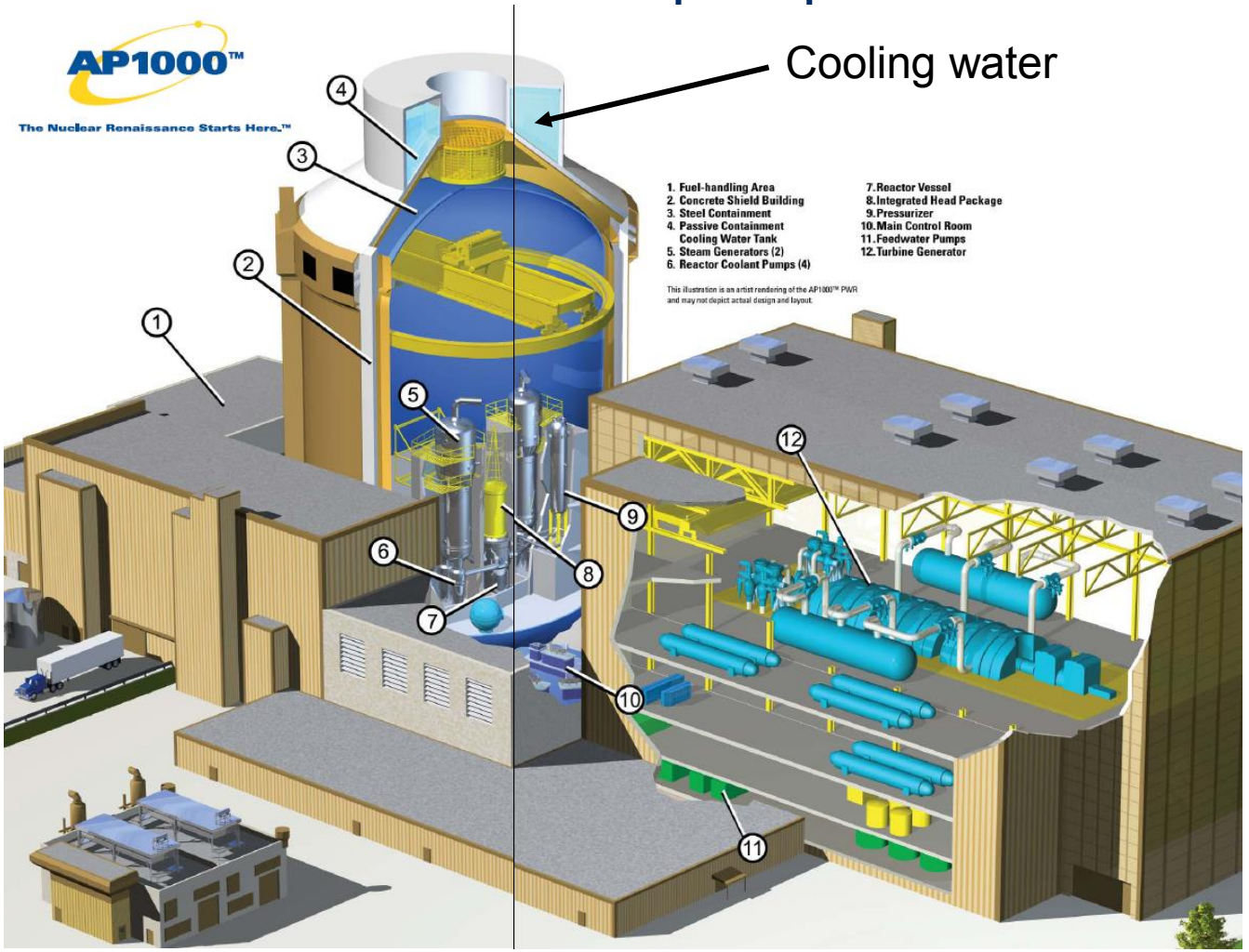
Generation III+ AP-1000 from Westinghouse

Plant Vogtle 3 and 4 construction site with Vogtle 1 and 2 in the background

July 2013

Emergency core cooling based on passive safety systems (Gravitation)–

Generation III+ nuclear power plant



Traditional nuclear plants

- May have multiple nuclear power plant units collocated at one site
- Units are operated independently from separate control rooms
- Most existing and planned plants are operated this way

Modular plants

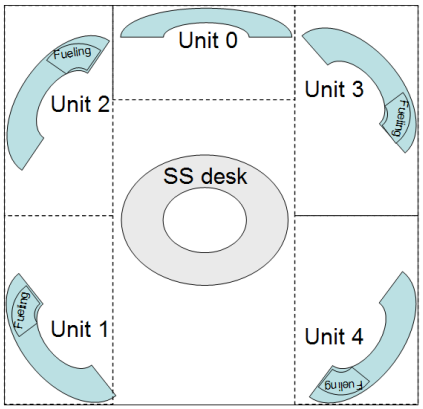
- Multiple reactor units are operated from a central control room
- A few existing and planned plants are operated this way
  - CANDU multi-unit reactors
  - Small Modular Reactors (SMRs)

CANDU multi-unit reactors

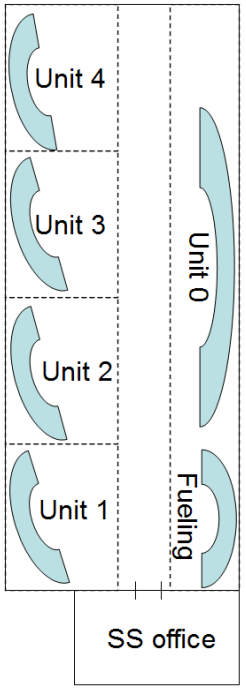
Industry visit to Canada, 2008

Plant	Design
Darlington plant & control room Ontario Power Generation	4 units operated from one control room
Pickering A plant & control room Ontario Power Generation	4 units operated from one control room
Pickering B plant & control room Ontario Power Generation	4 units operated from one control room
Bruce Power A plant & control room Bruce Power	4 units operated from one control room
Bruce Power B control room Bruce Power	4 units operated from one control room

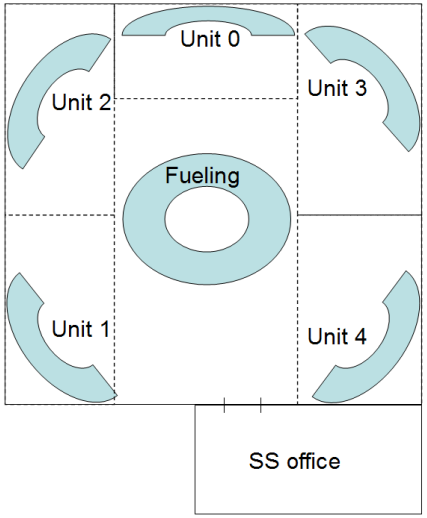
PICKERING



DARLINGTON



BRUCE POWER



Canadian multi-unit stations

- Constructed between 1960s and 1980s
- Traditional analog control panels with some retrofitted digital indicators and computerized displays
- Most computerized displays were two-color CRTs in typical 1980s style - rather conventional
- Control room layout and staffing solutions were extremely different from what we find elsewhere in the world

Operational characteristics #1

- Four plant units operated from one main control room
- Electrical functions were common for all units and assigned to “unit zero”
- The control area for each plant unit was originally designed to be handled by a single operator
- One shift supervisor manages the operation of all four units
- Additional people may be available in the control room to administer and manage work

Operational characteristics #2

- The staffing level in the control room has gradually increased over time
  - Pressure from the international nuclear community
- Typical staffing solutions are currently
  - 2 operators per unit during normal operation
  - 3-4 operators available per unit in upset situations
  - 2 or more additional licensed operators present to support plant units when needed

Operational characteristics #3

- When operators handle disturbances on a unit, they are not given specific roles with pre-defined functions; tasks are distributed dynamically depending on the needs
- In the case of a multi-unit disturbance (e.g. loss of grid on all units), the staffing level may be reduced to 1-3 operators per unit depending on where the resources are needed

Main experiences

- Initial staffing benefits of multi-unit operation was gradually lost due to
  - International safety requirements and conventions
  - Risk related to multi-unit disturbances
- Increased staffing has introduced “traffic” problems in the control environment
  - Up to 37 people in control area designed for 6-10 people

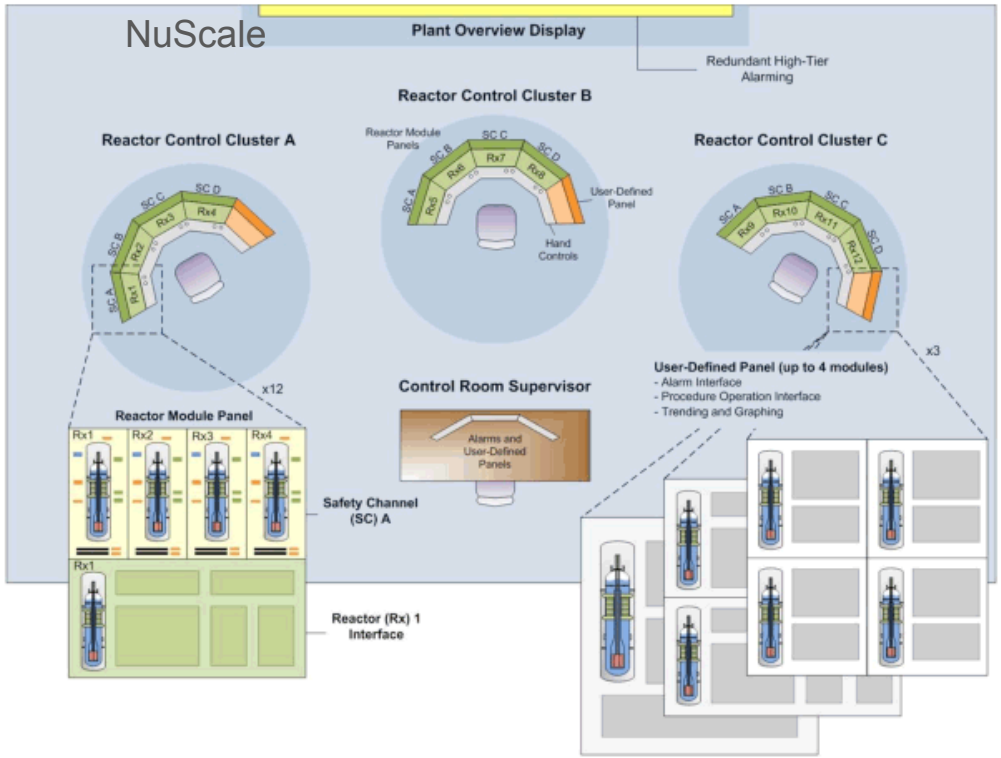
Small Modular Reactors (SMRs)

SMRs

- Advanced modular plants are under development in the US
- Initiated pre-licensing process for several reactor designs
  - NuScale
  - B&W mPower
  - Westinghouse and NexStart SMR Alliance
  - CAREM, Argentina

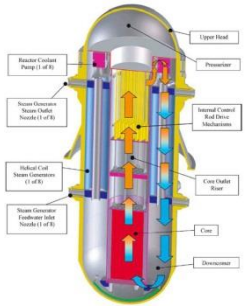
Operational concept

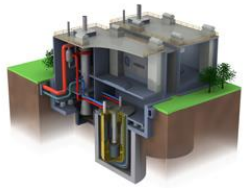
- Multiple reactor units operated from a central control room

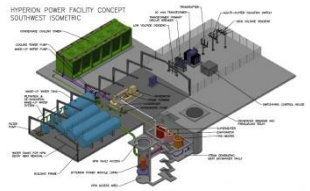


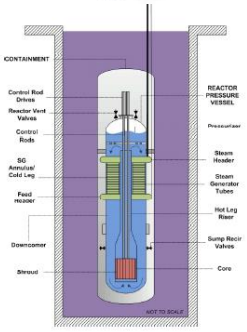
Claimed advantages of SMRs

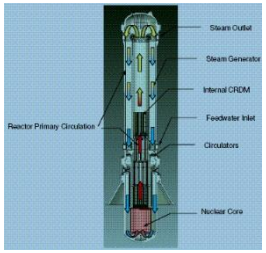
- Simple reactor design
- Natural circulation
- Highly automated
- Each module produces significantly less power than current plants
- Multiple modules can be stacked together and operated by a single crew
- Safe and easy to operate

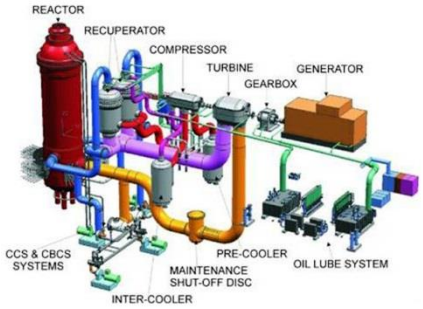


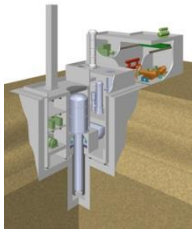












Issues under investigation

- How can operators transition smoothly between roles and tasks when they work on several units?
- Is it possible to maintain an overview of multiple units that are in different process states?
- May operators confuse plant units under high pressure?
- Can a small crew handle multi-unit disturbances (e.g., loss of grid on all units)?
- Collaboration between operators and automation

HWR-938: Staffing Strategies in Highly Automated Future Plants

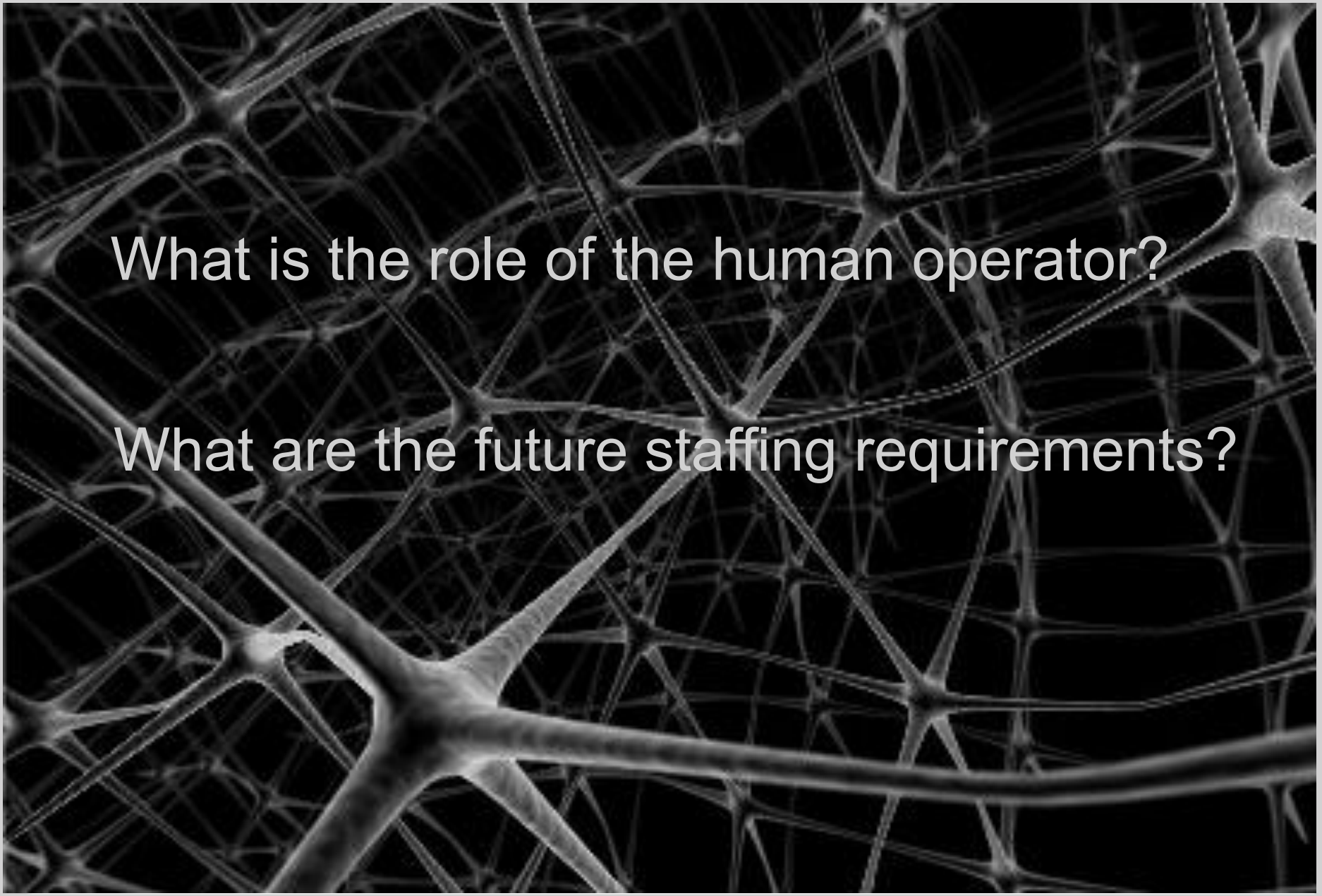
Presented by Øivind Berg

Maren H. Rø Eitrheim, Gyrd Skraaning Jr., Nathan Lau, Tommy Karlsson, Christer Nihlwing, Mario Hoffmann, Jan Erik Farbrot

OECD Halden Reactor Project

Staffing needs

- When computers do more of the work, the staffing needs should go down
- True impact of higher levels of automation on staffing requirements is uncertain


What is the role of the human operator?
What are the future staffing requirements?

Staffing needs in future NPP

- Introducing advanced reactor designs and high levels of automation may change the roles, responsibilities, composition, and size of the crews

- Possible changes:
  - Smaller CR crews
  - Crews responsible for a number of reactors
  - Off-site operations of one or more reactors
  - New staff positions requiring different qualifications

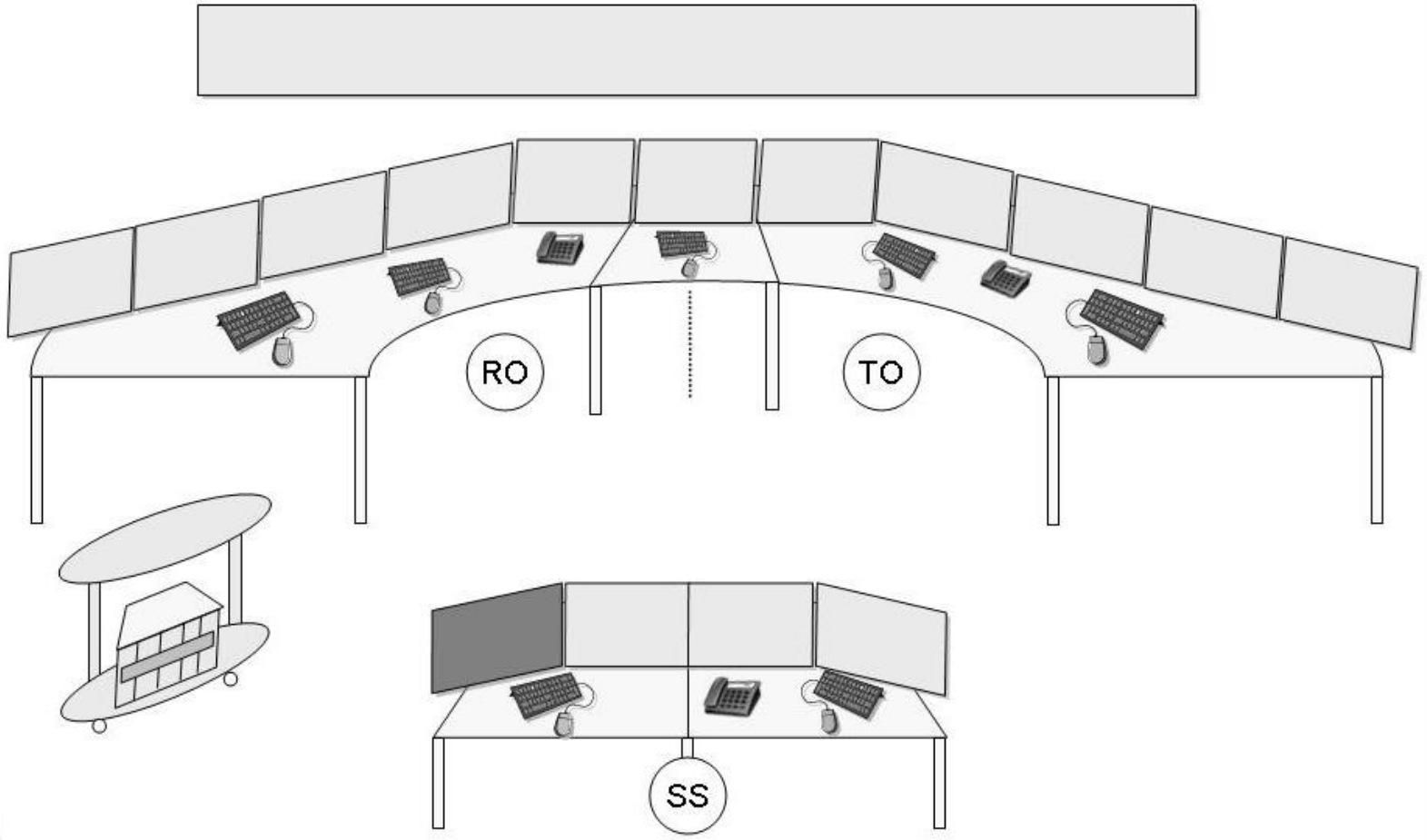
Research goal

- Explore staffing strategies that can support future operational concepts

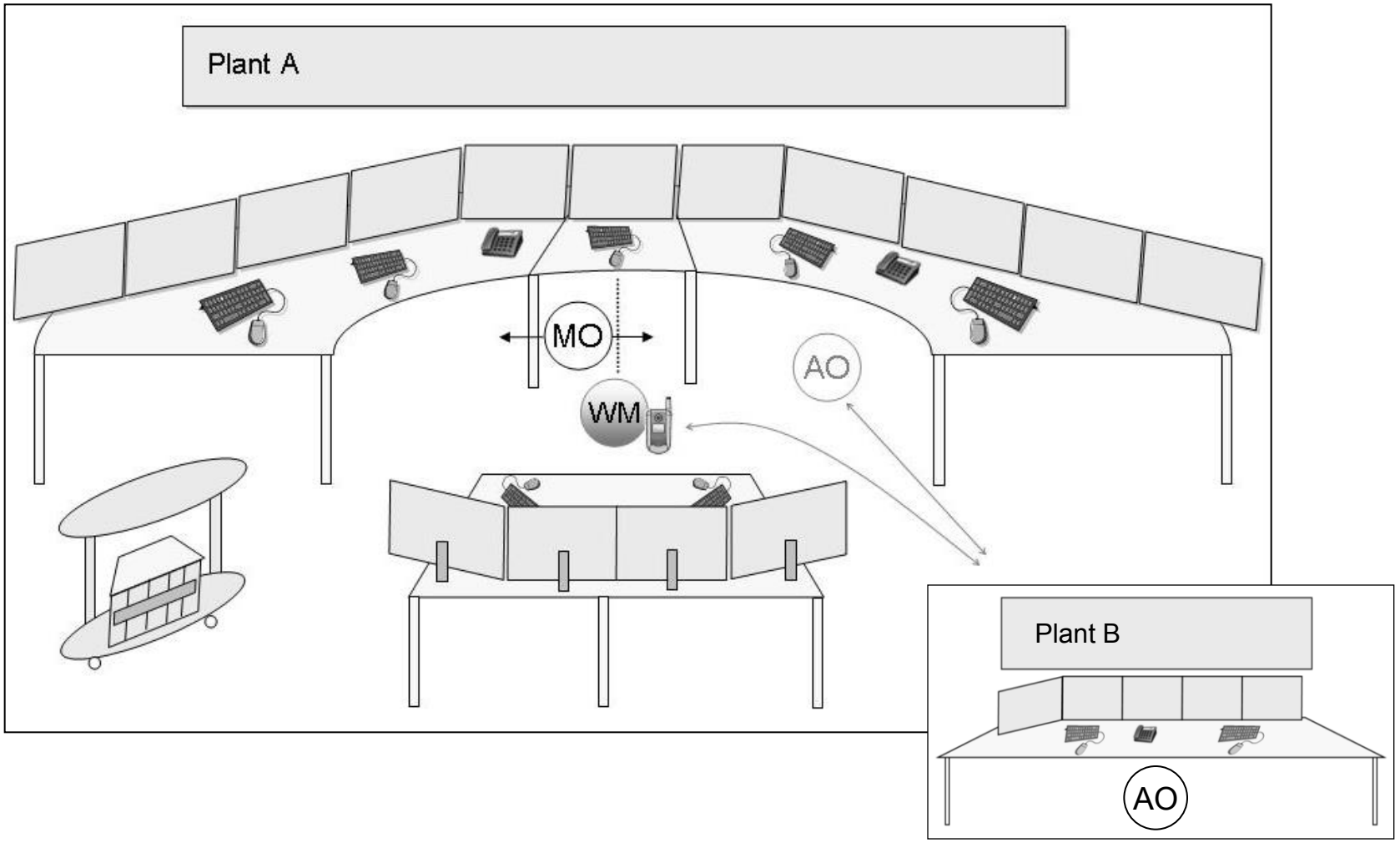
The 2009 HAMMLAB experiment:

How will three operators manage to control two nuclear processes?

Traditional staffing solution



Untraditional staffing solution

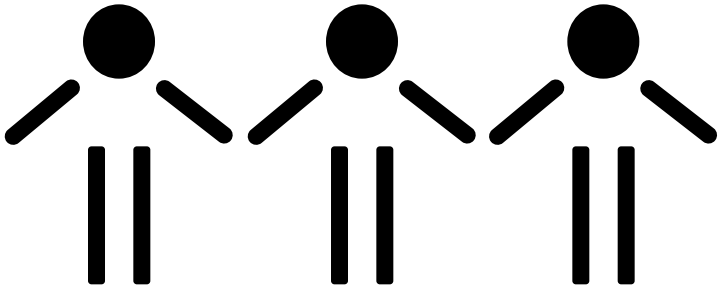


Untraditional operator roles

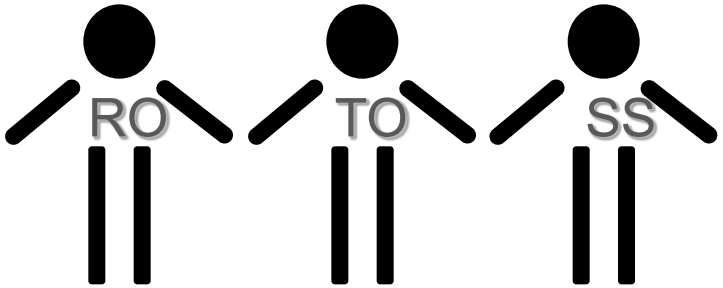
- Main Operator (MO)
  - responsible for reactor and turbine side of Plant A
  - monitors the automatic system
- Assistant Operator (AO)
  - controls the turbine side of Plant B
  - supports turbine side of Plant A when needed (as judged by the WM)
- Work Manager (WM)
  - responsible for Plant A and Plant B
  - makes decisions of operator allocation between plants
  - administrative tasks

Data collection

9 crews



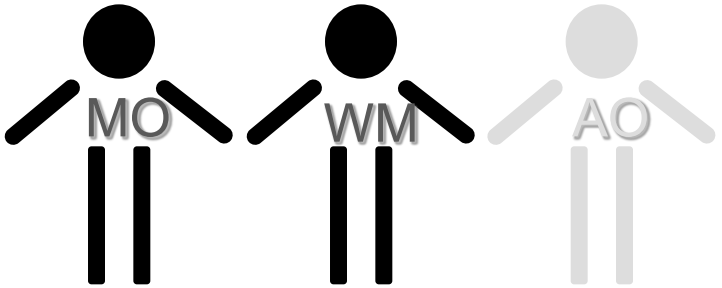
4 scenarios



TRADITIONAL

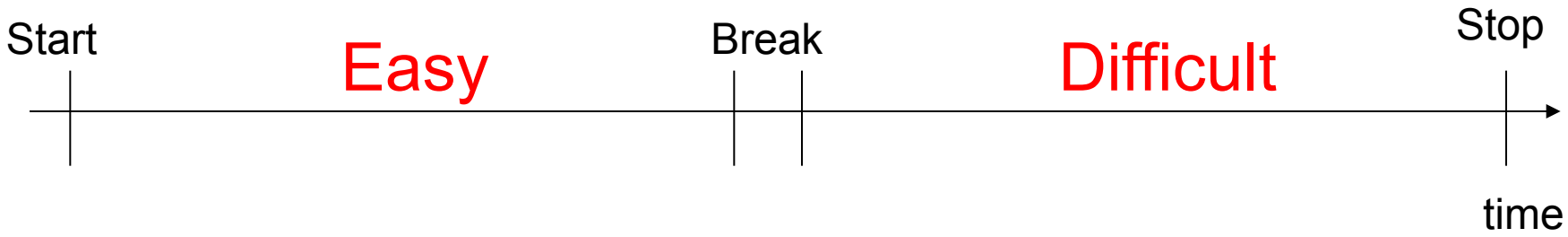
+

4 scenarios



UNTRADITIONAL

Scenarios

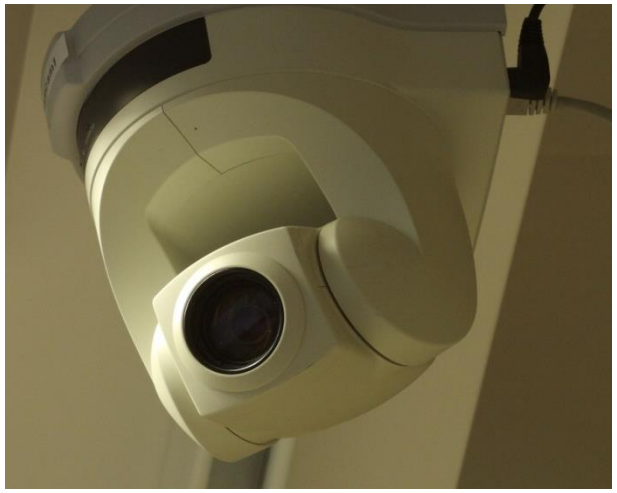


- Simple failures
- independent failures
- symptoms are causes
- low time pressure
- Automation always reliable

- Complex failures
- dependent failures
- masking of root causes
- high time pressure
- Automation may be unreliable
- Accumulated effect of failures

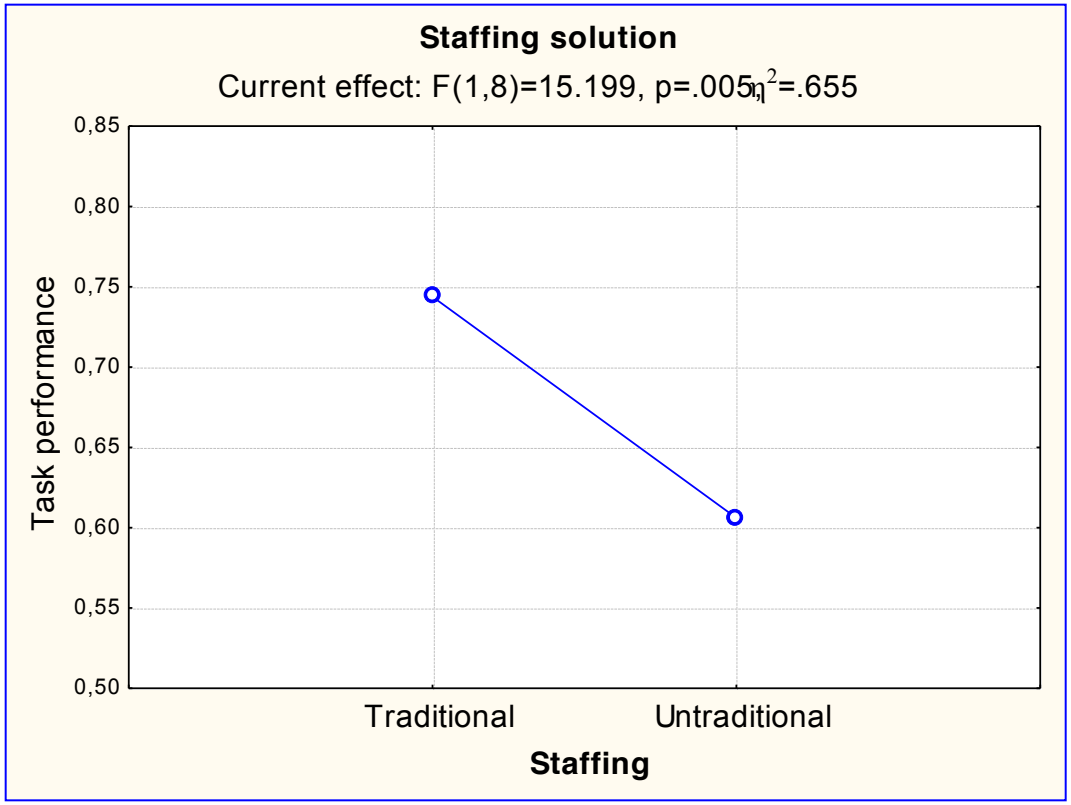
Human performance data

- Before first scenario run
  - Demographic questionnaire
- During scenario runs
  - Operator task performance
  - Situation awareness
  - Self-rated performance
  - Workload
- After last scenario run
  - Debriefing (semi-structured interview with the crew)



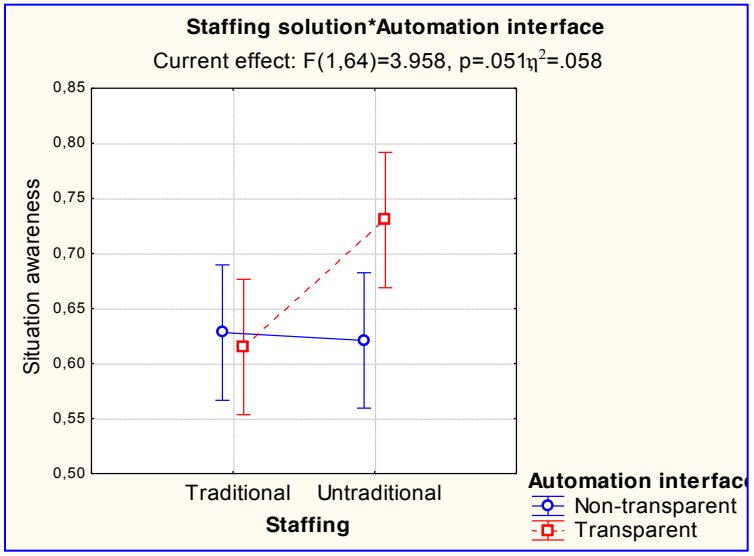
Task performance

- The untraditional staffing solution degraded operator task performance



Situation awareness (SA)

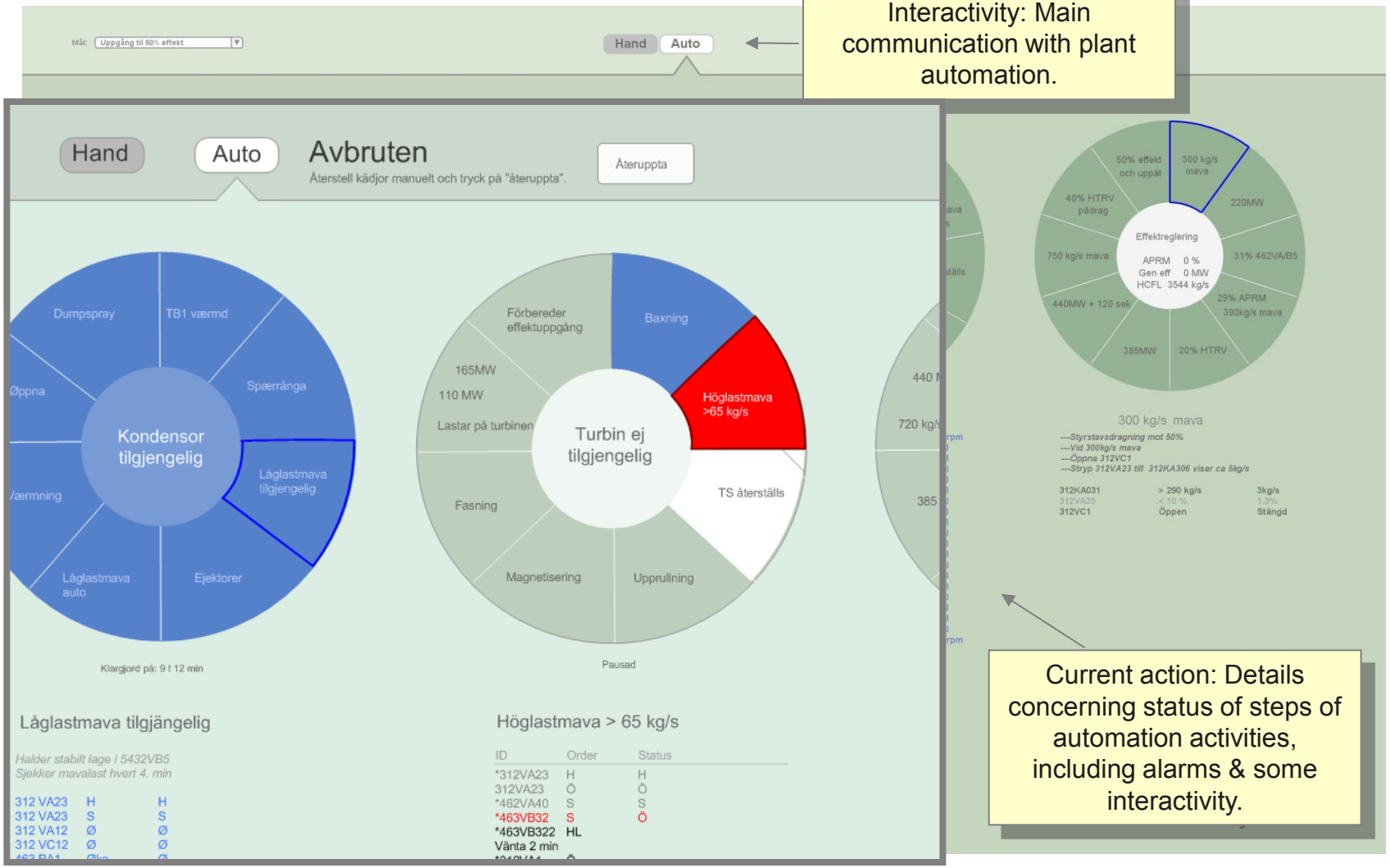
- Higher SA in the untraditional staffing solution with the transparent automation interface



Automation interface

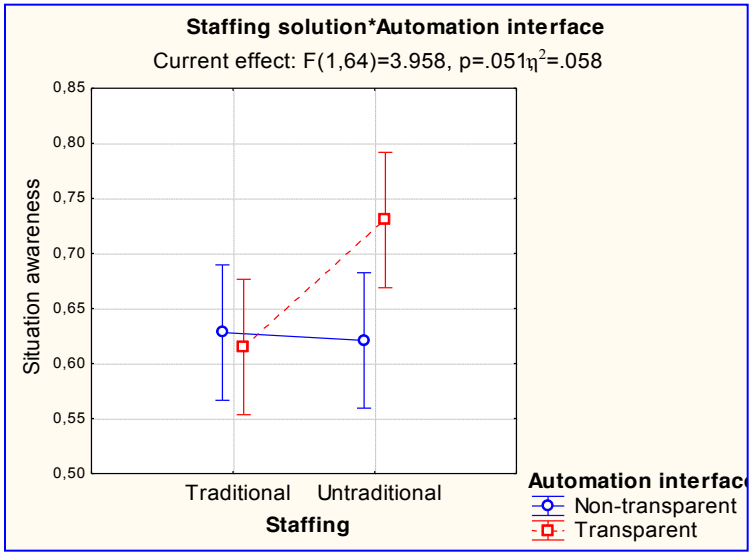
How information about the automation is shown to the operators

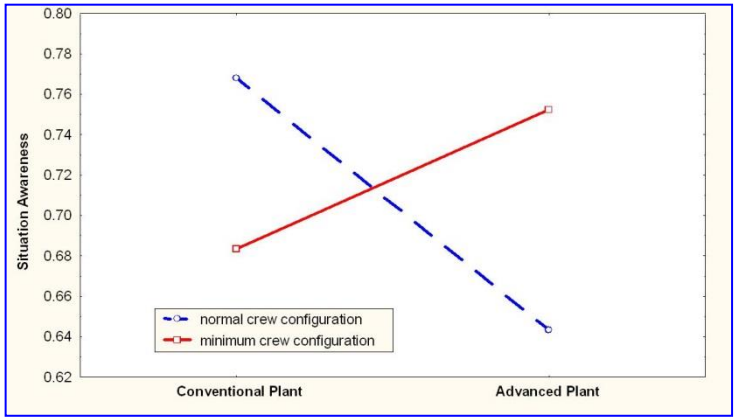
Transparent Automation Overview Screen



Situation awareness (SA)

- Higher SA in the untraditional staffing solution with the transparent automation interface
- A similar finding in a previous staffing study (HAMMLAB 1995)
- Innovative staffing strategies may improve situation awareness with new tools

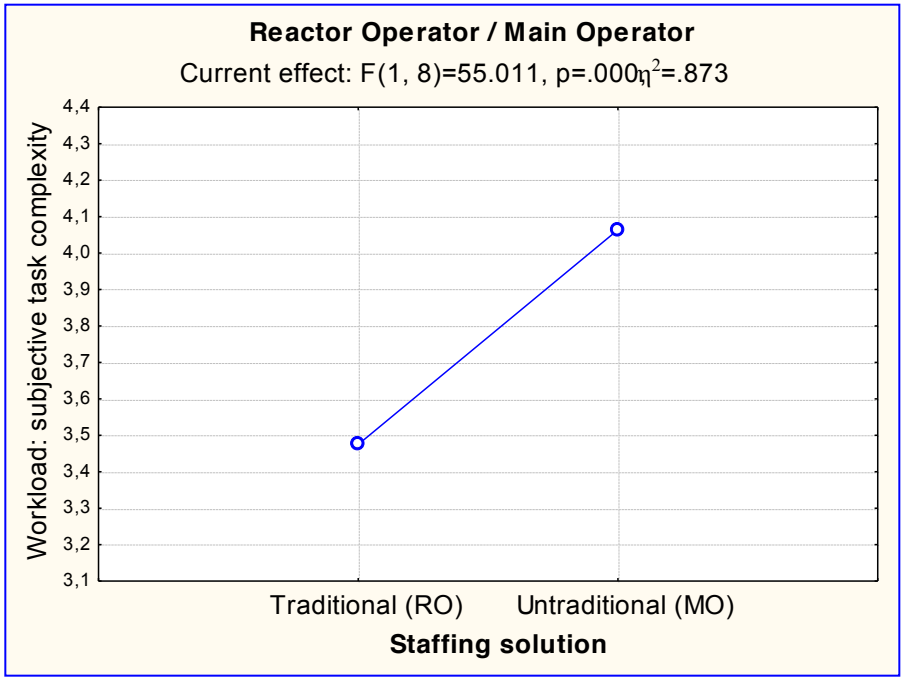


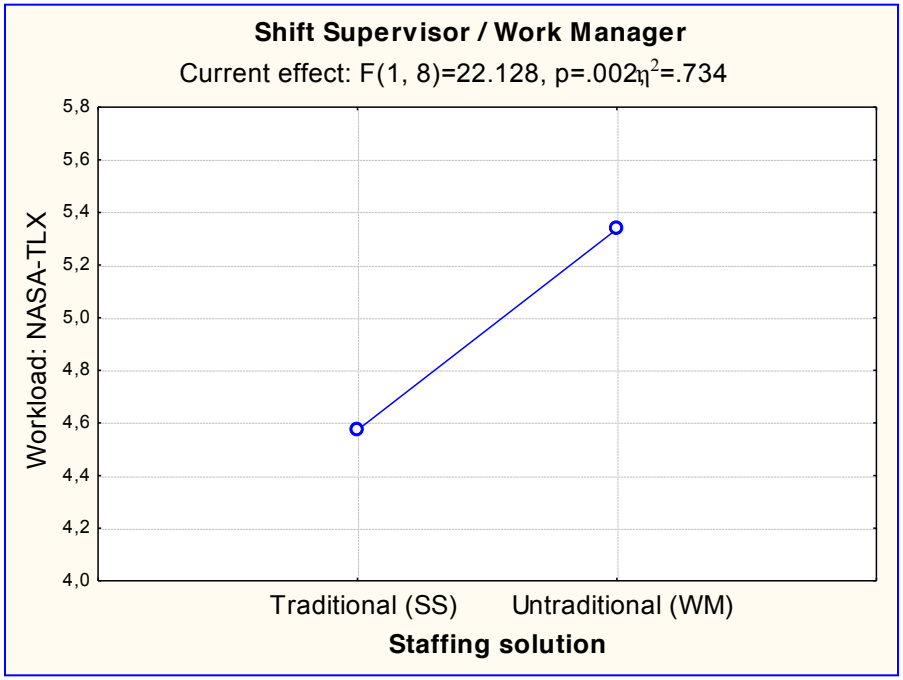


Hallbert, Sebok & Morisseau, 2000 (NUREG/IA-0137)

Workload

- Main Operators and Work Managers reported higher workload in the untraditional staffing solution





Conclusion

- How well did three operators manage to control two nuclear processes?
  - Though with degraded task performance, operators managed a considerable number of prescribed tasks
  - The new operator roles are beneficial for
    - Utilising new tools
    - Simplifying communication between the operators in the control room
- Controlling more than one nuclear process may be feasible, but more operators may be needed during disturbances

Extra slides - if time allows…..

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Energi
ALL Norsk
Olje og Gass

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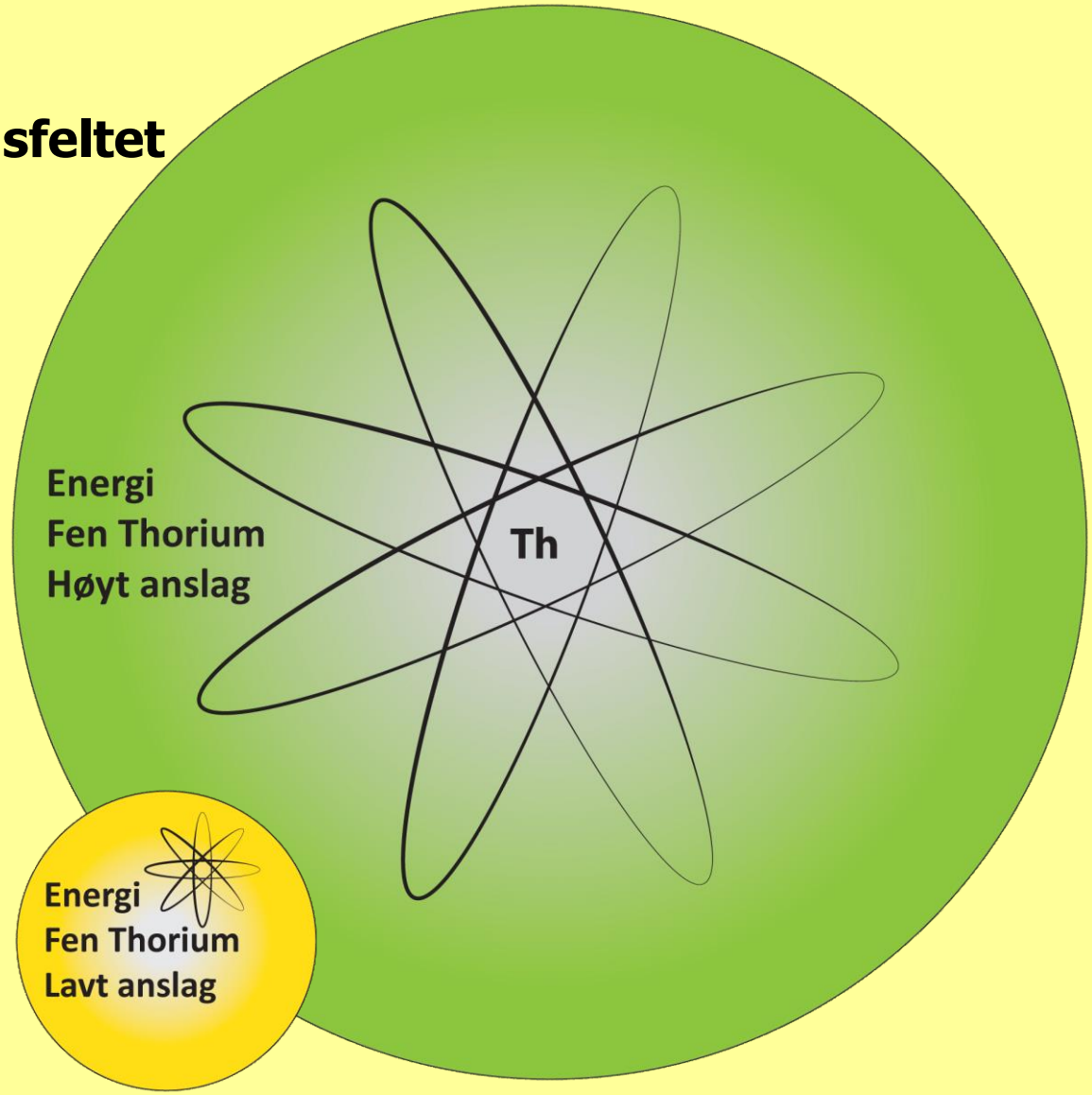
Energi i Thorium fra Fensfeltet

Mer energi enn i
ALL samlet
Olje og Gass
fra norsk sokkel !

Fen thoriumenergi:
trolig minst 10,
muligens over
100 ganger mer !



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DET EUROPEISKE PERSPEKTIV:
FENSFELTET
– EN STRATEGISK FRAMTIDSRESSURS

Norge er det eneste landet i Europa med betydelige kjente thoriumressurser

Andre kjente, store thoriumressurser er i BRIKS-landene og Nord-Amerika

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