THE IMPACT OF CHANGES IN UTILIZATION ON HUMAN PERFORMANCE

Case study applied human factors

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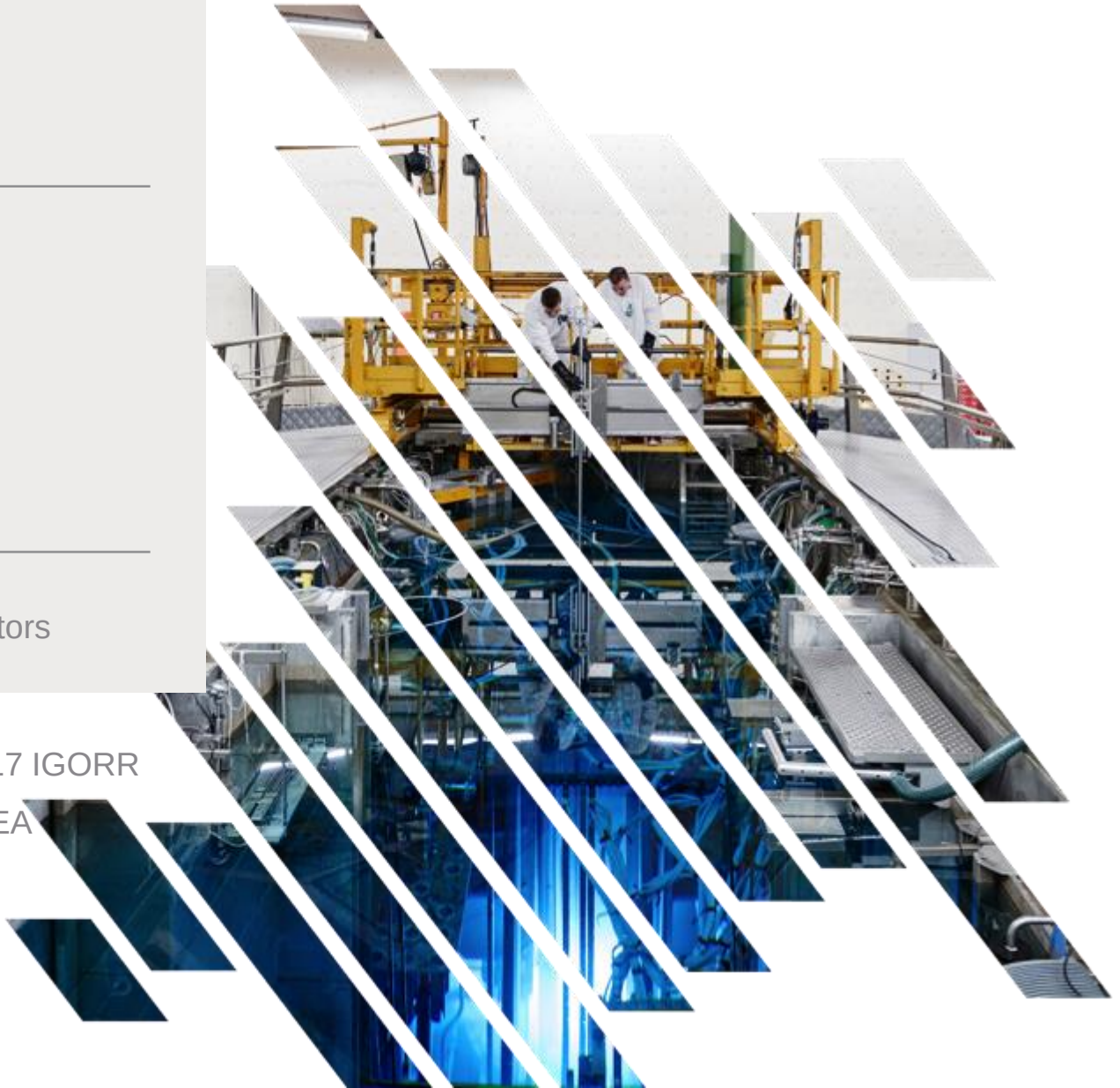

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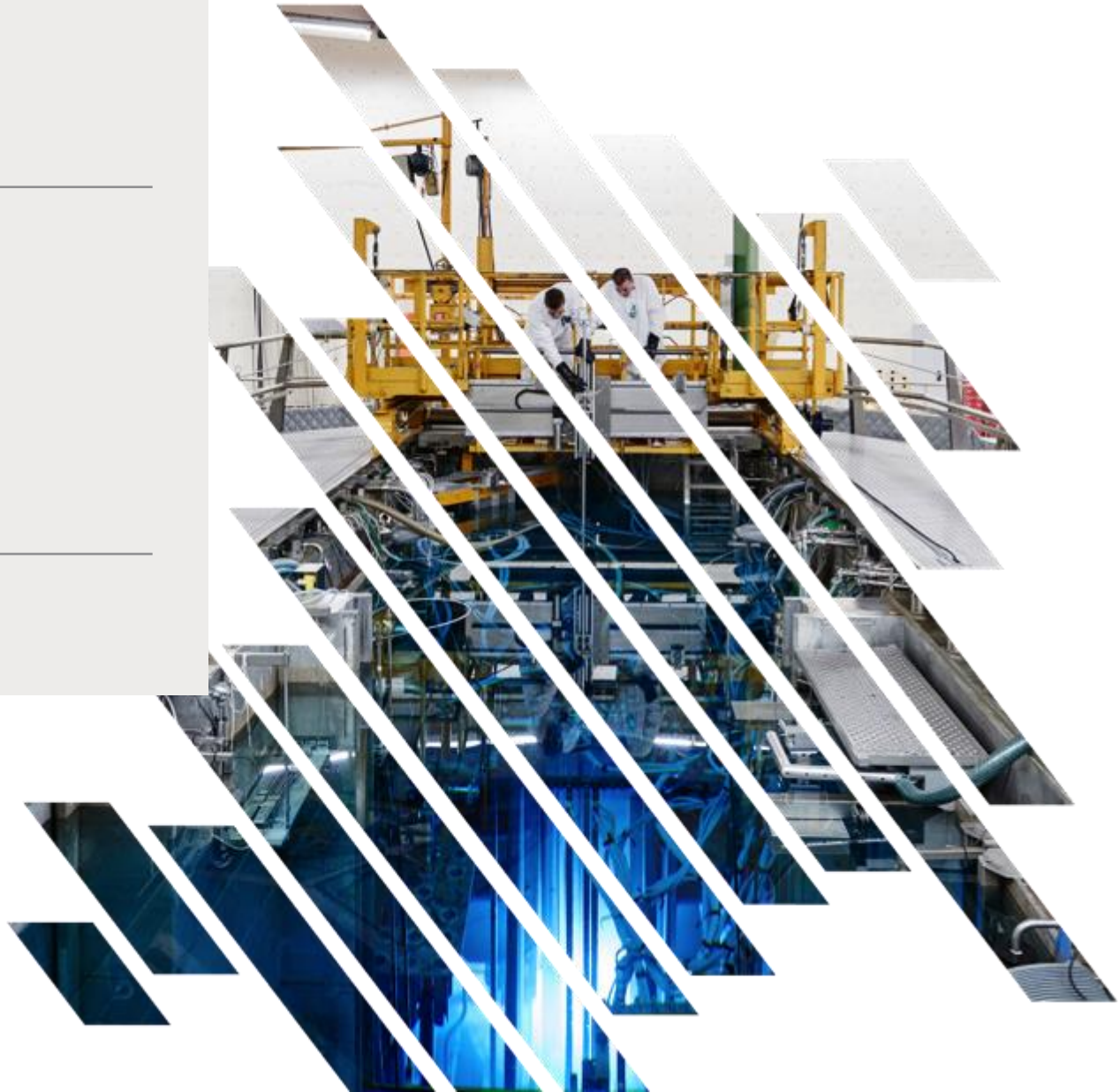
- Theoretical framework
- Case study
- Conclusions & Recommendations

CAUSE & CONTEXT



CAUSE & CONTEXT

Cause

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

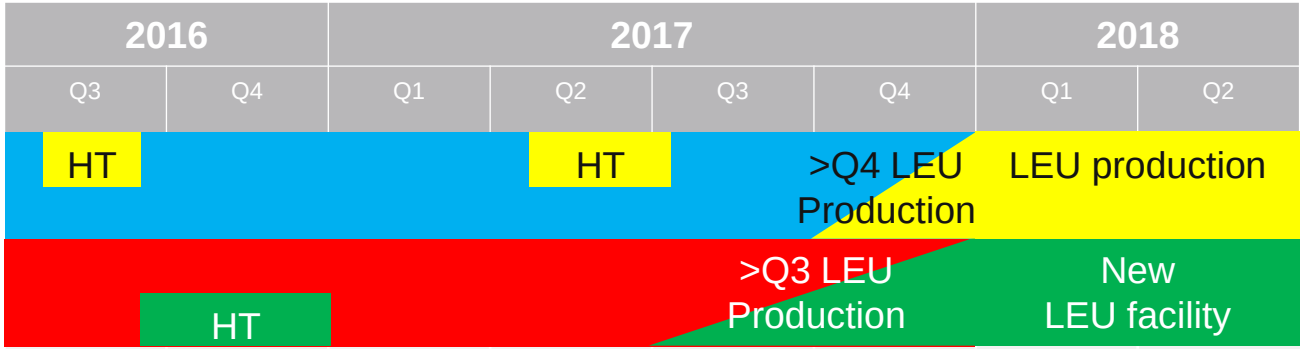
Context

- 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



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

LEU productie ready 2
= production HEU & LEU IRE en MM HEU
= partial loading IRE LEU

LEU productie ready 3
= production MM LEU & IRE LEU
= ANGITIA primary cooled
= ANTICA new PSF

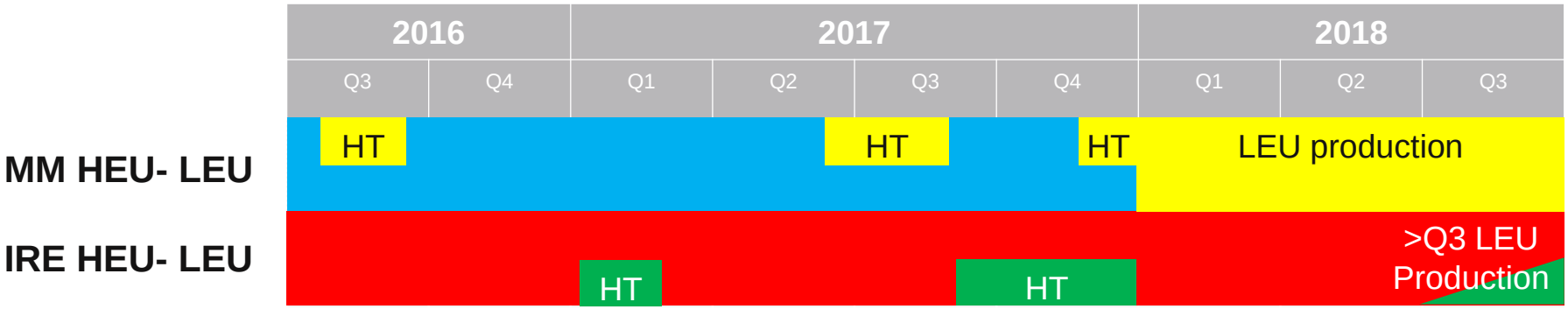
ABC Customer

Milestone project HFR Operational Readiness

HEU irridations

LEU irridations

CONTEXT: DEMAND OVER TIME



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

LEU productie ready 2
= production HEU & LEU IRE
en MM HEU

LEU productie ready 3
= production MM LEU
& IRE LEU
= ANGITIA primary cooled
= TINOS new PSF

ABC Customer

Milestone project HFR Operational Readiness

HEU irridations

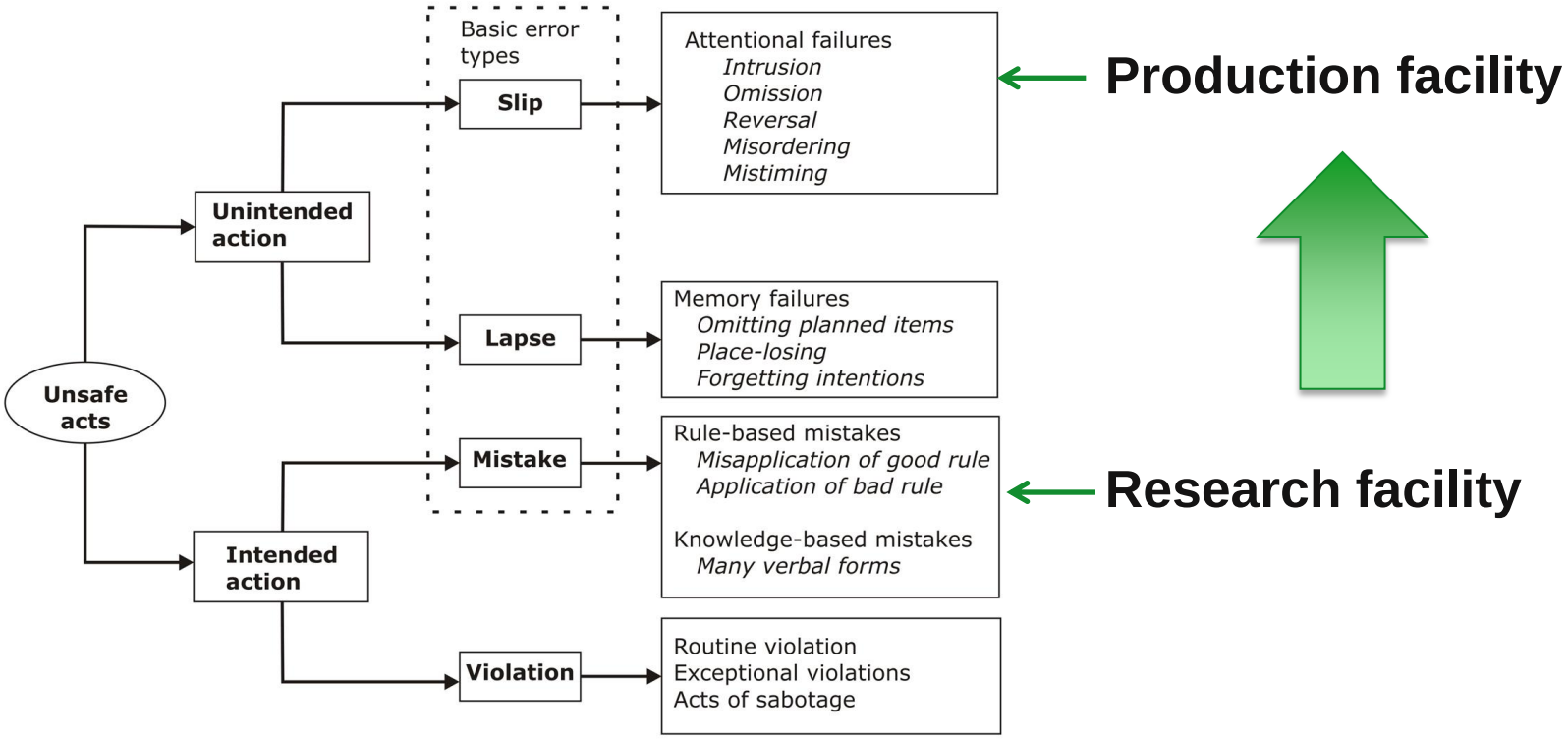
LEU irridations

CONTEXT: ORGANIZATIONAL CHANGE

	Research facility	Production facility
Deliverable:	Report	Material
Iterations:	One/Few	Many
Design focus:	Availability	Reliability
Design focus:	Unique result	Max. throughput
Quality:	Controlled	Constant
Time:	Controlled	Fixed
Deviations:	Exception report	Rejection

CONTEXT: ORGANIZATIONAL CHANGE

Model of human error (Reason, 1990)

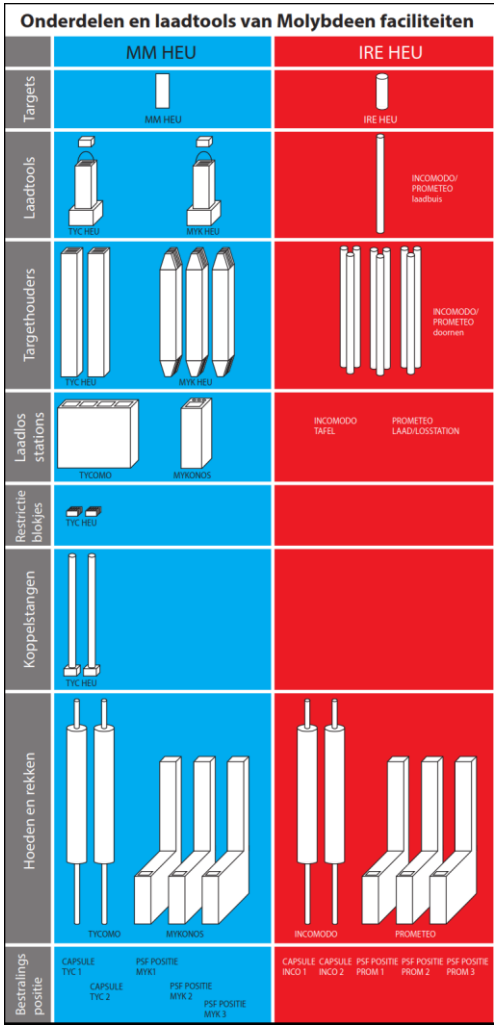


CONTEXT: TECHNOLOGICAL COMPLEXITY

- 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

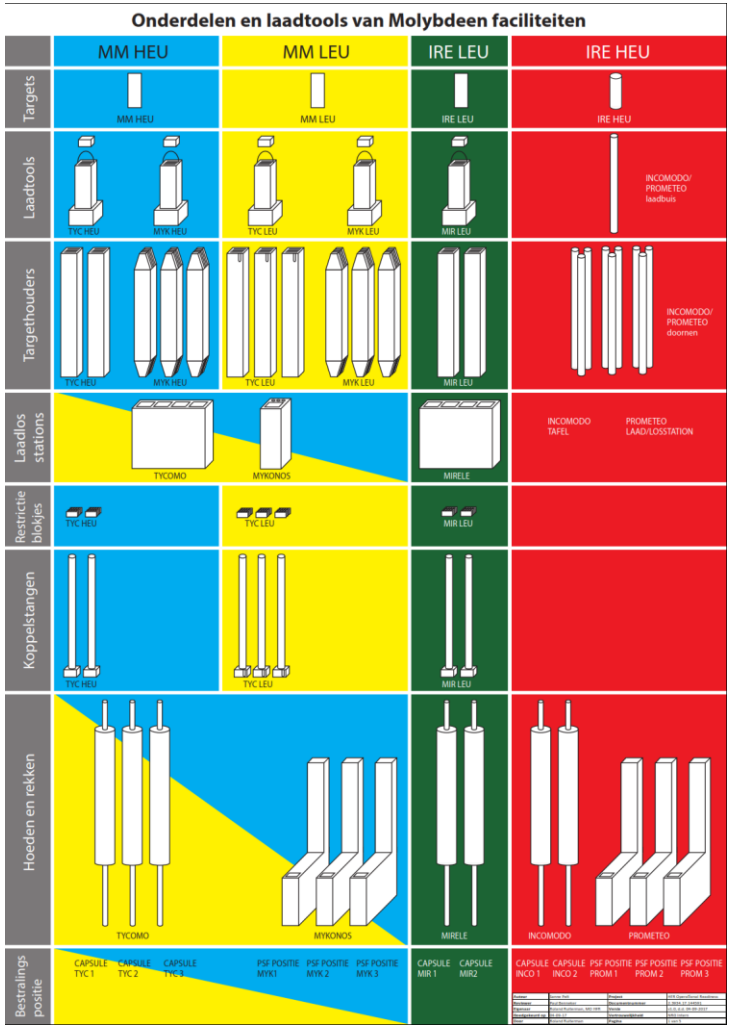
Similarities in design of HEU and LEU rigs pose risks of mixing components and targets. Quality issue, possibly nuclear safety.

CONTEXT: TECHNOLOGICAL COMPLEXITY



HEU only

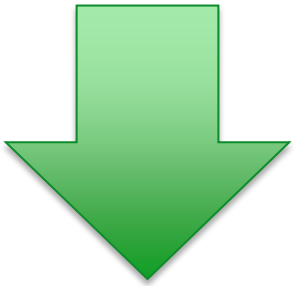
HEU & LEU



CONTEXT: CONCLUSION

The solution is influenced by:

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

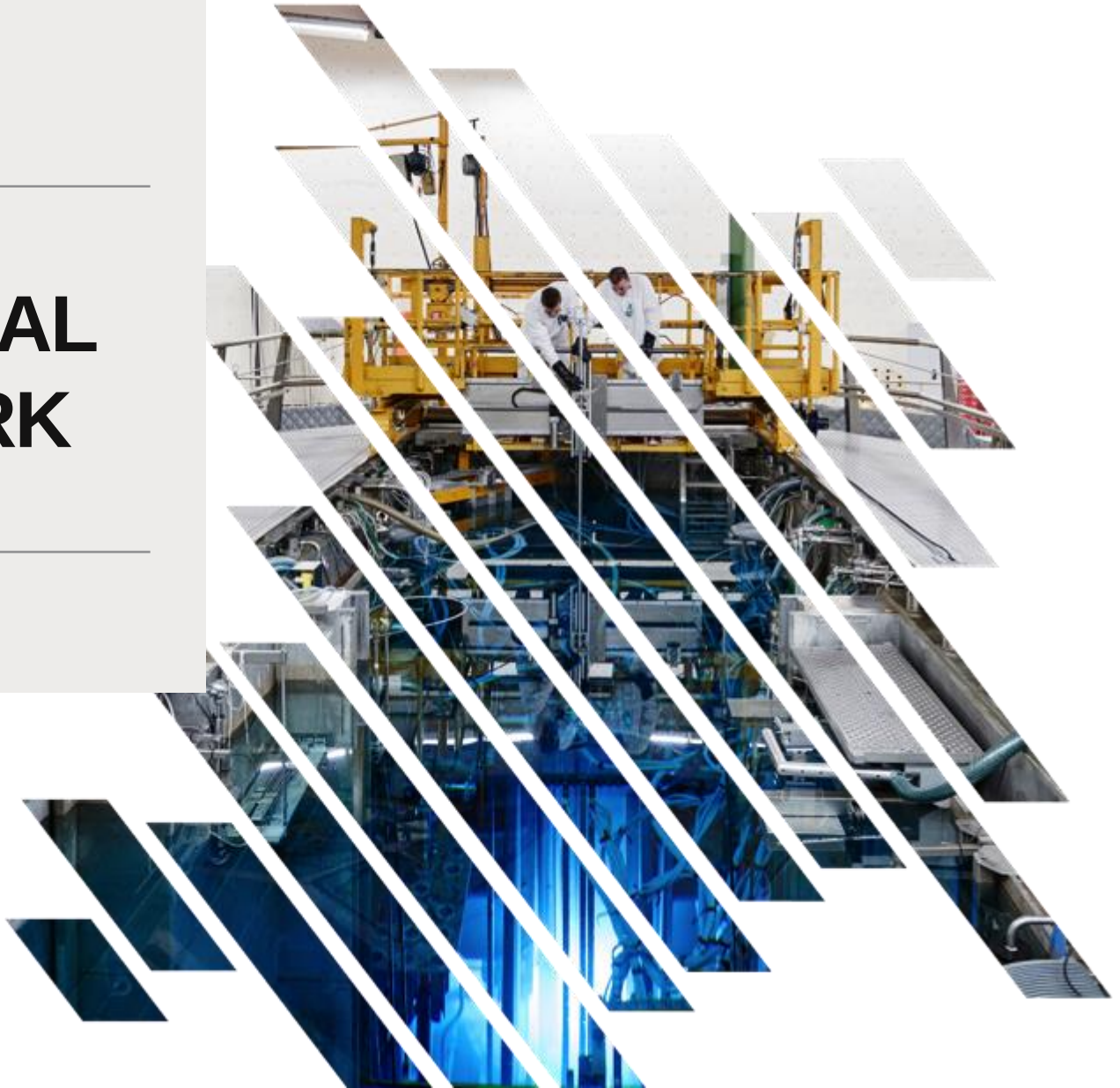


Wicked problem

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

Laurence J. Peter

THEORETICAL FRAMEWORK



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

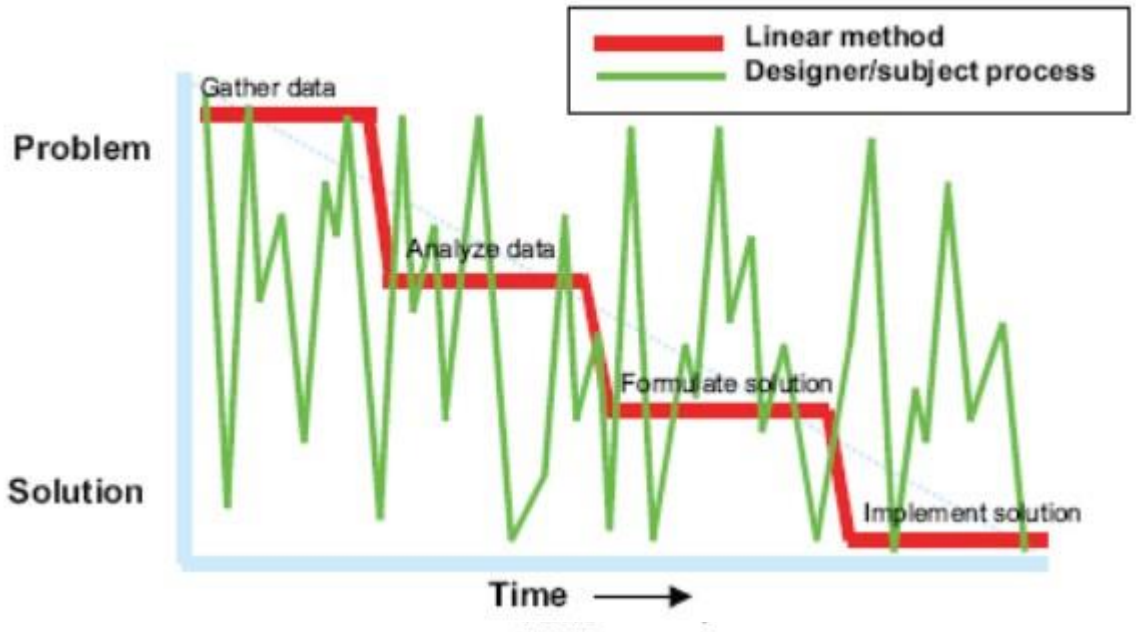
- J. Conklin, *Dialogue Mapping: Building Shared Understanding of Wicked Problems*, 2005

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

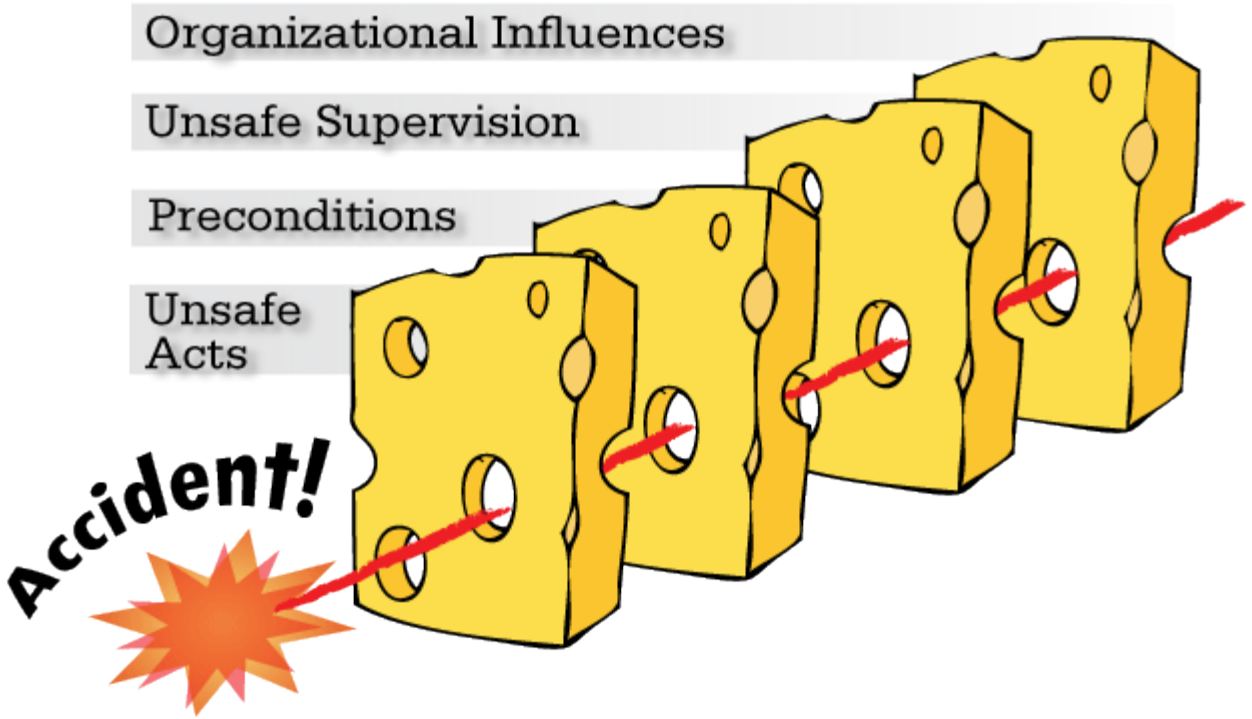
WICKED PROBLEMS: SOLVING



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



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

[SOURCE: ISO 9241-210:2010, 2.7, modified]

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]

CASE STUDY

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

CONSTRAINT: 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

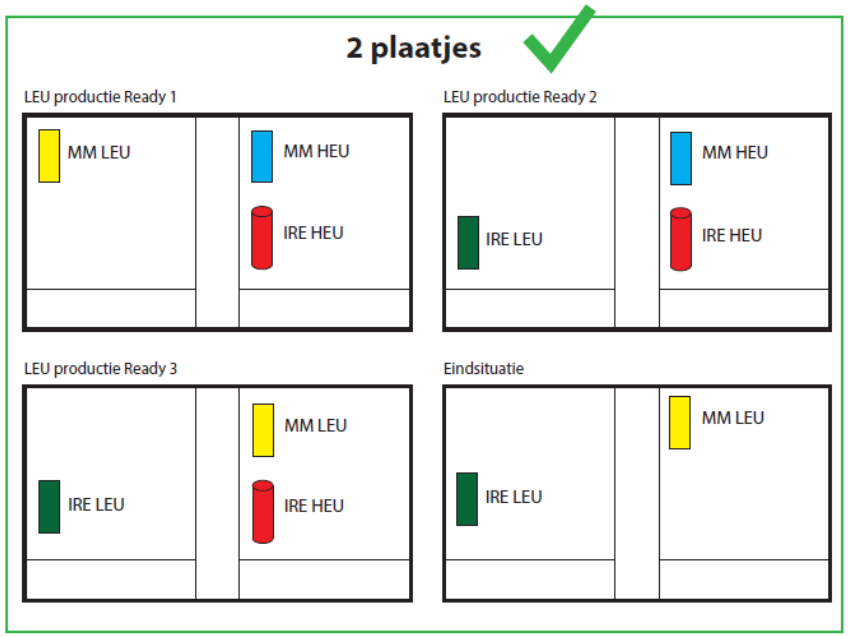
SET CONSTRAINTS IN PLANNING

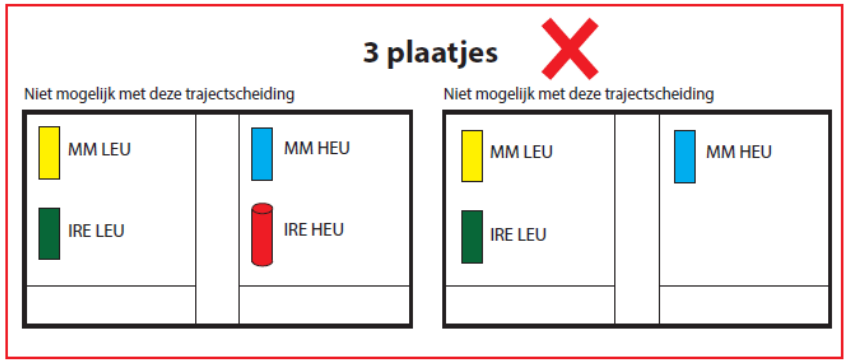
- Observe operators during work, and involve them to understand what will reduce complexity in day to day operations
- Constrain this complexity by solving it on the highest possible organisational level (solve the problem on a different level from where it occurs)
- Reduce complexity and costs of engineering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

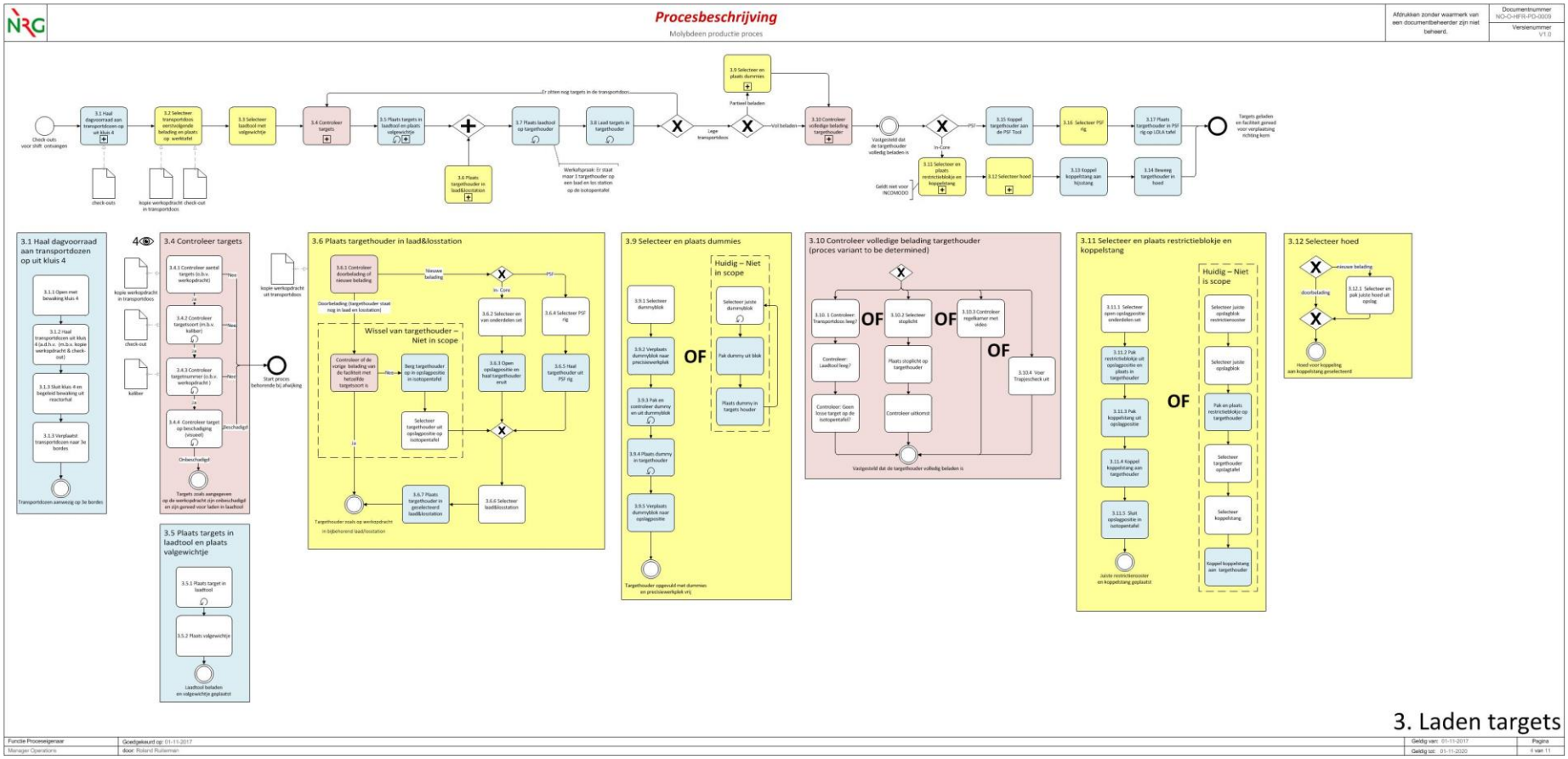
1st iteration: guide words & process flow diagrams

- 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

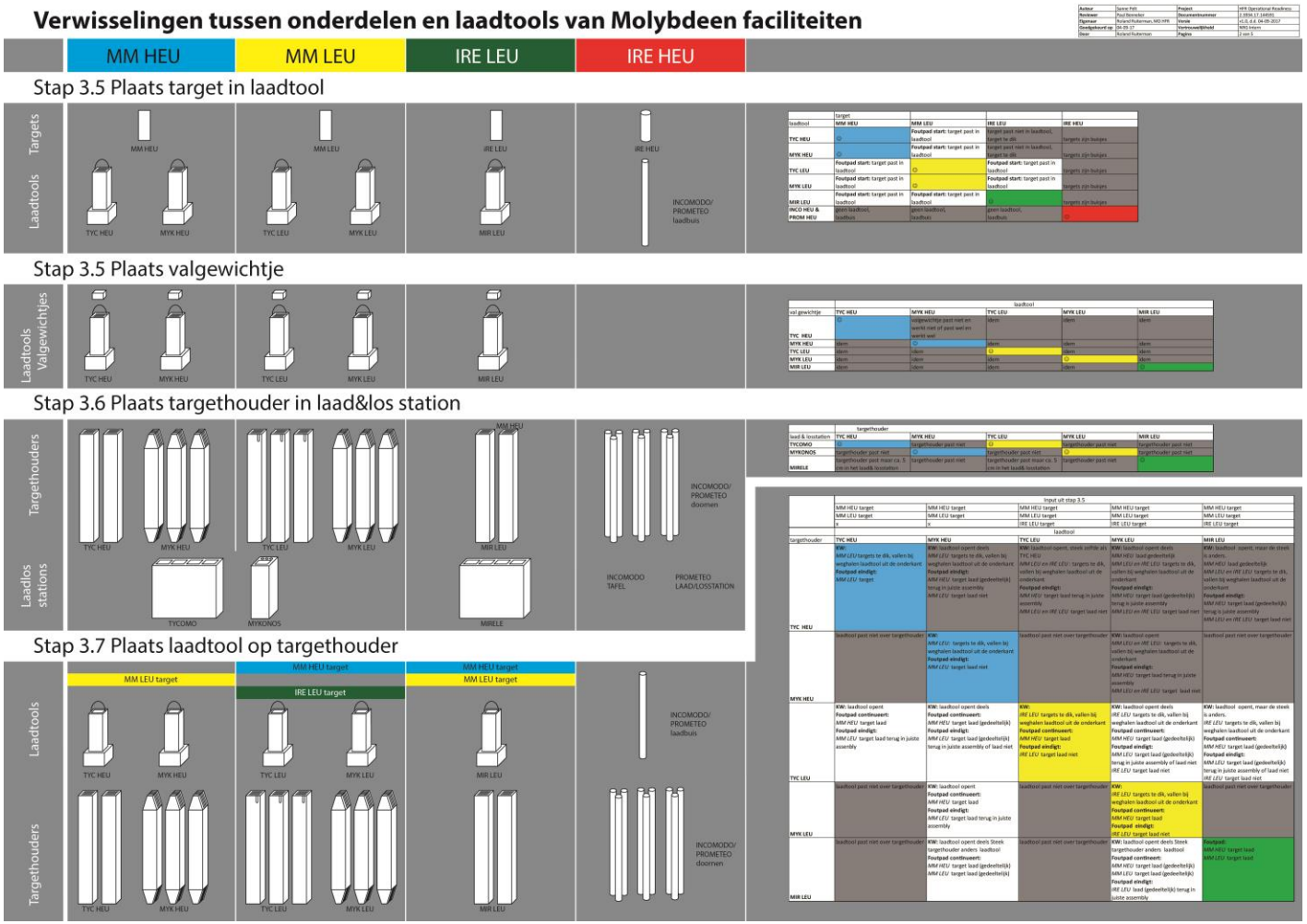
Van toepassing op:						HAZOP tabel	versie 20170906								
Tyvorno I-ITU	Tyvorno I-LEU	Mire b	Mirfunnes I-HEU	Mirfunnes I-LEU	Proces stap nr	Processtap	Doel van de stap	Gidswoorden Human HAZOP	Oorzaak/ Beinvloedende factor	Afwijking (indien faciliteit specifiek, is dit aangegeven)	Gevolg (indien faciliteit specifiek, is dit aangegeven)	Mechanismen voor detectie en herstel	Maatregelen	Aanpassing opgenomen in	Opmerking
x	x	x	x	x	3	**Laden targets**	Het laden van de targets in de targethouder en de targethouder in de faciliteit, zodat de targets bestraald kunnen worden.								
x	x	x		x	3.1	Haal dagvoorraad aan transportdozen op uit kluis 4	De targets die die dag bestraald moeten worden, naar het 3e bordes halen, zodat ze vanaf daar in de targethouder geladen kunnen worden.								
x	x	1.01	x	x	3.1.1	Open met bewaking kluis 4.	De transportdozen uit kluis 4 halen	A4 Actie te veel/ te weinig		1. te weinig transportdozen in de kluis	1. Vertraging	1. meer check-outs mee dan er dozen inde kluis staan 2. afwijking melden	geen		
x	x	1.02	x	x	3.1.2	Haal transportdozen uit kluis 4 (o.b.v. Werkopdracht in transportdoos & check-outs)	De transportdozen uit kluis 4 halen	A4 Actie te veel/ te weinig	verwisseling	1. Fout in voorgaand proces. Andere doos of nummers en/of aantal komen niet overeen	1: verkeerde transportdoos mee naar bordes 2: afwijkende targets niet opgemerkt 3: afwijking in splijtstofadministratie	1.:Controle werkopdracht uit regelkamer met werkopdracht in transportdoos aan rand 3e bordes 2.:Proces 3.4: Controle targetsoort en targetnummers aan rand 3e bordes	1. Verhogen herkenbaarheid inhoud transportdozen: transportrekken targetsoorten deelfde kleur geven als de werkopdrachten 2. Integreren kaliber targetsoort in transport doos	1. +2. HFR Operational Readiness BMA 2016-033	
x	x	1.03	x	x	3.1.3	Sluit kluis en begeleid bewaker uit reactorhal	De beveiliging targets zeker stellen	O1 Opzettelijk overtreding	kluis te lang open en geen bewaking	Targets worden opzettelijk meegenomen	Targets uit de kluis	Goede bewaking	geen		
x	x	1.05	x	x	3.1.4	Verplaats de transportdozen naar 3e bordes	Targets naar 3e bordes brengen	A8 Verkeerde actie op het juiste object	Ergonomie; afleiding	Transporttrommel laten vallen	Fysieke schade personeel (arbo/persoonlijk letsel)	Geen	geen		
x	x	1.06	x	x	3.1.4	Verplaats de transportdozen naar 3e bordes	Targets naar 3e bordes brengen	A8 Verkeerde actie op het juiste object	Ergonomie; afleiding	Transporttrommel laten vallen	transporttrommel/target raakt beschadigd; vertraging	Geen	geen		
x	x	x	x	x	3.1.4	Verplaats de transportdozen naar 3e bordes	Targets naar 3e bordes brengen	A8 Verkeerde actie op het juiste object	Ontwerp transportdozen	Transporttrommel laten vallen	Bij meerdere dozen: target terugstoppen in verkeerde transportdoos	1. Processtap 3.4 Targets controleren	1. Ontwerp transportdozen aanpassen, zodat targets er niet uit vallen als de doos valt	1. HFR Operational Readiness BMA 2016-033	
x	x	x	x	x	3.2	**Selecteer transportdoos**	Het selecteren van de transportdoos met targets voor de eerst volgende belading, zodat de juiste targets geladen worden.								
x	x	1.03	x	x	3.2	Selecteer transportdoos eerst volgende belading en plaats op de werktafel (m.b.v. kopie werkopdracht in transportdoos & check-out)	Het selecteren van de transportdoos met targets voor de eerst volgende belading, zodat de juiste targets geladen worden.	S2 Verkeerde selectie gemaakt	Herkenbaarheid transportdozen, werkopdrachten en check-outs	Volgorde bestralingen verwisselen, (Transportdozen met targets, werkopdracht en check-out)	1. Verder in proces met verkeerde werkopdracht, check-out en targets tot moment van in bestraling nemen. Kwaliteitsgevolg: 1. te vroeg hebben beladen verkeerde faciliteit 2. te laat in bestraling nemen juiste faciliteit (inschatting max. 1. vertraging)	1. 4-ogen principe 2. voorbesproken bij overnemen wacht welke faciliteit eerst gaat; tijd in bestraling nemen staat op werkopdracht 3. Detectie in het proces 6 'Hoed op/ Rek tegen kern plaatsen' als wordt gecheckt op welk moment de faciliteit in bestraling moet worden genomen.	1. Dezelfde kleuren toepassen op de transportdozen en werkopdrachten en check-outs 2. Targetsoort groot vermelden op werkopdracht 3. Check-outs targetsoort specifiek maken en targetsoort op check-outs noteren 4. Werkafspraak maken: Er staat maar 1 transportdoos in het werkgebied	1. +2. +3. HFR Operational Readiness BMA 2016-033 4. HFR Operational Readines Lijst 'HEU - LEU werkafspraken'	Transportdozen worden veelal geplaatst op de overstapbank op het 3e bordes. Er is geen vaste plek voor.
x	x	x	x	x	3.3	**Selecteer laadtool met valgewichtje**	Het selecteren en pakken van de laadtool met het valgewichtje van het laadbordtool, die nodig is voor het laden van de targets in de targethouder.								
x	x	3.07	x	x	3.3	Selecteer laadtool met valgewichtje	Het selecteren en pakken van de laadtool met het valgewichtje van het laadbordtool, die nodig is voor het laden van de targets in de targethouder.	S2 Verkeerde selectie gemaakt	Herkenbaarheid laadtool	Verkeerde laadtool geselecteerd, matcht niet met targets	1. Verder tot 3.5, gevolgen staan daar genoteerd	1. Naam op laadtool	1. Naam van laadtool op laadtoolbord weergeven 2. Kleurmarkering targetsoort doorvoeren op laadtool bord 3. Doorvoeren modulariteit op laadtoolbord. Targetsoort niet nodig in cyclus = laadtool afgeschermd op bord	1. + 2. +3. HFR Operational Readiness BMA 2016-033	
x	x	3.11	x	x	3.3	Selecteer laadtool met valgewichtje	Het selecteren en pakken van de laadtool met het valgewichtje van het laadbordtool, die nodig is voor het laden van de targets in de juiste faciliteit.	S2 Verkeerde selectie gemaakt	Herkenbaarheid gewichtjes bij laadtool	Fout uit vorig proces: verkeerd gewichtje bij laadtool	1. Verkeerd gewichtje past wel; werkt net zo goed al correct gewichtje: geen gevolgen 2. Verkeerd gewichtje past niet: komt niet voor, want dan kan de tool niet opgeslagen worden met het gewichtje erin en wordt de fout al eerder hersteld, geen gevolgen	nvt	nvt	nvt	voor verdere uitwerking zie notitie 2.3934.17.144591 'Verwisseling van onderdelen Molybdeen faciliteiten' v1.0

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 asses if additional measures are neccesary (Probabilistic approach)

RESEARCH RESULTS



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

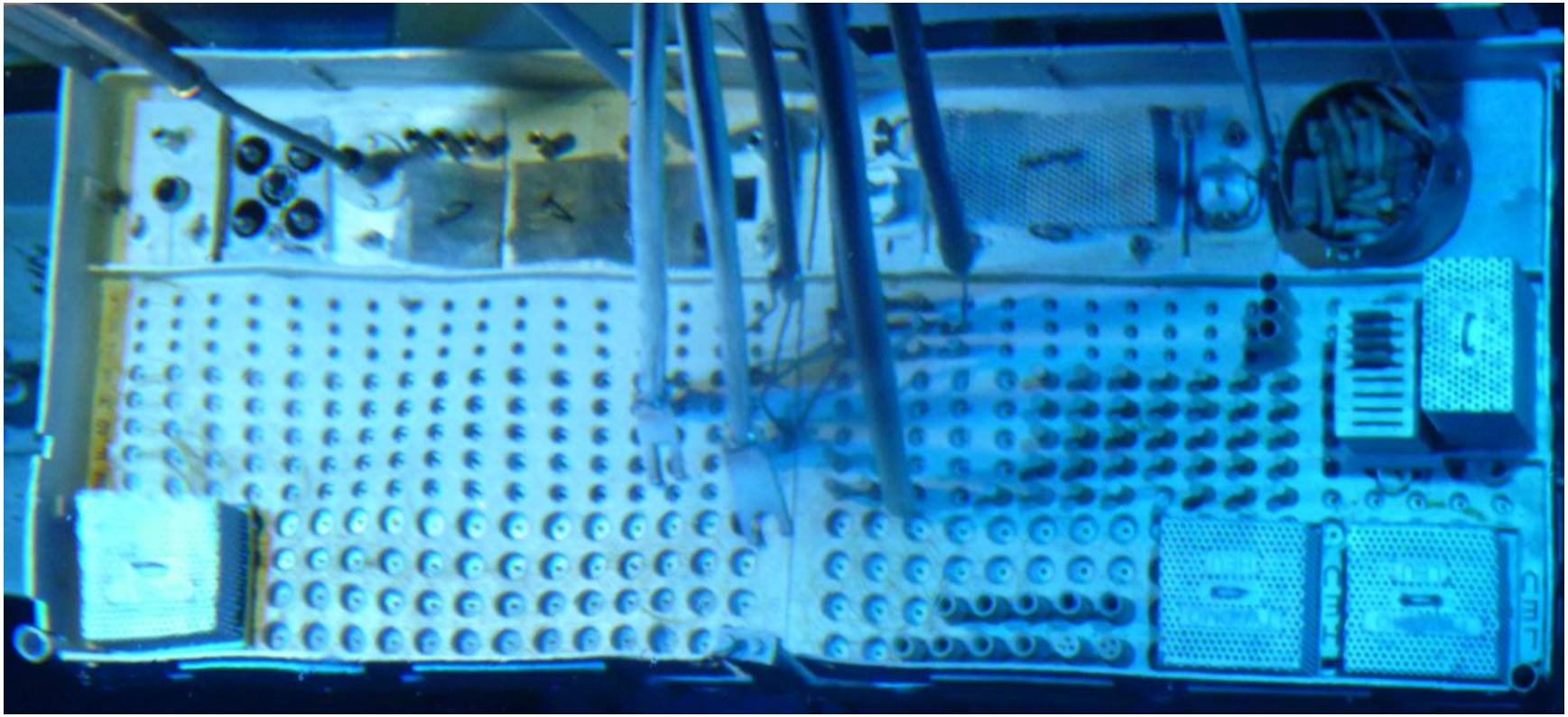
- Insight into where the risks of human errors are in the production process and across whole system of irradiation facilities used
- Ability to asses consequences for operability as part of new business cases for irradiations
- Process flow diagrams for future use
- Wider spreads knowledge of the day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

BASIC DESIGN - PROCESS

Human Centred Design

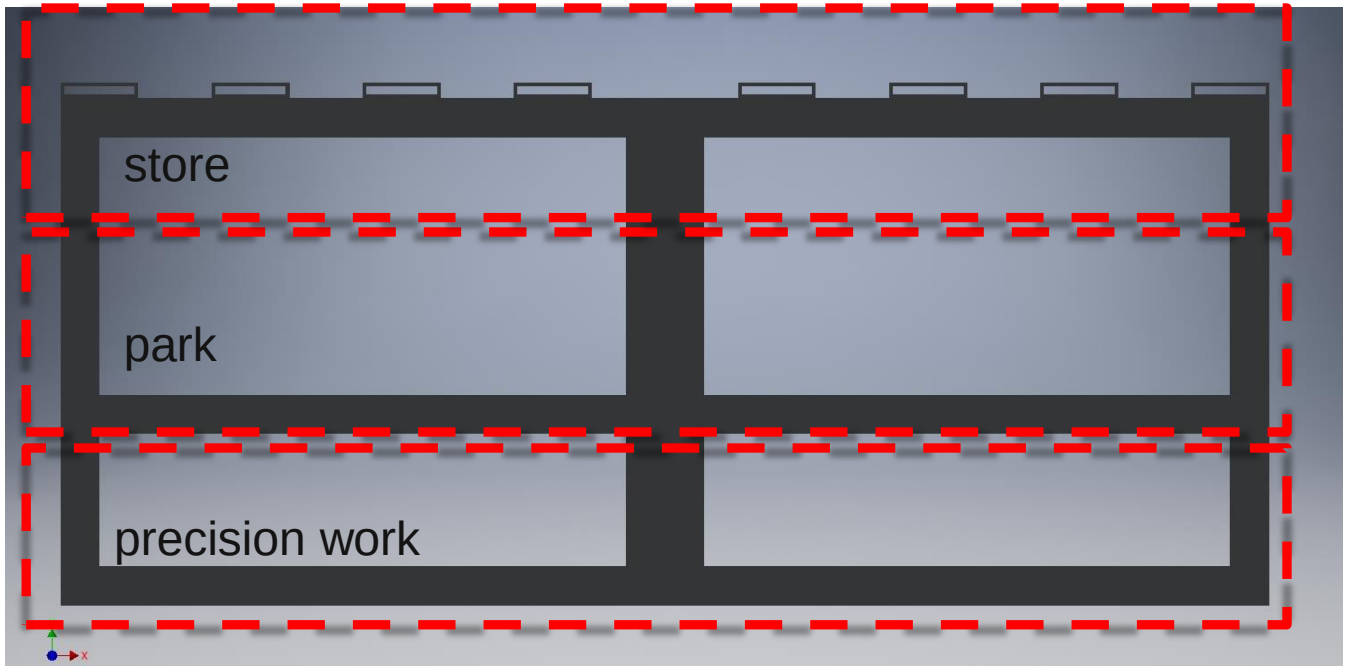
- Focus on selecting basic working principles to be applied to the whole system
- Define specifications together with users
- Iterate in small steps, starting with simple sketches (prototypes)
- Aske for user feedback to check if it will work
- Fail early results in 1st time right final design

BASIC DESIGN – OLD ISOTOPE TABLE



BASIC DESIGN – ISOTOPE TABLE

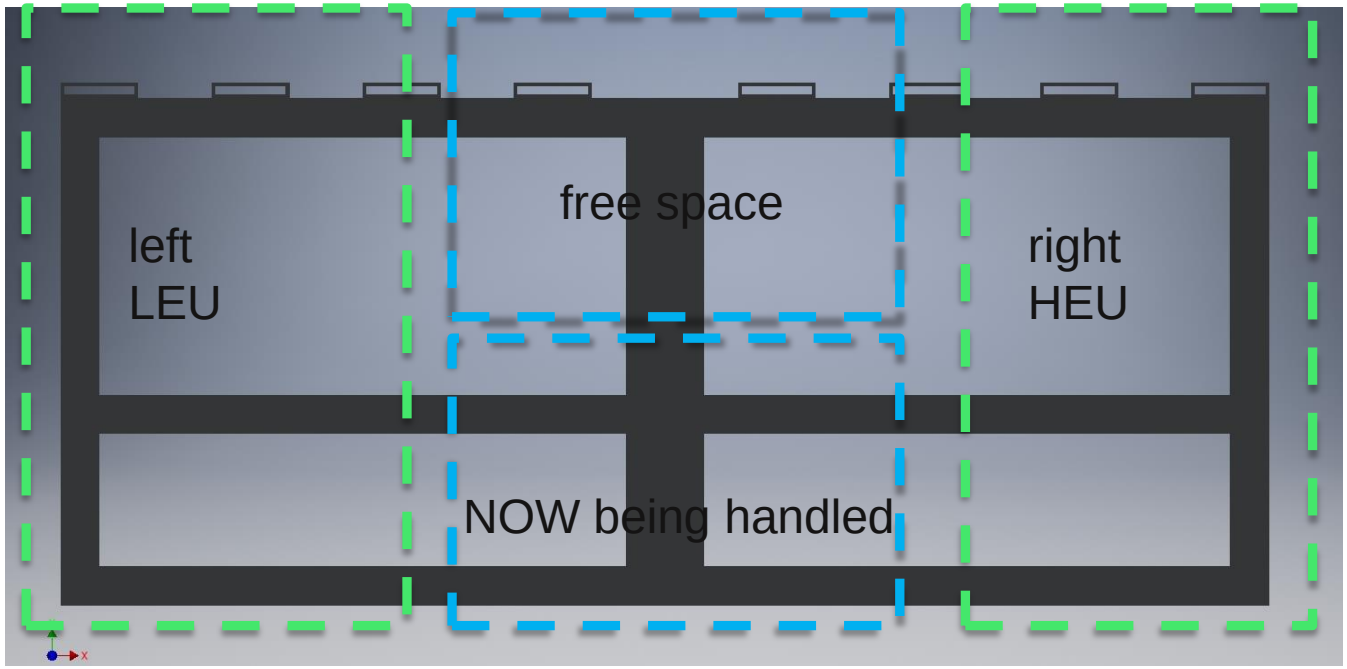
Less precise movements



Precise movements

BASIC DESIGN – ISOTOPE TABLE

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



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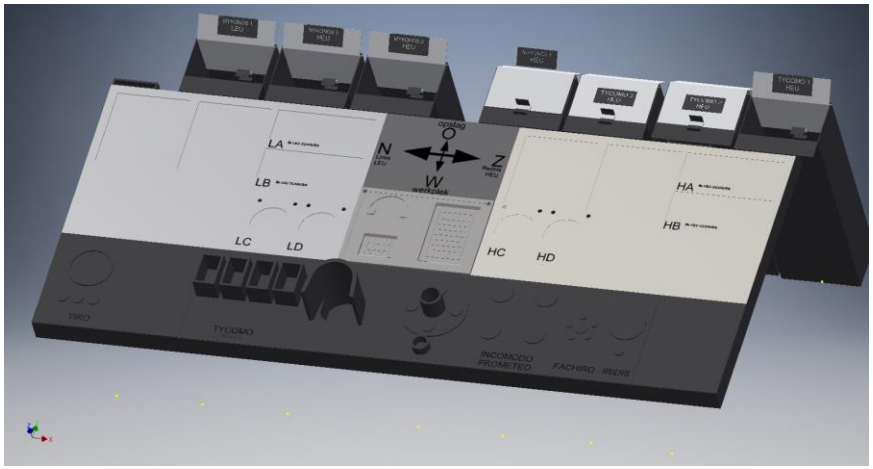
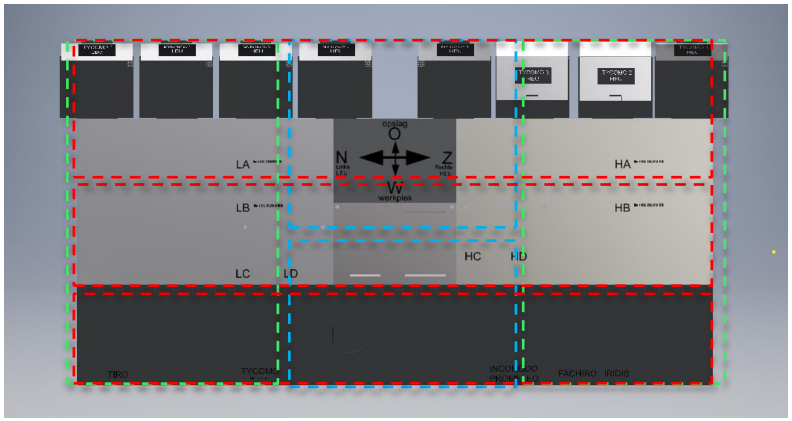




DETAIL DESIGN - METHOD

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
- Usecues 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

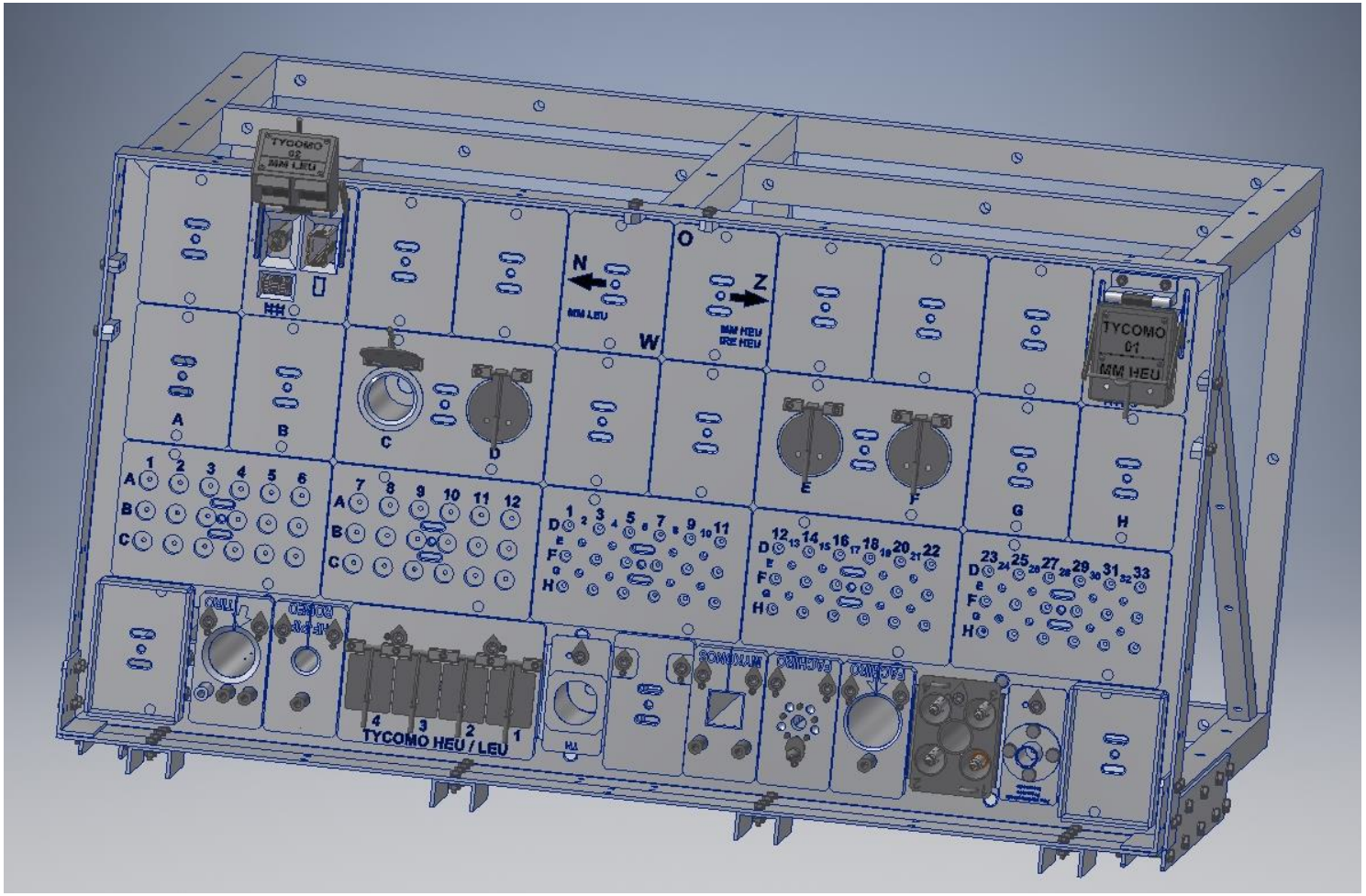
Minimal amount of choices during production (made possible by constraints in planning)

- 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

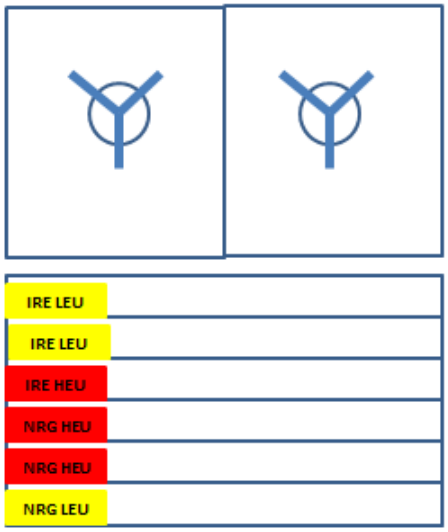
Target	Vault	Transport box	Work order	Check-out	Tool storage	Loading tools
MM HEU				none	none	none
MM LEU				none	none	none
IRE HEU				none	none	none
IRE LEU				none	none	none

BASIC DESIGN - COLOUR CODE NEW

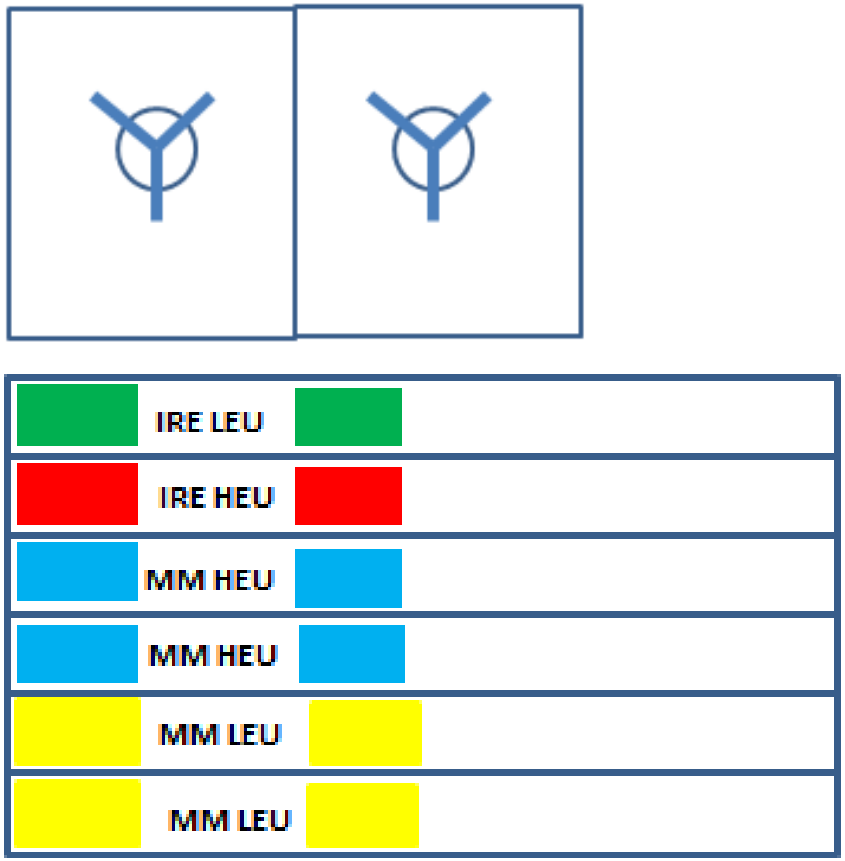
Target	Vault	Transport box	Work order	Check-out	Tool storage	Loading tools
MM HEU						
MM LEU						
IRE HEU						
IRE LEU						

DETAIL DESIGN - TARGET VAULT

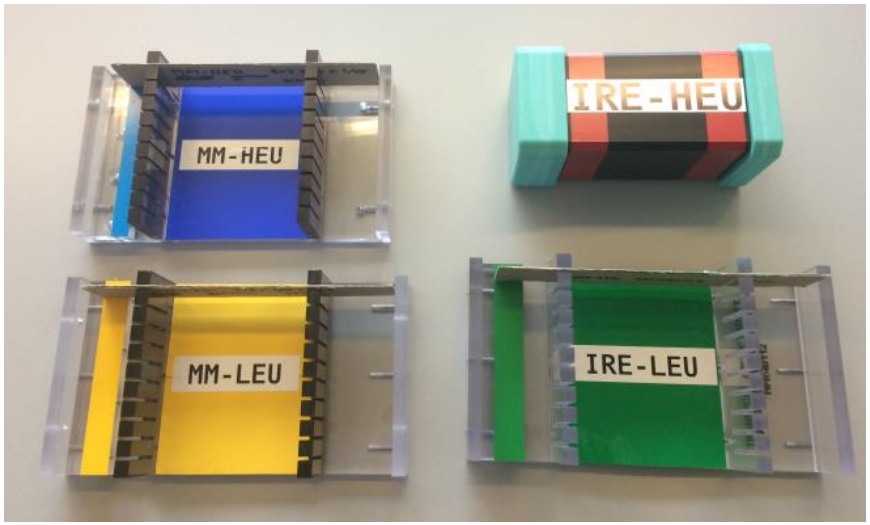
Kluis 2:



Kluis 2:



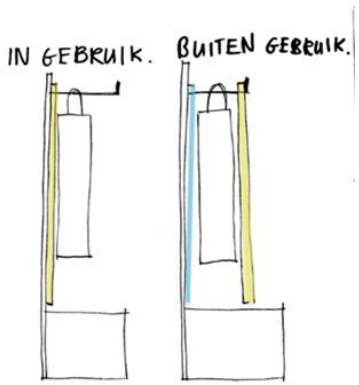
DETAIL DESIGN - TRANSPORT BOXES

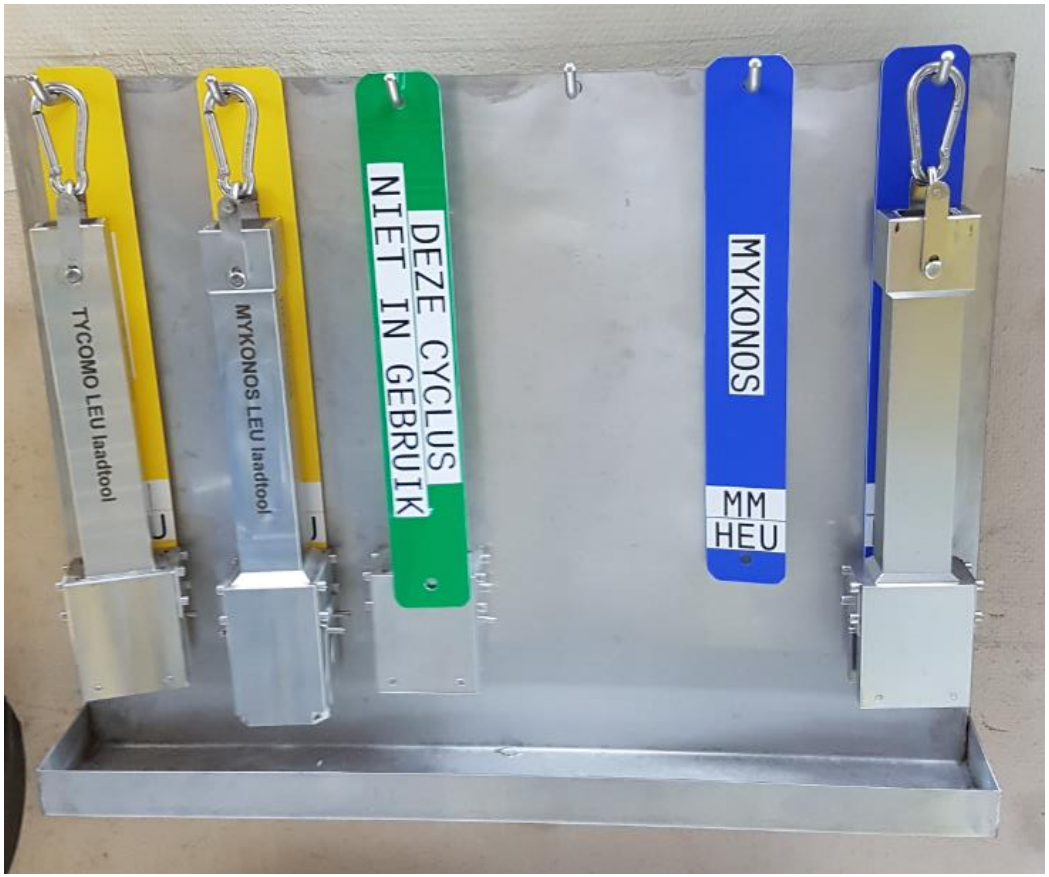


Built in calibre to check if you have the right targets
Transparent boxes, so you can see the inside

DETAIL DESIGN - TOOL STORAGE

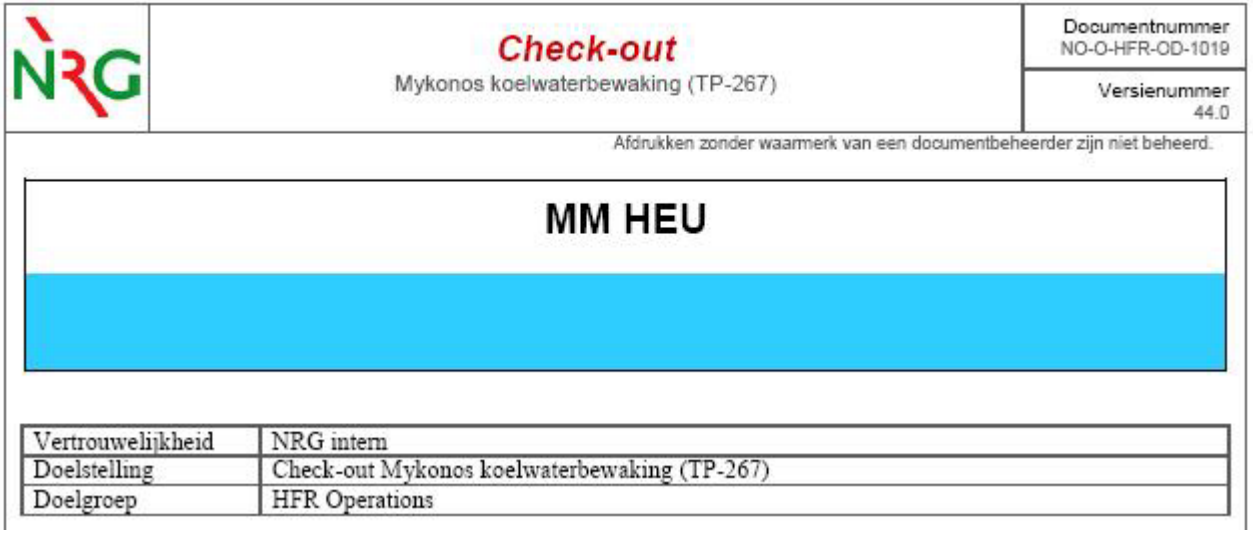
DETAIL DESIGN - LOADING TOOLS





DETAIL DESIGN - OPERATIONAL DOCS

Check-outs and loading procedures



	Check-out Mykonos koelwaterbewaking (TP-267)
	Documentnummer NO-O-HFR-OD-1019
	Versienummer 44.0

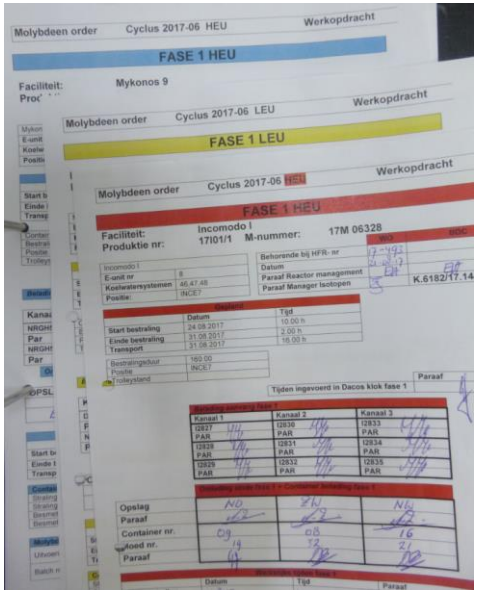
Afdrukken zonder waarmerk van een documentbeheerder zijn niet beheerd.

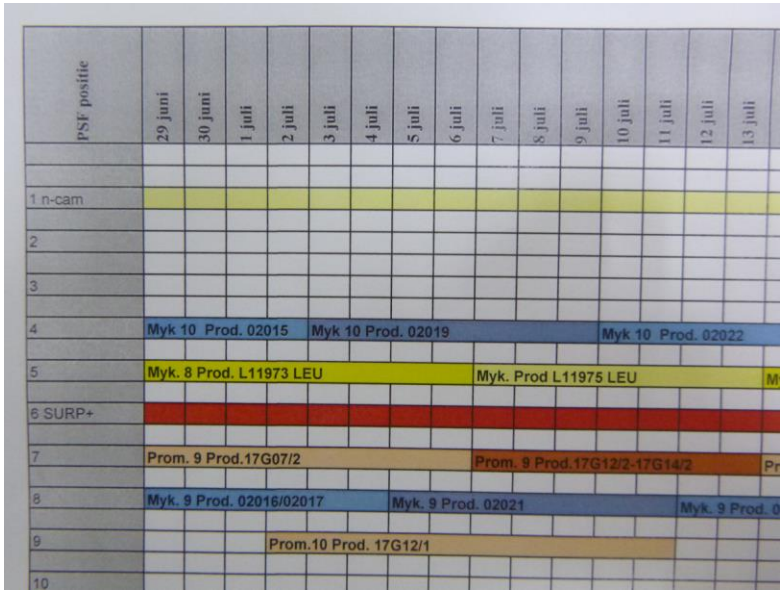
MM HEU

Vertrouwelijkheid	NRG intern
Doelstelling	Check-out Mykonos koelwaterbewaking (TP-267)
Doelgroep	HFR Operations

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