Stepwise Human Factors Verification & Validation - Towards continuous validation of complex systems

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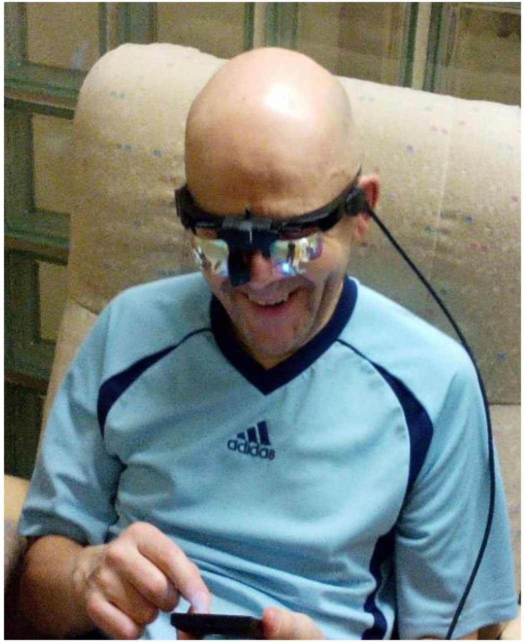
Human Factors & Service Engineering

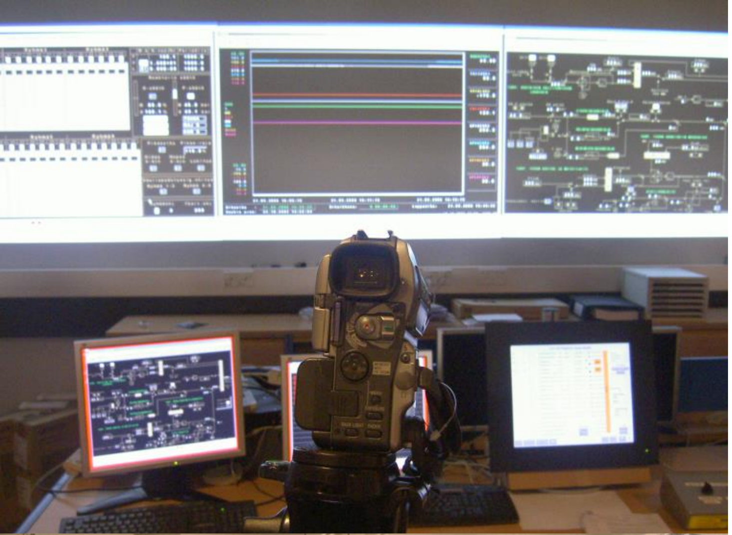
Who am I?



- Current position:
  - Principal scientist
- Previous positions:
  - Helsinki School of Economics
  - University of Helsinki
  - KELA etc.
- Education:
  - PhD in psychology

Main contents

- Modernization of I&C and CR systems in Finnish NPPs
- Validation in system design
- Key characteristics of the stepwise approach
- Simulators’ role in stepwise V&V
- Main activities in sub-system V&V
- Human Engineering Discrepancy (HED) identification and resolution process
- Usability Case in CR V&V
- Conclusions
- Questions
- Relevant literature
- Abbreviations



Main aim of the presentation

- Advocate a continuous validation approach
- Introduce a sub-system V&V methodology
- Present a usability case approach for aggregation and documentation of V&V data

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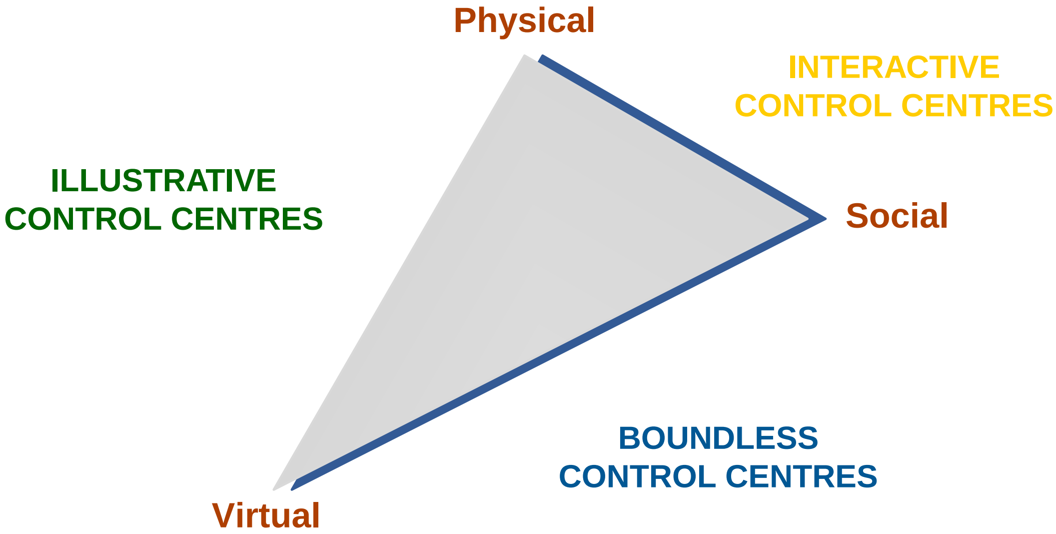
Examples of complex systems:

Control rooms come in many forms…

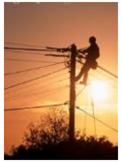


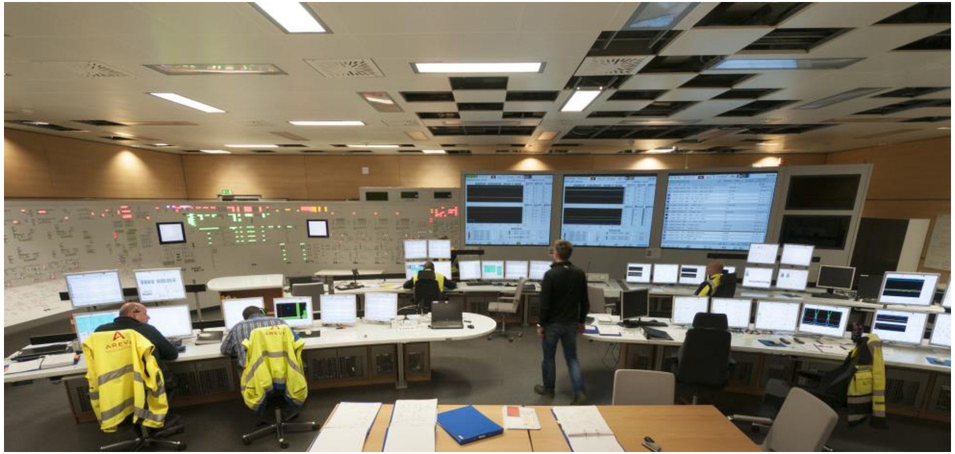






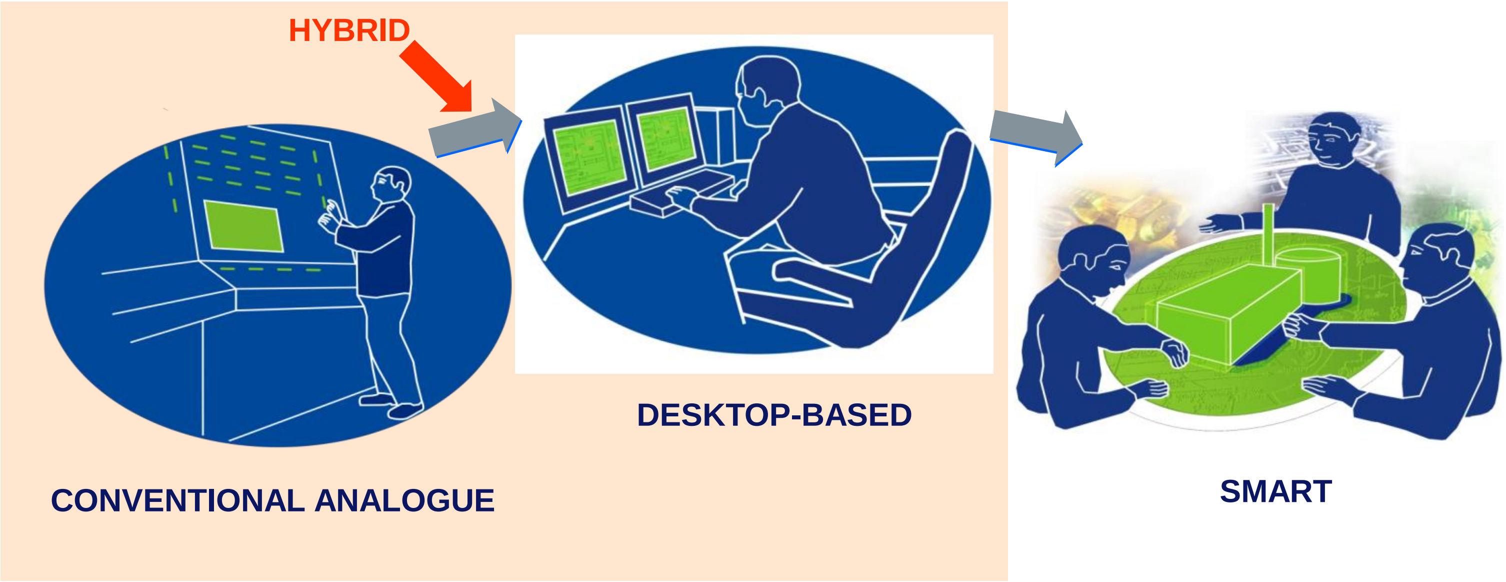
Nuclear power plant main control room:



TVO Olkiluoto

Modernization of I&C and CR systems in Finnish NPPs

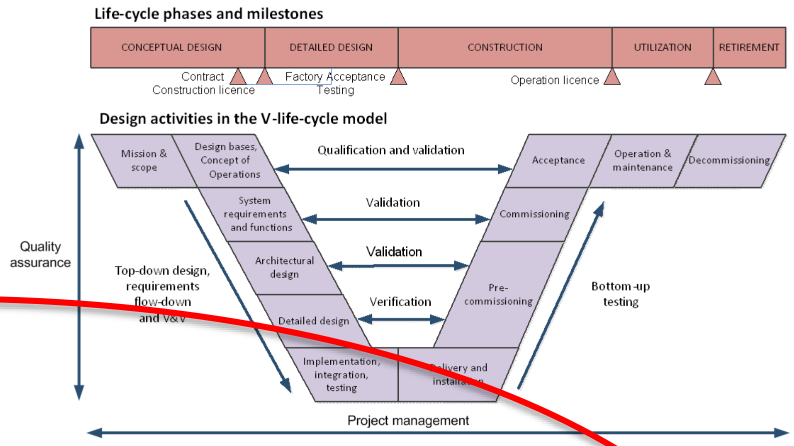
History and future of human-system interfaces in nuclear domain



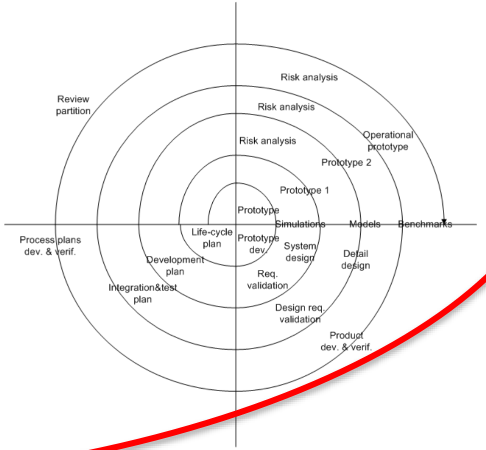
V&V in system design

System design

- System design process can be illustrated in various ways:
  - Linear depiction
  - V-model
  - Iterative design
- Design of complex socio-technical systems should be:
  - Continuous/incremental/ evolutionary
    - Incremental, cyclic and concurrent specification of design solutions

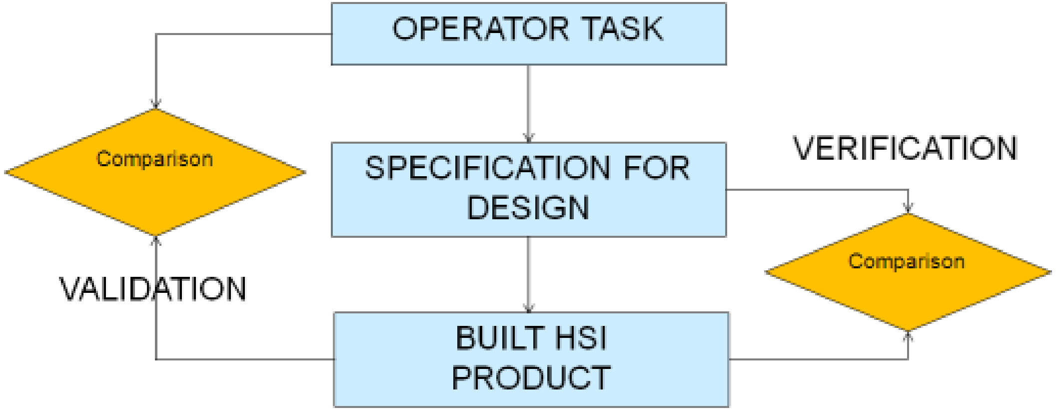


(modified from Tommila & Alanen, 2015)



Verification and validation in the design process

- Verification
  - Process to show that something has been constructed according to its specifications and requirements
  - **Are we building the system right?**
- Validation
  - Process to show that something that has been designed can carry out the task for which it is intended, specifically in such a way that the design is able to support effective integrated performance of particular function
  - **Are we building the right system?**



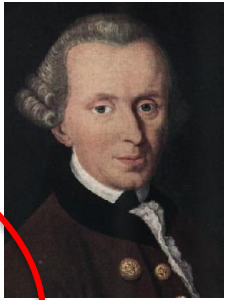
Role of verification and validation in the CR life-cycle

- Aim is to ensure that plant personnel is able to successfully perform safe plant operations throughout the plant life-cycle (or licensing period)
  - In addition:
    - Aim is to monitor that the potentials of the new technology are realized

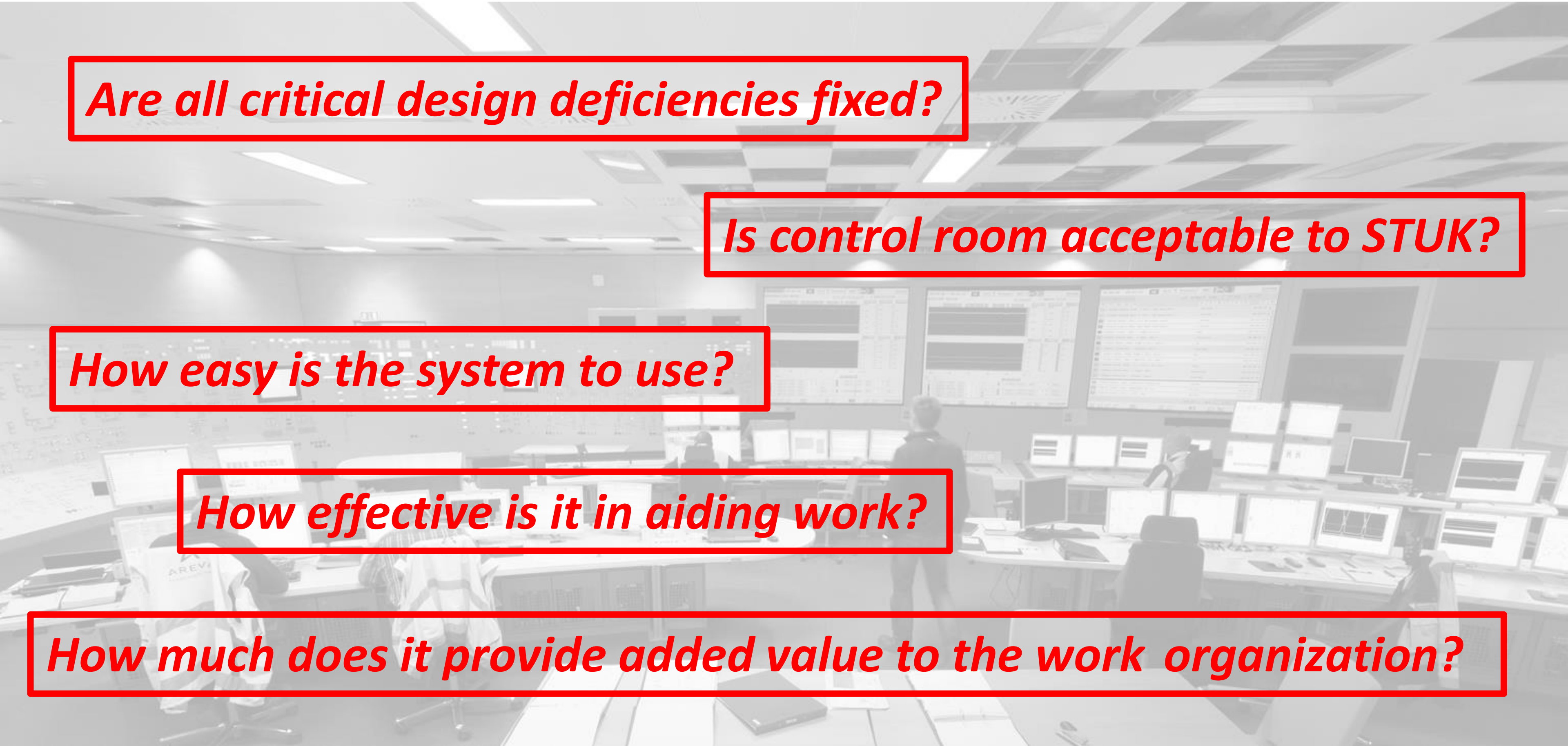
- Good HF V&V will help the achievement of, e.g.:
  - Ease of training, ease of system operation and maintenance, error prevention, improved interoperability, reduction of workload, improved situation awareness, improved teamwork and communication, enhanced command and control, improved system safety, and better system performance

Possible approaches to validation
(e.g., Wise & Wise, 1993)

- Approaches to evaluation:
  - **Lockean**
    - Validation activities should give **one clear answer** to the question of whether the system is valid or not
  - **Kantian**
    - It is not possible to give a single answer to the validity question, but **many answers** that illuminates the question of the system’s validity from different perspectives
  - **Hegelian**
    - Hegelian approach is used in legal hearings: the design is the case; one side asks questions about the validity of the system, and the other side tries to give answers to these questions



Examples of questions to be asked



Are all critical design deficiencies fixed?

Is control room acceptable to STUK?

How easy is the system to use?

How effective is it in aiding work?

How much does it provide added value to the work organization?

Key characteristics of our approach

Key characteristics of our approach

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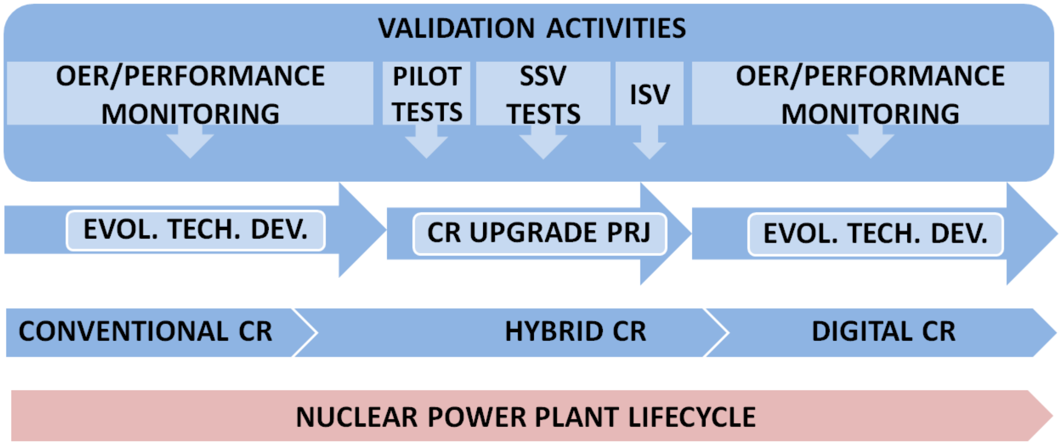
- Longitudinal, life-cycle perspective
  - All CR systems' periods from cradle to grave are considered, and V&V evidence is gathered throughout the life-cycle of the product
- Stepwise approach
  - CR is evaluated one system/a group of systems at a time
- Emphasis on contextual assessment of systems usability
  - Multilayered system of activity in which the CR systems are used constitutes the context of use for the systems
- Grading approach
  - E.g., evaluation of HSI design is tailored according to, e.g., the safety criticality and level of novelty of the design
- Requirement-based
  - V&V activities are mainly requirement-referenced

Life-cycle perspective on CR V&V

Life-cycle perspective on V&V

- The life cycle of control rooms stretches over decades and several development phases
- Human factors data is gathered during the life cycle with multiple methods
- There is a need to systematize human factors data and to prove the fulfilment of human factors and safety requirements



Considering instrumental genesis in system design and evaluation

- Instrumental genesis
  - "*Progressive construction* of the use of an artefact by an actor for a given purpose within a given environment"
    (http://www.slideshare.net/doremido/instrumental-genesis-main-concepts-presentation)

    -> **Design is continued in usage**

- Two dimensions of instrumental genesis (Rabardel & Bormaud, 2003):

  1) **Instrumentation:** formation and evolution of utilization and development of new mode of operation/practice

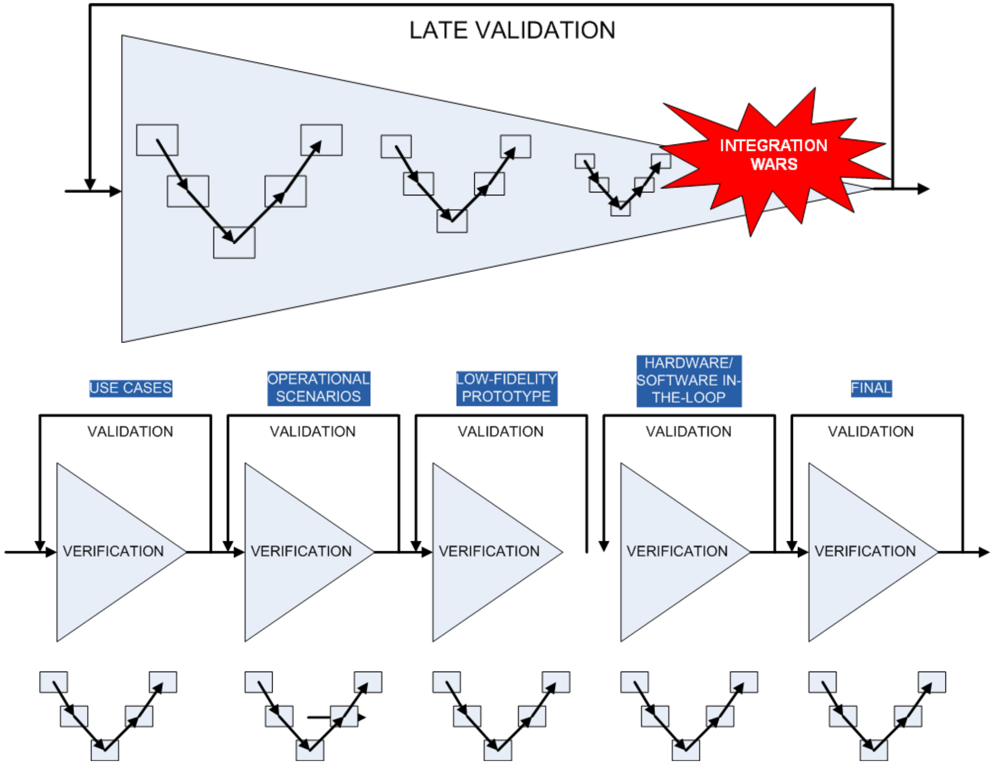
  2) **Instrumentalization:** evolution of the system itself

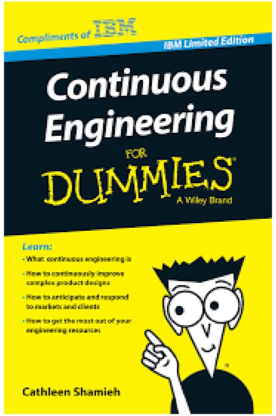
Stepwise approach to V&V

Let’s move towards continuous validation!

Late validation

Continuous validation

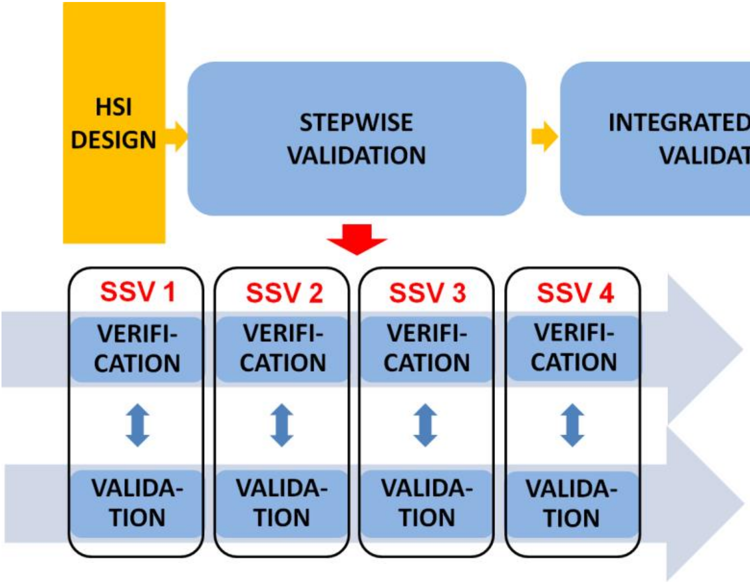




(modified from Shamieh, 2014)

Process for verification and validation of CRs

- There is a progression from testing of subsets of CR systems to testing of the integrated whole
- Safety-critical systems are evaluated one cluster at a time



Definition of stepwise validation

- Process to determine that all the sub-systems (HSI component, product, workstation or work area) adequately support plant personnel in the safe operation of specific plant processes
  - Consist of a sequence of tests **providing cumulative evidence of the validity of the new design**
  - Main activity: dynamic tests in simulator
  - Quality/validity requirements (mostly) similar as for Integrated System Validation
  - Applicable to both new plants and to plant modifications

Objectives of stepwise V&V/sub-system validation

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- Reasons for conducting SSV:
  - Provides evidence of the **functionality** and **usability** of HSIs (HSI elements, products, work stations, work areas, CR layout) based on successive test packages whose scope is limited
  - Provides **preliminary validation** of the **operational concept** for different plant conditions
  - Provides **comprehensive evaluation** of HSIs included in the scope of a particular project stage
  - Provides **cumulative evidence** of systems usability (over SSV test activities)
  - Provides **design feedback** and **recommendations**

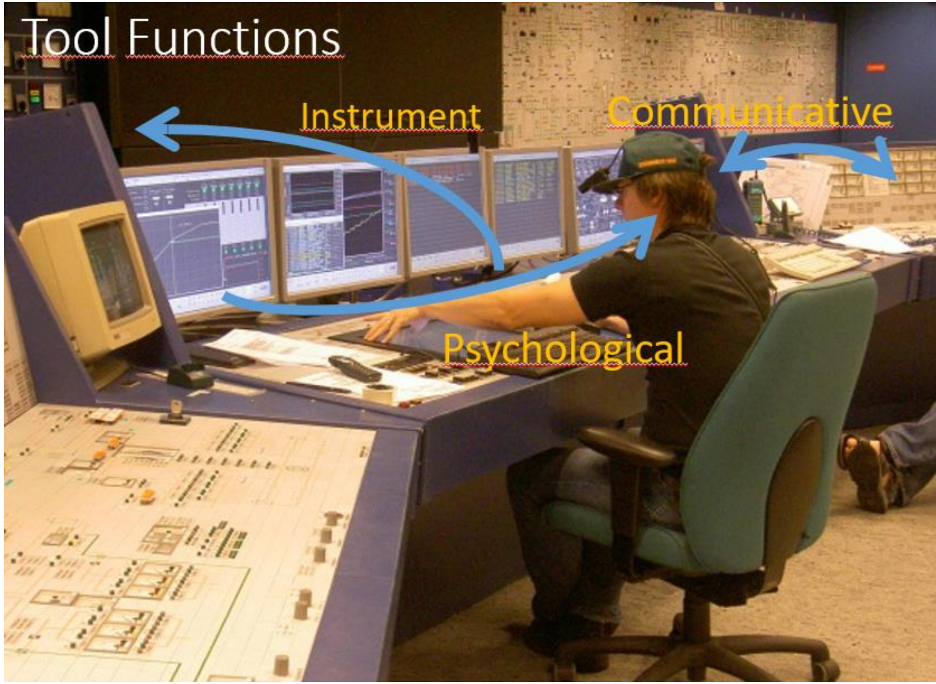
Contextual assessment of Systems Usability

Systems Usability

- Denotes the capability of the technology

  to fulfil the **instrumental**, **psychological**, and **communicative** functions of the tool in the activity to support the fulfilment of core-task demands in the work

- System usability is evidenced in technology usage in appropriate **performance outcome**, **way of acting** and **user experience**



Systems Usability Framework

Use your hammer!

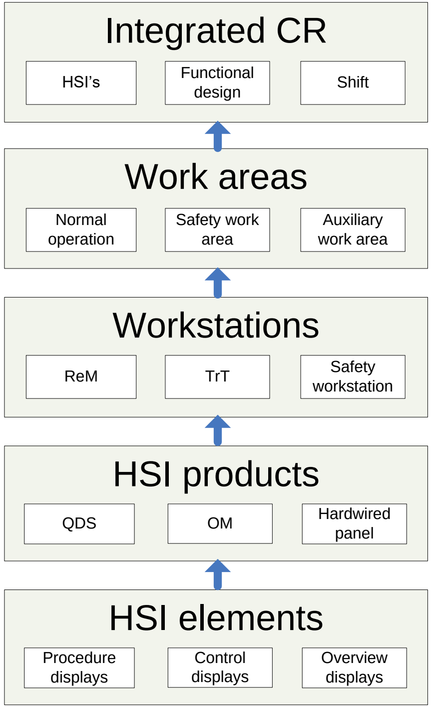
	Performance: Outcome	Way of Acting: Orienting to core-task	User Experience: The development potential of use
Instrumental Function	Instrumental performance	Instrumental way of acting	Experience of instrument
Psychological Function	Psychological performance	Psychological way of acting	Experience of psychological tool
Communicative Function	Communicative performance	Communicative way of acting	Experience of communicative tool

Evaluation scope & graded approach

Evaluation scope

- **Inventory of physical facilities** describes the human-system interfaces and other equipment associated with personnel tasks that are within the scope of the HSI design to be verified and validated
- The facilities can be further divided into the following entities
  - HSI elements
  - HSI products
  - Workstations
  - Work areas
  - Integrated CR

Example from the Fortum Loviisa case:



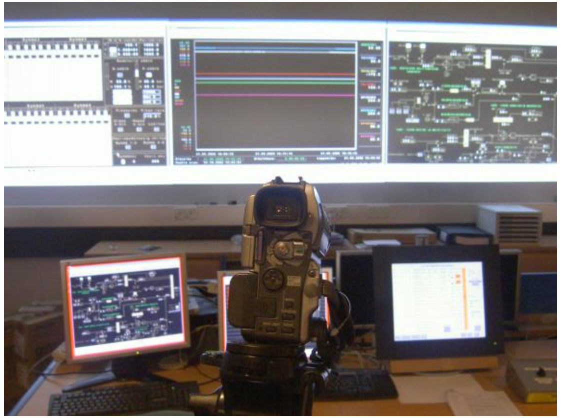
Graded approach

- Typically, HFE V&V activities are graded in such a way that the biggest effort is placed on the evaluation of the most critical systems
- Depth of treatment is based on the risk and importance that is associated with each modification
  - Main criteria for the grading of the evaluation are:
    - **safety criticality**
    - **system complexity**
    - **degree of novelty**

Simulators’ role in stepwise V&V

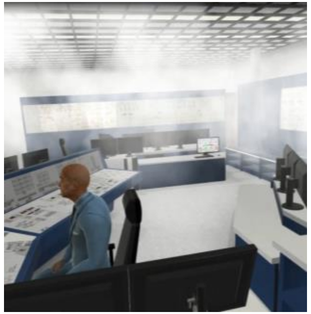
Simulators' role in multi-stage validation

- Simulators play an essential role in CR V&V
- Different kinds of simulators are needed in different phases of assessment
  - **Engineering and Development (E&D) simulator** in pre-validation
  - **Training simulator** in Integrated System Validation
  - **Testing simulator** in closed loop testing of digital I&C



Verification and validation of control rooms in VR environment with Fortum

- We have tested together with Fortum the use of immersive 3D Virtual Reality environments in control room validations
- Our results suggest that
  - VR simulations enable an early evaluation of CR systems cost-effectively, rapidly and reliably
  - Evaluations in VR CR can produce relevant HF findings/ observations
  - VR environments provide new tools and methods for CR evaluations
  - VR simulations provide new opportunities to CR design and operator training



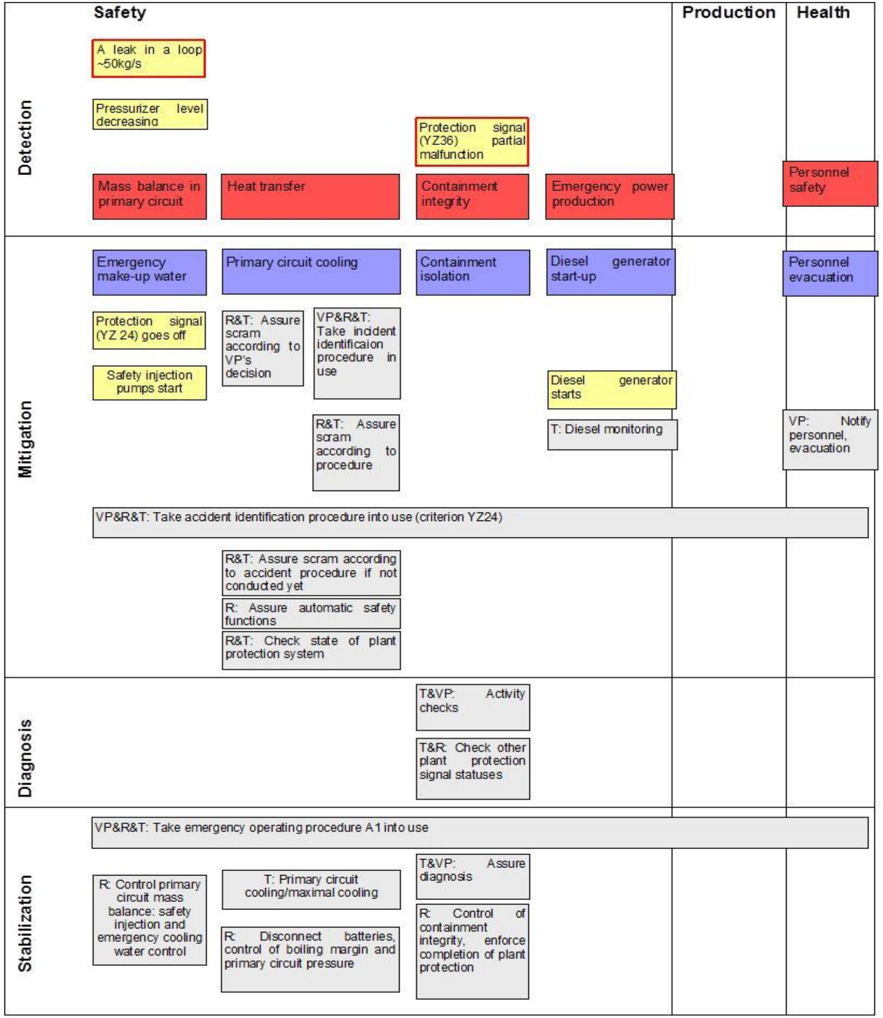
Operational conditions selection and scenario modelling

Operational condition selection for stepwise validation

- Scenario is like a play, operational condition is a like scene

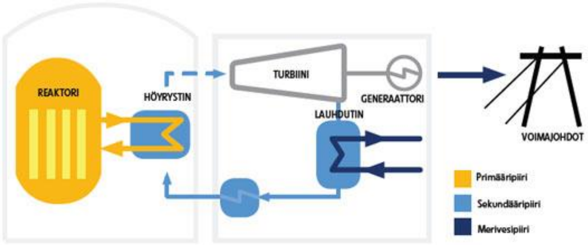
- **Sub-system validation:**
  - Quite exhaustive testing of operational conditions
    - All safety systems are included
    - All Emergency Operating Procedures are included

- **Integrated System Validation:**
  - Careful selection of demanding operational conditions for Integrated System Validation
    - ISV is a ’stress test’ for the new CR



Scenario modeling provides a conceptual basis for the assessment

Example: Functional Situation Model for LOCA in a VVER plant



Performance measurement in sub-system validation

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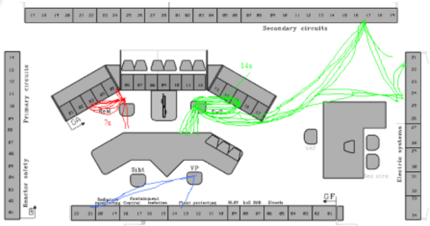
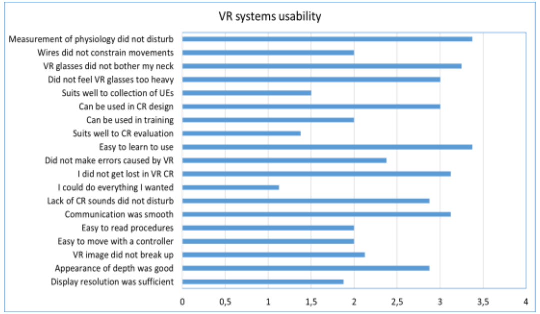
Systems Usability measures

- Three kinds of measures are used:

Tool functions	Perspectives to activity: Performance: Outcome	Way of Acting: Orienting to core-task	User Experience: The development potential of use
Instrumental Function	- Task completeness - Errors - Time	- Focus on relevant phenomena - Effective prioritizing	- Feeling of a well-functioning tool
Psychological Function	- Task load - (Interruptions)	- Meaningful and established practice - Conceptualization of the process situation	- Feeling of embodiment - Self-confidence - Feeling of control
Communicative Function	- Verbal interactions - Spatial interactions	- Teamwork practices - Shared awareness	- Appropriate trust - Understanding logics of systems





Some novel measures that we have used/tested

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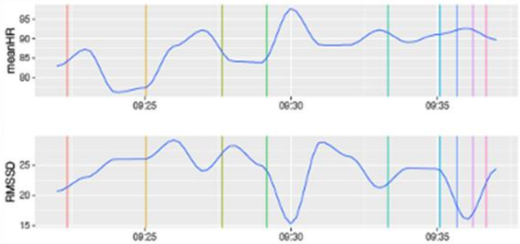
Eye tracking

Cardiac monitoring

Electrodermal activity

Gaze- and biosignal-cued retrospective process tracing interview



Data collection/analysis and documentation

Data collection and analysis

- Preliminary activities
  - Recruitment of participants
  - Pilot testing
- Test activities
  - Heuristic evaluation of HSIs by usability experts
  - Observation of training sessions
  - Structured interviews of participating operators
  - HSI-oriented walkthroughs with participating operators
  - Simulator testing (= usability testing)
  - Process tracing interviews
  - Questionnaires (measuring workload, SA, usability)
  - Debriefing interviews
- Data analysis
  - E.g. analysis of video-recordings

Systems Usability Case in CR V&V

Safety Case

- ”a documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment”
  - i.e., Safety Case demonstrates the safety of a system
- Safety is demonstrated by presenting evidence and argumenting why it supports particular safety claims
- Key elements of a safety case:
  - Goals/Claims, Evidence and Arguments

Systems Usability Case

- Establishment of a Systems Usability Case:
  - Creating an **accumulated,** documented body of evidence **throughout the design process** that provides
    - a convincing and valid argument of the **degree of systems usability** of a system for a given application in a given environment

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Human Engineering Discrepancy (HED)

- Human Engineering Discrepancy = design problem

Evidence: Test data from one SSV test	Description: Feature of the new system	Type of HED	Identifier
Observation: On one occasion there was a fault in starting a timer which resulted in a total stop in activity	Timer must be started to ensure a sufficient period for the identification of the situation	Concept of operations	HED_SSV1_3
Walkthrough: More than one operator raised the issue of difficulties faced in detecting small arrows	Small arrow symbols are used to denote the correct path in procedures	User interface	HED_SSV1_7
Debriefing: Several comments concerning the focus and reliability of operating activities in the new concept	New safety concept includes several repetitions of actions and transitions between interfaces	Concept of operations	HED_SSV1_132

Validation process based on the SUC approach

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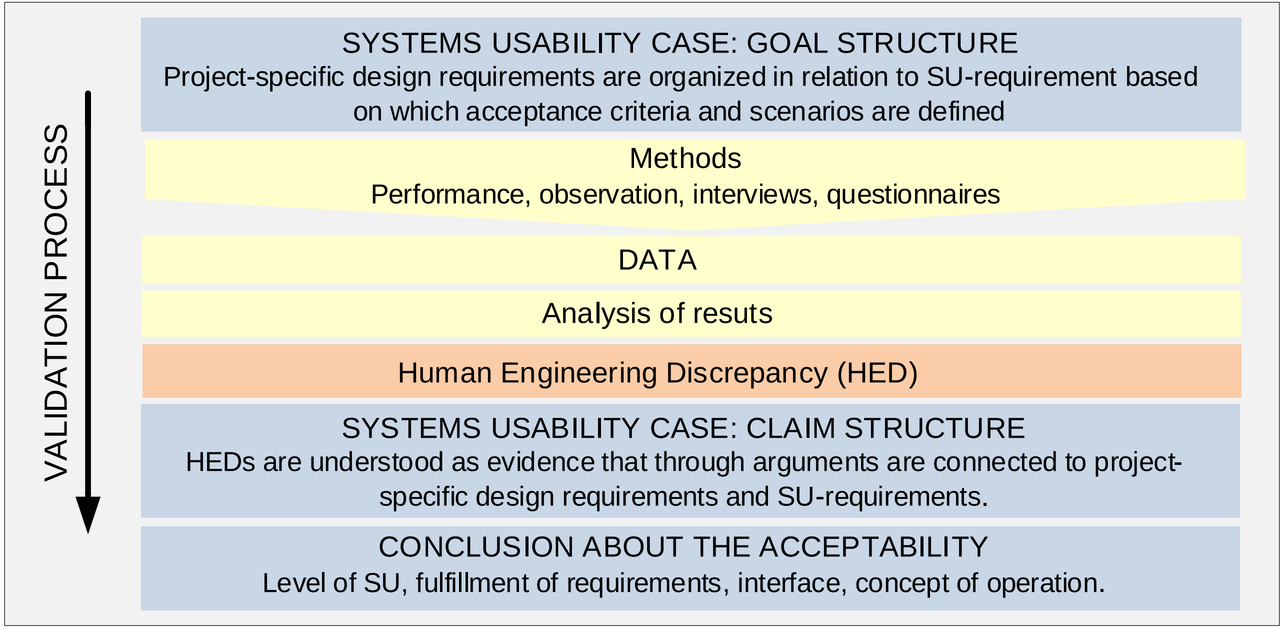
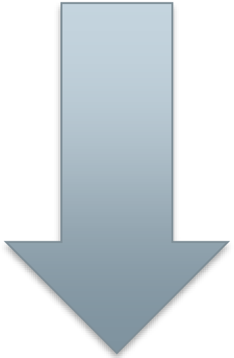
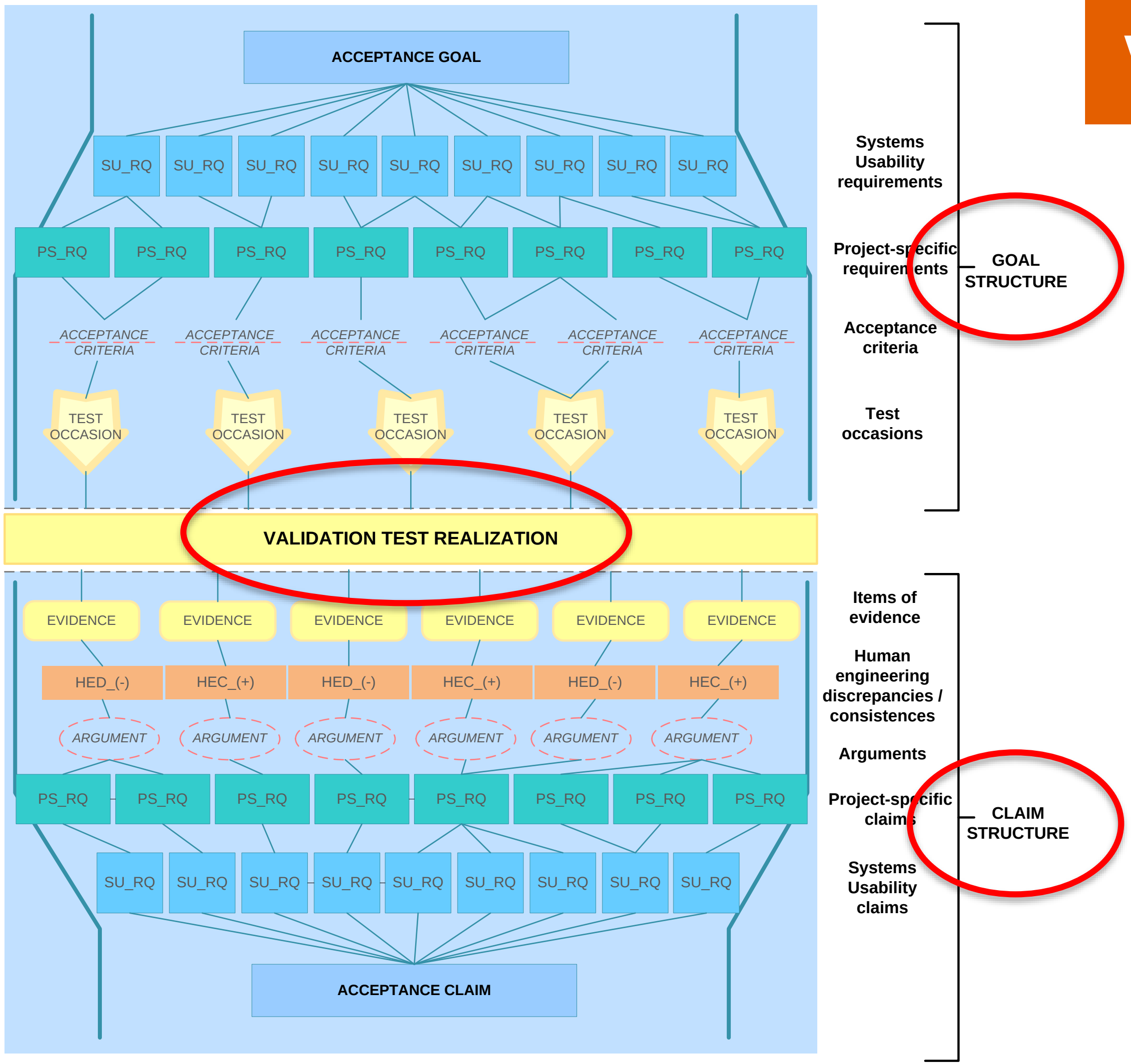


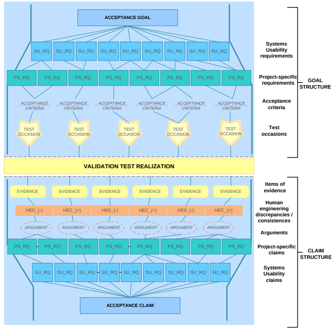
SUC framework

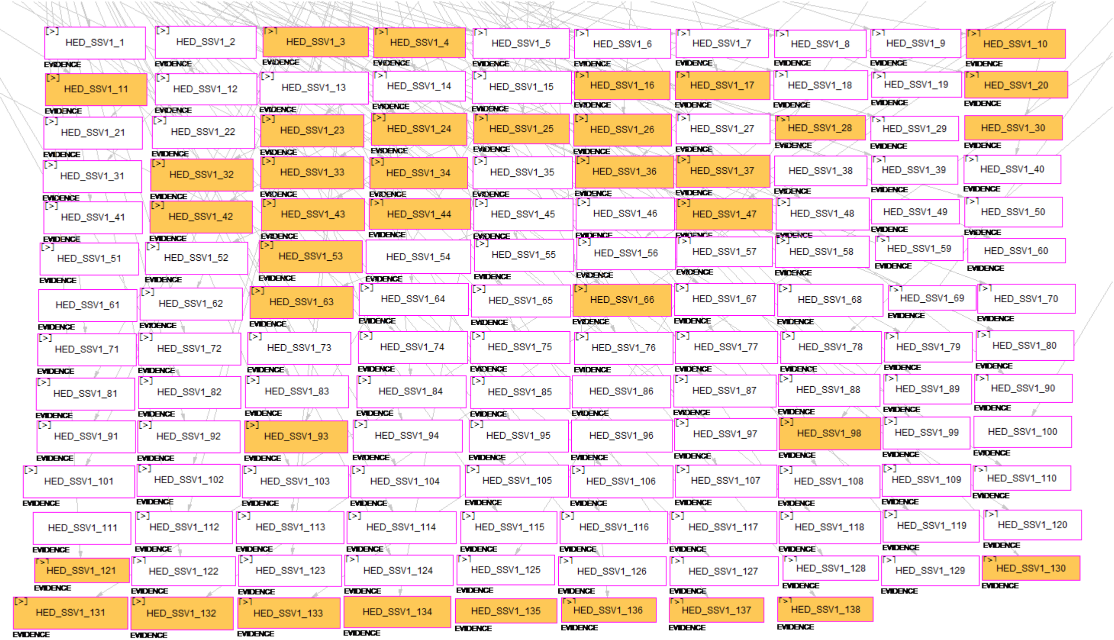




List of Human Engineering Discrepancies

- Each HED is given a unique identifier and a description in a separate file





Some examples of HED-argument pairs

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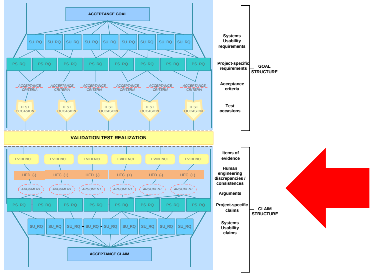
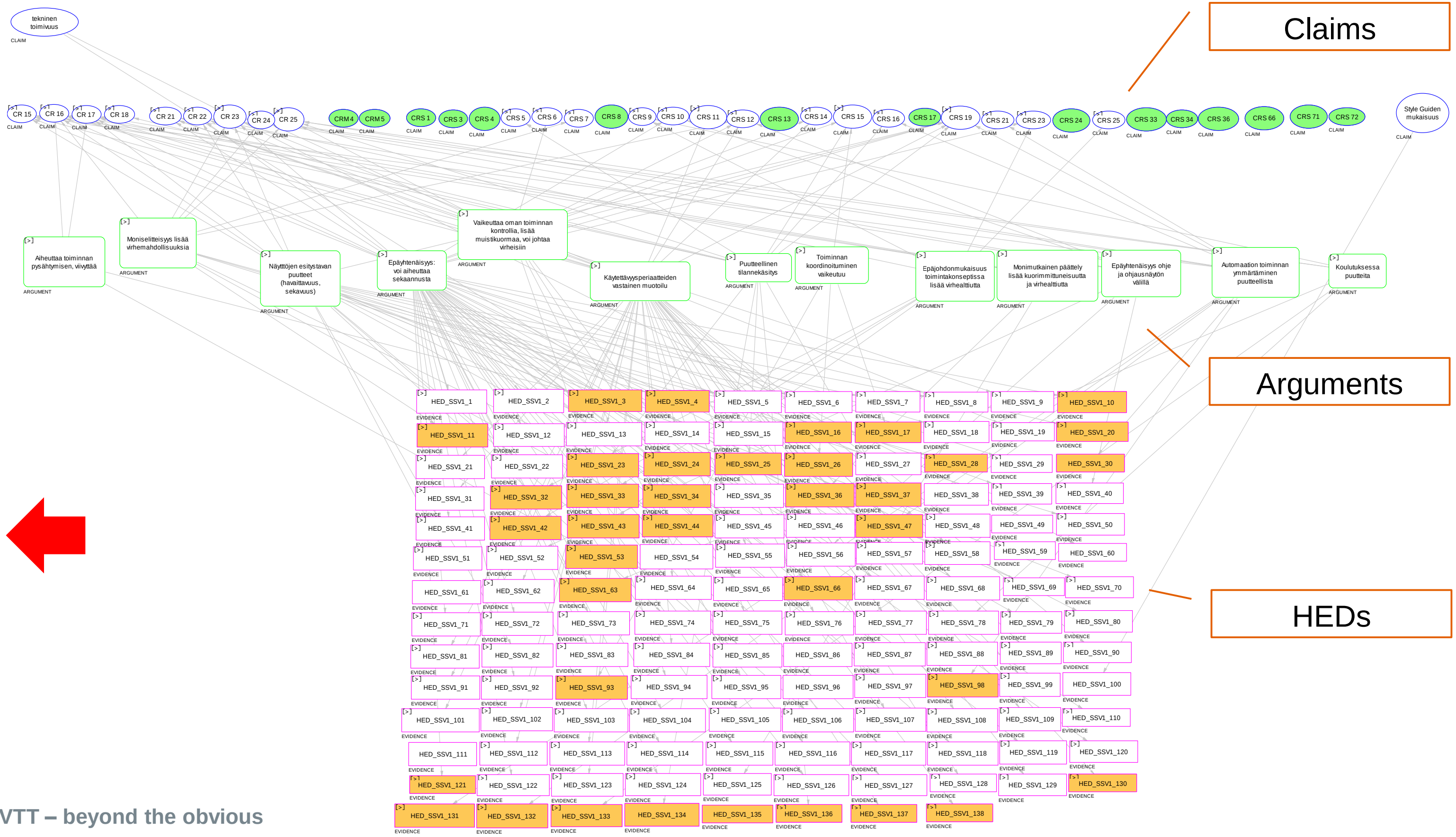
Identifier	Type of HED	Description	Evidence	Argument
HED_SSV1_3	Concept of operations	Utilization of a semi-automatic timer may hinder the progress of activity	Observation: On one occasion the unsuccessful start of the timer resulted in total stop in activity	**Stops activity**
HED_SSV1_7	User interface	Small arrow symbols are difficult to detect due to small size	Walkthrough: More than one operator raised the issue	**Against common usability principle**
HED_SSV1_132	Concept of operations	Complexity of the new safety concept complicates operative work	Debriefing: Several comments concerning the focus and reliability of activity in the new concept	**Reflects insufficient understanding of some features of digital automation**

Connecting HED-argument pairs to the claims





Complete Systems Usability Case for a SSV test

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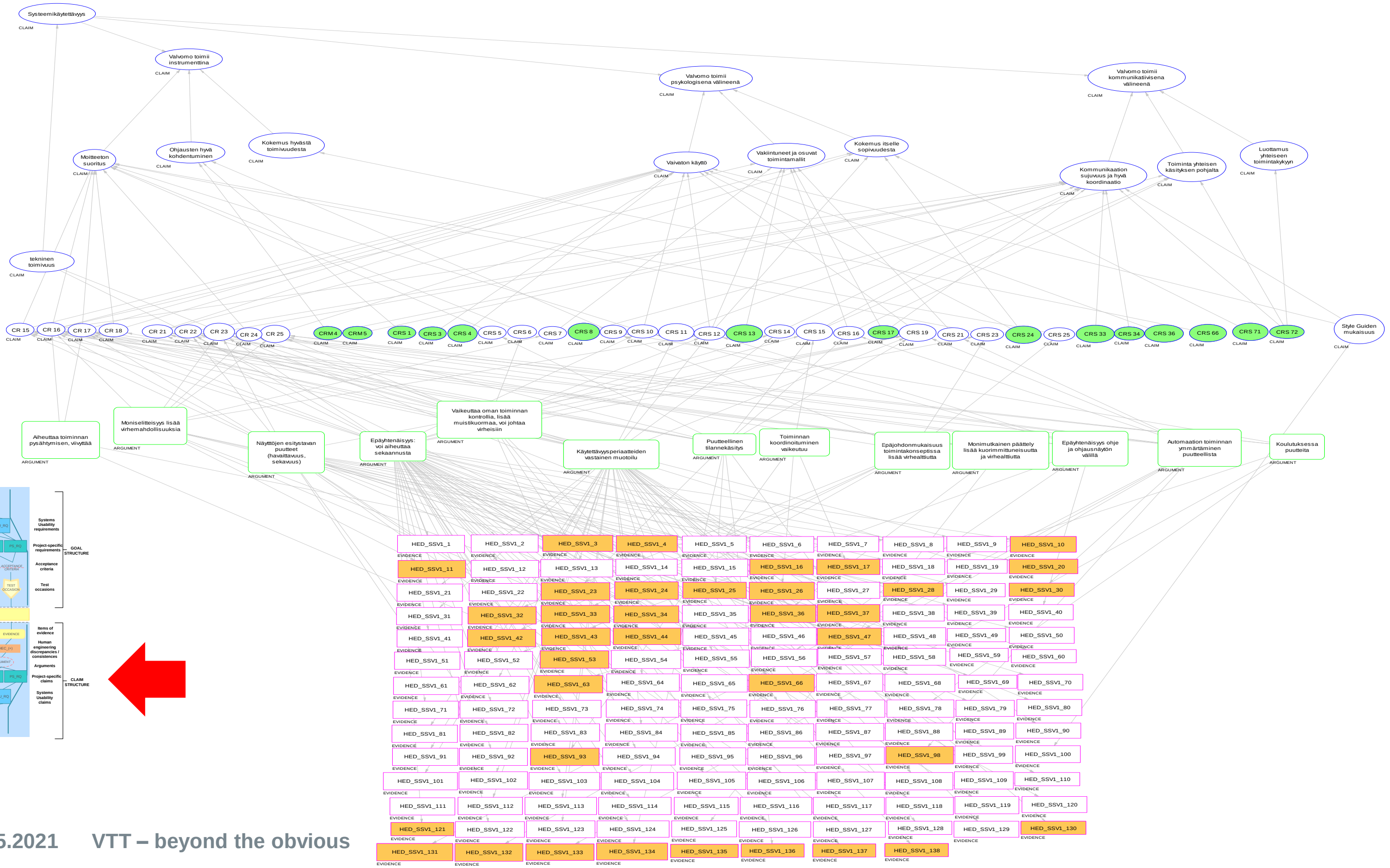
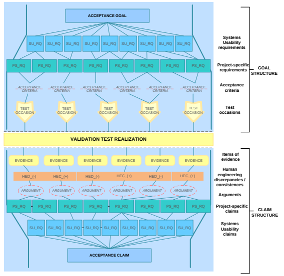
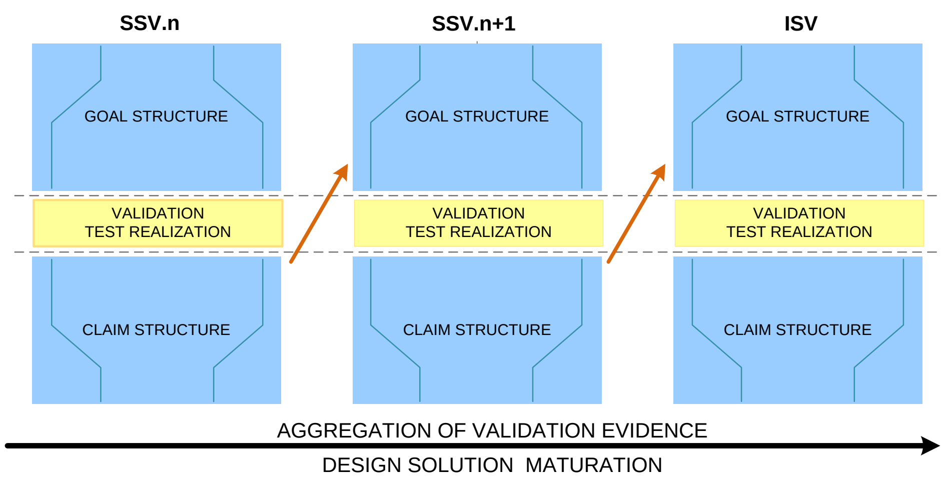
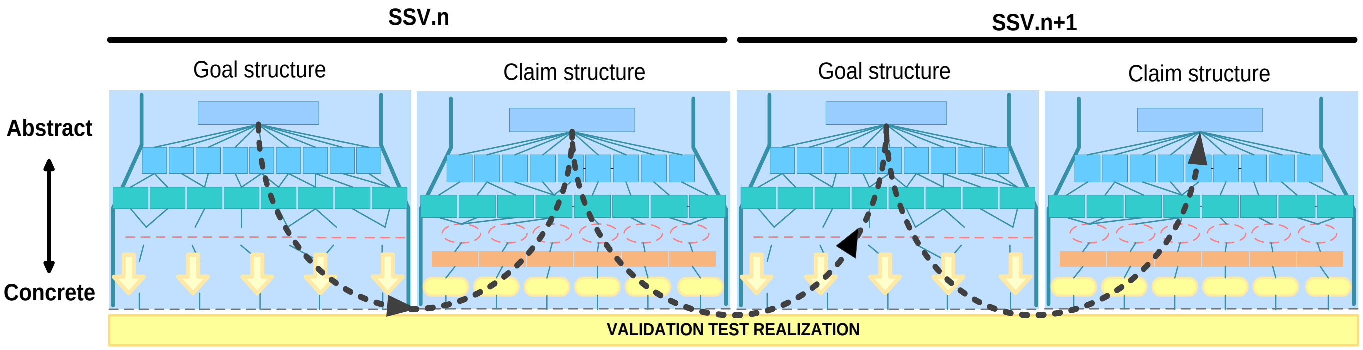




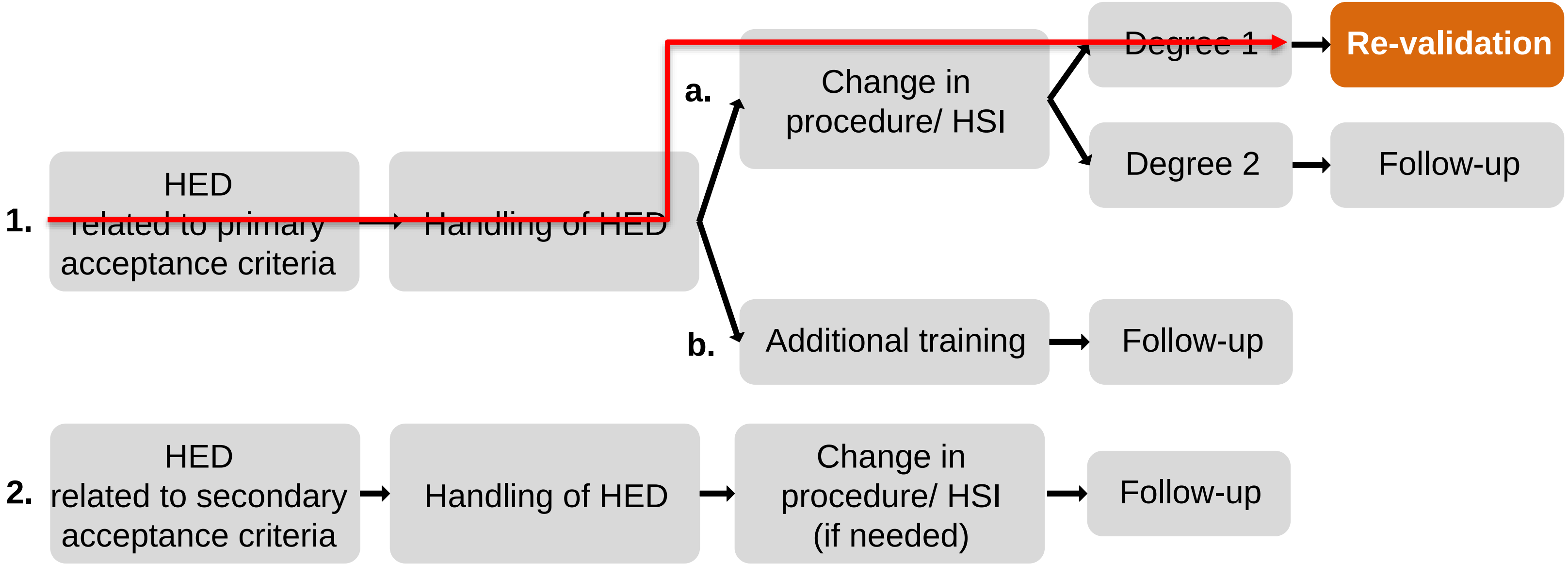
SUC development





HED treatment in V&V

HED treatment



Derivation of final conclusions

Example of an overall assessment utilizing the Systems Usability Framework

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	Performance	Way of acting	User experience
Instrumental	1. Faultless performance • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension **ISV: Example 1 and 3 HEDs**	4. Focus on relevant phenomena and control operations • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension	7. Feeling of a well-functioning tool • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension **ISV: Operators estimated the new HSIs rather good and suitable for their use. Less than ten HEDs from which only one connects to possibility of error (reflections on horizontal screen surface).**
Psychological	2. Effortless usage • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension	5. Meaningful and established practices • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension **ISV: Example 2 HEDs**	8. Feeling of fit for yourself • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension
Communicative	3. Fluent communication and good coordination • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension	6. Acting based a on shared understanding • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension	9. Trust in joint capabilities • Specific requirements related • Amount and type of HEDs • Description of the status of the SU dimension

Lessons learned

Lessons learned

- Goal structure of the SUC plays an important role as reference base for the V&V
  - Specification of acceptance criteria is a laborous process
- It has to be determined in advance under what conditions it can be said that the system is successfully validated
- Synthesis of validation results is based on a dialogue between the validation and design teams
  - BUT: the dialogue should not compromise the independence of the validation team
- In most cases there is no single answer to the validation questions, but several answers which have to be presented in a systematic and ordered way
- Validating a complex system is a temporarily extended process with no clear end point
  - Needs further monitoring and follow-up since the system has been launched
- SUC is a living document that requires updating after each new validation

Questions

Questions to Dr. Laarni
Automotive design has been migrating towards digital interface from the traditional analog interface (i.e., touch screens instead of buttons). I would consider traffic a complex system (especially in city environments). Should this design shift be considered overall negative or is it something humans will adapt to?
1. What is Jari's expereince of acceptance / receptiveness of HF input in projects? 2. What makes a difference is support for HF integration on projects? 3. What responsibility could / should be taken by the HF practitioner to help create an environment of acceptance in practice?
How would you describe the role of human operators is evolving in highly automated plant operations and affecting the Systems Usability case structures (for example the amount and type of requirements)?

Relevant literature

VTT

Bergroth et al. (2018). Use of Immersive 3-D Virtual Reality Environments in Control Room Validations. Nuclear Technology Volume 202, 2018 - Issue 2-3.

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Abbreviations

VTT

CR	Control room	LOCA	Loss of coolant accident
DV	Design verification	NPP	Nuclear power plant
E&D	Engineering and development	RO	Reactor operator
EOP	Emergency operating procedure	SS	Shift supervisor
HED	Human engineering discrepancy	SSV	Sub-system validation
HF	Human factors	SU	Systems usability
HFE	Human factors engineering	TO	Turbine operator
HMI	Human-machine interface	TSV	Task-support verification
HRA	Human reliability analysis	UC	Usability case
HSI	Human-system interface	UI	User interface
I&C	Instrumentation and control	V&V	Verification and validation
ISV	Integrated system validation	VVER	Water-water energetic reactor