THE IMPACT OF CHANGES IN UTILIZATION ON HUMAN PERFORMANCE

Case study applied human factors

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CONTENTS

• Cause & Context
• Theoretical framework
• Case study
• Conclusions & Recommendations
CAUSE & CONTEXT
CAUSE & CONTEXT

Cause
HEU – LEU target conversion for $^{99}$Mo production

Context
• Stakeholder landscape
• Demand over time
• Organizational change
• Technological complexity
CONTEXT: STAKEHOLDER LANDSCAPE

- Converting the entire chain:
  - End users in multiple countries
  - Multiple processing/packing plants
  - Multiple reactors
- Different requirements and regulations for each stakeholder
- Competition between processors
  - GMP $^{99}$Mo demand stable during conversion
## CONTEXT: DEMAND OVER TIME

### Timeline Table

<table>
<thead>
<tr>
<th>Year</th>
<th>Q3</th>
<th>Q4</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
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<th>Q2</th>
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<td>2018</td>
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<td>LEU Production</td>
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</tbody>
</table>

**MM HEU-LEU**
- LEU production ready 1
  - Production HEU & LEU MM en IRE HEU

**IRE HEU-LEU**
- LEU production ready 2
  - Production HEU & LEU IRE en MM HEU
  - Partial loading IRE LEU

**ABC Customer**
- Milestone project HFR Operational Readiness
- HEU irradiations
- LEU irradiations

**LEU productie ready 3**
- Production MM LEU & IRE LEU
  - ANGITIA primary cooled
  - ANTICA new PSF
CONTEXT: DEMAND OVER TIME

<table>
<thead>
<tr>
<th>MM HEU- LEU</th>
<th>IRE HEU- LEU</th>
</tr>
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<tbody>
<tr>
<td>2016 Q3 HT</td>
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<td>2017 Q2 HT</td>
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<td>2017 Q3 HT</td>
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<td>2016 Q4 HT</td>
<td>2017 Q3 HT</td>
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<td>2018 Q1 LEU production</td>
<td>2018 Q2 &gt;Q3 LEU Production</td>
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<tr>
<td>2018 Q3 LEU production</td>
<td>2018 Q3 LEU Production</td>
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</table>

ABC Customer

Milestone project HFR Operational Readiness

- HEU irradiations
- LEU irradiations

LEU production ready 1
- production HEU & LEU MM en IRE HEU

LEU production ready 2
- production HEU & LEU IRE en MM HEU

LEU production ready 3
- production MM LEU & IRE LEU
- ANGITIA primary cooled
- TINOS new PSF
## CONTEXT: ORGANIZATIONAL CHANGE

<table>
<thead>
<tr>
<th></th>
<th>Research facility</th>
<th>Production facility</th>
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<tbody>
<tr>
<td>Deliverable:</td>
<td>Report</td>
<td>Material</td>
</tr>
<tr>
<td>Iterations:</td>
<td>One/Few</td>
<td>Many</td>
</tr>
<tr>
<td>Design focus:</td>
<td>Availability</td>
<td>Reliability</td>
</tr>
<tr>
<td>Design focus:</td>
<td>Unique result</td>
<td>Max. throughput</td>
</tr>
<tr>
<td>Quality:</td>
<td>Controlled</td>
<td>Constant</td>
</tr>
<tr>
<td>Time:</td>
<td>Controlled</td>
<td>Fixed</td>
</tr>
<tr>
<td>Deviations:</td>
<td>Exception report</td>
<td>Rejection</td>
</tr>
</tbody>
</table>
CONTEXT: ORGANIZATIONAL CHANGE

Model of human error (Reason, 1990)

- **Slip**
  - Attentional failures
    - Intrusion
    - Omission
    - Reversal
    - Misordering
    - Mistiming
  - Basic error types

- **Lapse**
  - Memory failures
    - Omitting planned items
    - Place-losing
    - Forgetting intentions

- **Mistake**
  - Rule-based mistakes
    - Misapplication of good rule
    - Application of bad rule
  - Knowledge-based mistakes
    - Many verbal forms

- **Violation**
  - Routine violation
  - Exceptional violations
  - Acts of sabotage

**Production facility**

**Research facility**
CONTEXT: TECHNOLOGICAL COMPLEXITY

- Irradiation rigs already available or under construction
- More (slightly) different targets types
- More and (slightly) different irradiation facilities
- HEU and LEU part subsets for irradiation facilities
- Same reactor and support systems

Similarities in design of HEU and LEU rigs pose risks of mixing components and targets. Quality issue, possibly nuclear safety.
CONTEXT: TECHNOLOGICAL COMPLEXITY

HEU only

HEU & LEU
The solution is influenced by:

• Stakeholders with different interests
• Shifting demand in time
• Multiple organizational levels
• Production lines that are related

“Some problems are so complex that you have to be highly intelligent and well informed just to be undecided about them.”

Laurence J. Peter
WICKED PROBLEMS: TRAITS

- The problem is not understood until after the formulation of a solution.
- Wicked problems have no stopping rule.
- Solutions to wicked problems are not right or wrong.
- Every wicked problem is essentially novel and unique.
- Every solution to a wicked problem is a 'one shot operation.'
- Wicked problems have no given alternative solutions.

References
WICKED PROBLEMS: TAMING

Taming options:

• Lock down the problem definition
• Assert that the problem is solved
• Specify objective parameters by which to measure the solution’s success
• Cast the problem as ‘just like’ a previous problem that has been solved
• Give up on trying to get a good solution to the problem
• Declare that there are just a few possible solutions, and focus on selecting from among these options
WICKED PROBLEMS: SOLVING
**HUMAN FACTORS THEORY**

Swiss cheese model – Reason *(SOURCE: www.hfacs.com)*

Representing different levels of an organization where there are active or latent causes for accidents

- Organizational Influences
- Unsafe Supervision
- Preconditions
- Unsafe Acts

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**Accident!**
METHODS OF DESIGN

Human Centred Design
An approach to system design and development that aims to make systems more usable by focusing on the use of the system; applying ergonomics, human factors, and usability knowledge and techniques

Design for optimal operator performance
Systematic consideration of human factors, including the human–machine interface, shall be applied at an early stage in the design process for a research reactor facility, including its experimental facilities, and shall be continued throughout the entire design process.
[SOURCE: SSR-3, Requirement 35]
PROJECT

It’s wicked and it’s about human performance

Project brief
Enable safe and reliable supply of irradiated $^{99}$Mo targets according to customer demand during the HEU to LEU target conversion.

Case study
• Setting constraint in planning
• Research
• Basic design
• Detailed design
• Close-out
CONRAINT: CUSTOMER DEMAND

- Zero impact of conversion on the supply of $^{99}$Mo under GMP conditions
- Start of LEU target irradiation when a step down the chain is ready for testing
- Completing conversion before HEU supply runs out
- Predictable (low) cost over time
SET CONSTRAINTS IN PLANNING

- Observe operators during work, and involve them to understand what will reduce complexity in day to day operations
- Constrain this complexity by solving it on the highest possible organisational level (solve the problem on a different level from where it occurs)
- Reduce complexity and costs of engineering solution
- Ultimately reduce complexity for operations

Taming the wicked
- Locking down the problem
- Declare that there are just a few possible solutions, and focus on selecting from among these options
SET CONSTRAINTS IN PLANNING

- Every facility is dedicated **HEU or LEU** during a cycle.
- For production regime a **maximum of 2 plate targets** is allowed.
- Setting these constraints early on allowed business to implement it into the HEU-LEU conversion planning.
CONSTRAINT: RESEARCH BASE

- Lack of risk assessment of the logistic process and cross-influence of irradiation rigs during this part of the production process
- Current Design & Safety Reports for irradiation facilities focus on risks during irradiation
- Minimal experience in taking the human factor into account in risks assessment
- No process flow diagrams available on operator task level
- Knowledge on previous engineering design choices concentrated in small amount of people
- Knowledge on current layers of defense spread throughout organization

- SSR-3 – req. 35 Design for optimal operator performance not implemented on a logistic process and cross-influence
- SSG-24 annex II, chapter 7/8, not sufficient for design of production line
RESEARCH - APPROACH

- Develop method of the analysis by trial and error
- Accept concurrent analysis and design
- Focus on understanding the larger problem, while solving the smaller ones

Accepting the wicked
The problem is not understood until after the formulation of a solution
RESEARCH - APPROACH

Start:
• Starting point: current known method of HAZOP
• Guide words: same as a previous HAZOP focussed on human error
• Preparation: detailed process steps as described in Excel
• 1st & 2nd session: go through process guided by Excel sheet

Lessons learned:
• Excel sheet insufficient to ensure participants have the same process step in mind
• Guide words don’t fit discussions about different kinds of errors
RESEARCH - APPROACH

1st iteration: guide words & process flow diagrams
• Preparation: Made Process Flow Diagrams based on operating procedures
• Guidewords:
  • Adapted from SHERPA [SOURCE: Sherpa, Embrey]
  • Based on Reason, based on operator behaviours → easy to use
  • Differentiate between actions, selections and checks
• Sessions: Standing in front of PFD, naming possible errors, processes into Excel afterwards by facilitator

Lessons learned:
• Unclear how the complete system of parts possibly interacts (incomplete mechanical exclusions)
• Discussion about chances of loading the wrong targets remains and is based on opinions
RESEARCH - RESULTS
## RESEARCH - RESULTS

### 3.1 Selecteer laadtool

<table>
<thead>
<tr>
<th>Processtap</th>
<th>HAZOP tabel</th>
<th>Beinvloedende factor</th>
<th>Specifiek, is dit aangegeven</th>
<th>Kwaliteitsgevolg</th>
<th>Afwijking (indien faciliteit specifiek, is dit aangegeven)</th>
<th>Human HAZOP Gidswoorden</th>
<th>Afwijking</th>
<th>Overzicht</th>
<th>HFR Operational Readiness BMA 2016</th>
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<tbody>
<tr>
<td>3.1.1.1</td>
<td>De transportdozen uit kluis 2 halen</td>
<td>Verkeerd gewichtje bij laadtool</td>
<td>Nvt</td>
<td>Herkenbaarheid laadtool</td>
<td>2. Te laat in bestraling nemen juiste targets</td>
<td>Selectie gemaakt</td>
<td>Verkeerde actie</td>
<td>A8 Verkeerde actie op het juiste object</td>
<td>1. +2. +3. HFR Operational Readiness BMA 2016</td>
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<td>Selectie gemaakt</td>
<td>Verkeerde actie</td>
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</table>

### 3.1 Selecteer laadtool met valgewichtje

<table>
<thead>
<tr>
<th>Processtap</th>
<th>HAZOP tabel</th>
<th>Beinvloedende factor</th>
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<th>Kwaliteitsgevolg</th>
<th>Afwijking (indien faciliteit specifiek, is dit aangegeven)</th>
<th>Human HAZOP Gidswoorden</th>
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<td>Verkeerde actie</td>
<td>A8 Verkeerde actie op het juiste object</td>
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<td>Selecteer laadtool met valgewichtje</td>
<td>Verkeerd gewichtje bij laadtool</td>
<td>Nvt</td>
<td>Herkenbaarheid laadtool</td>
<td>2. Te laat in bestraling nemen juiste targets</td>
<td>Selectie gemaakt</td>
<td>Verkeerde actie</td>
<td>A8 Verkeerde actie op het juiste object</td>
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</tbody>
</table>
RESEARCH - APPROACH

2nd Iteration: additional deliverables

- Error Path Analyses: Go through all combinations of facilities and parts to identify error paths that lead to wrong subassemblies being irradiated (Deterministic approach)
- Human Reliability Analyses of target mix-ups to look at this objectively and assess if additional measures are necessary (Probabilistic approach)
RESEARCH RESULTS

Verwisselingen tussen onderdelen en laadtools van Molybdeen faciliteiten

<table>
<thead>
<tr>
<th>Laadtool</th>
<th>Targets</th>
</tr>
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<tr>
<td>MM HEU</td>
<td>MM LEU</td>
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<tr>
<td>IRE LEU</td>
<td>IRE HEU</td>
</tr>
</tbody>
</table>

**Stap 3.5 Plaats target in laadtool**

**Stap 3.5 Plaats valgewichtje**

**Stap 3.6 Plaats targethouder in laad&los station**

**Stap 3.7 Plaats laadtool op targethouder**
RESEARCH RESULTS

Primary
• Recorded system of facilities and parts, their interactions and consequences for quality and nuclear safety
• Measures to reduce errors defined and implemented as the research developed

Secondary
• Insight into where the risks of human errors are in the production process and across whole system of irradiation facilities used
• Ability to asses consequences for operability as part of new business cases for irradiations
• Process flow diagrams for future use
• Wider spreads knowledge of the day to day logistics
BASIC DESIGN - PROCESS

Human Centred Design

- Focus on selecting basic working principles to be applied to the whole system
- Define specifications together with users
- Iterate in small steps, starting with simple sketches (prototypes)
- Ask for user feedback to check if it will work
- Fail early results in 1st time right final design
BASIC DESIGN – OLD ISOTOPE TABLE
BASIC DESIGN – ISOTOPE TABLE

Less precise movements

Precise movements

store
park
precision work
BASIC DESIGN – ISOTOPE TABLE

← left/right separation, middle is subject to change →

left LEU  free space  right HEU

NOW being handled
BASIC DESIGN – ISOTOPE TABLE
DETAIL DESIGN - METHOD

Design for optimal operator performance

• Apply workplace physical and cognitive ergonomics
• Goal: support operators in successfully and easily completing the set tasks

For instance:

• Labelling all components
• Use cues to provide the user with feedforward and feedback
• Bevels to guide components placements under water
• Easy to open but integrated covers over components storage
DETAIL DESIGN - ISOTOPE TABLE

Design for production = routine acts

**Minimal amount of choices during production (made possible by constraints in planning)**

- Left/ right division of workspace for 2 plate targets
- Fixed configuration during 1 cycle
- Not in use, not in sight (not stored on the table)
- Set of parts for 1 facility stored together & only 1 set in table

**Optimized for planned use**

- All parts have an assigned location
- All parts are within reach
- All locations are labelled
DETAIL DESIGN - ISOTOPE TABLE
## BASIC DESIGN - COLOUR CODE OLD

<table>
<thead>
<tr>
<th>Target</th>
<th>Vault</th>
<th>Transport box</th>
<th>Work order</th>
<th>Check-out</th>
<th>Tool storage</th>
<th>Loading tools</th>
</tr>
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<tbody>
<tr>
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<tr>
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</tr>
<tr>
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# BASIC DESIGN - COLOUR CODE NEW

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<tr>
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<th>Work order</th>
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<th>Tool storage</th>
<th>Loading tools</th>
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<td>MM LEU</td>
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<td>Yellow</td>
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<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>IRE HEU</td>
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<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>IRE LEU</td>
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<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
</tr>
</tbody>
</table>

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DETAIL DESIGN - TARGET VAULT

Kluis 2:

IRE LEU
IRE LEU
IRE HEU
NRG HEU
NRG LEU

IRE LEU
IRE HEU
MM HEU
MM LEU
MM LEU
DETAIL DESIGN - TRANSPORT BOXES

Built in calibre to check if you have the right targets
Transparent boxes, so you can see the inside
DETAIL DESIGN - TOOL STORAGE
DETAIL DESIGN - LOADING TOOLS
Check-outs and loading procedures

MM HEU

<table>
<thead>
<tr>
<th>Vertrouwelijkheid</th>
<th>NRG intern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doelstelling</td>
<td>Check-out Mykonos koelwaterbewaking (TP-267)</td>
</tr>
<tr>
<td>Doelgroep</td>
<td>HFR Operations</td>
</tr>
</tbody>
</table>
DETAIL DESIGN - PLANNING DOCS

- Irradiation work orders
- Irradiation planning
CLOSE-OUT - PROCES

Human Centred Design

- Evaluation: ask for user feedback after implementing the design
- No major points – users are very enthusiastic
- User very appreciative of aftercare
CONCLUSIONS & RECOMMENDATIONS
CONCLUSIONS

- Implement a design process targeted towards production lines instead of irradiation rigs (DSR)
- Set up a assessment framework for the design of production lines
- Add HFE as a required competence in the organisation
- Asses the HFE main features’ impact early on in the design process
- Let go of the linear design process, allow for iteration
- Add the voice of the user to client meetings
RECOMMENDATIONS

Add an assessment framework for production to the current framework for Nuclear Safety

- Ergonomics
- Efficiency
- Quality and reliability

Allow this assessment framework to fit a design process that incorporates:

- Early prototyping
- Quick iteration cycles
- User feedback