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# Panel discussion: Critical Conditions for Successful Implementation of New Nuclear Build in Europe Today

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**3rd International Nuclear Conference**

**THE OPPORTUNITIES OF NUCLEAR ENERGY FOR THE DECARBONISATION OF ENERGY SECTOR IN EUROPE - TECHNOLOGY, PROJECTS, SERVICES**

**25-26 January 2024, Sofia**

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# GENERAL CHALLENGES

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**Energy crisis in Europe in recent years has shown that declining from the use of nuclear power was one of the factor contributing to the crisis. It was once again demonstrated that nuclear power is a low carbon emission, safe, sustainable, and dispatchable source capable to supply electricity in large amount needed for industrial economies and at affordable prices essential both for the industry as well as population**

**General challenges for large power light water reactors:**

- **Limited human resources (CEZ needs 4000 new people before 2040)**
- **Financing: equal conditions needed for nuclear as for RES (in CR last year 24 mld investment plus 40 mld CZK to operation of RES)**
- **Limited manufacturing capacities: support to industry, massive involvement of European industry necessary (see the situation with RES)**
- **Process of notification to EC too complicated and too long, equal rules for all sources necessary**
- Major reactor accident anywhere, major delays in planned constructions, security issues
- Political obstacles, unstable political situation



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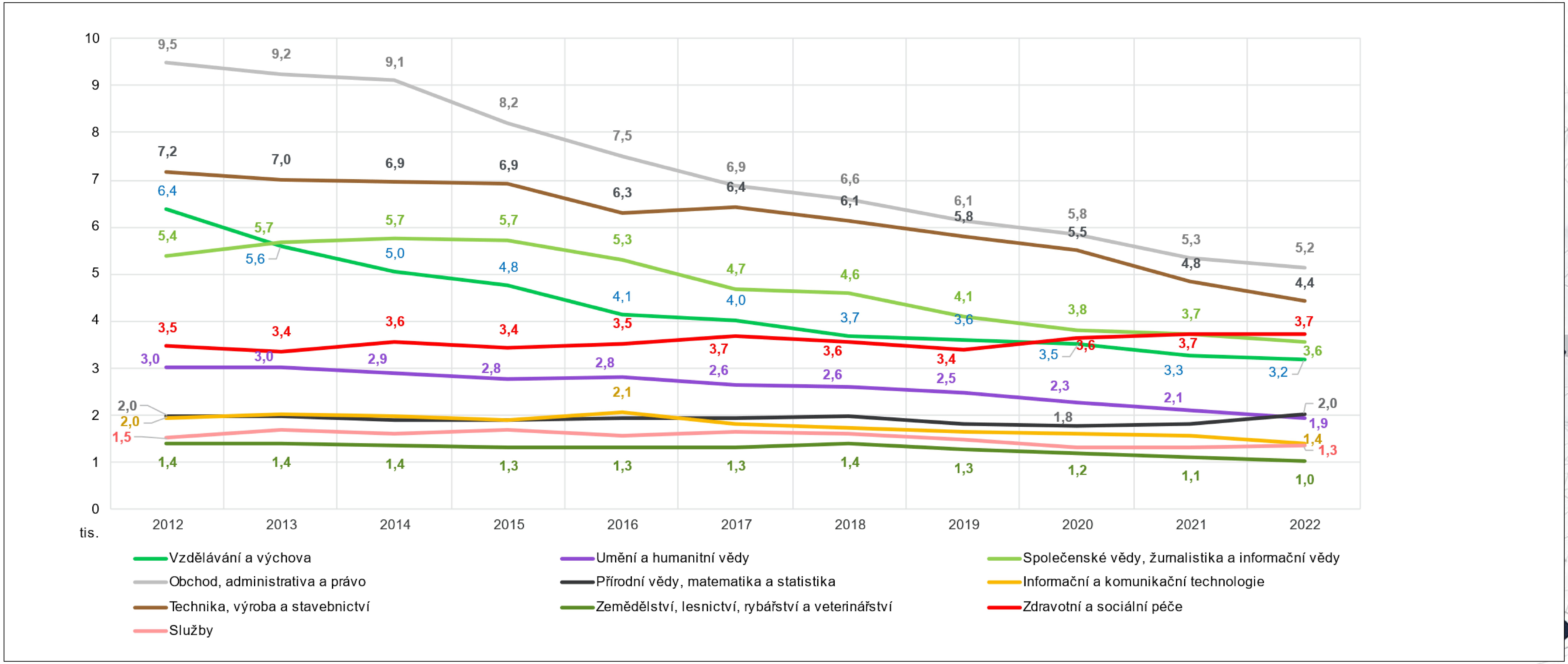
# HUMAN RESOURCES

## Number of technically oriented Czech university students in 10 years reduced from 7200 to 4400 student in one year

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# CHALLENGES WITH INNOVATIVE DESIGNS (SMR)

# TYPICAL TECHNOLOGIES FOR INNOVATIVE REACTOR DESIGNS

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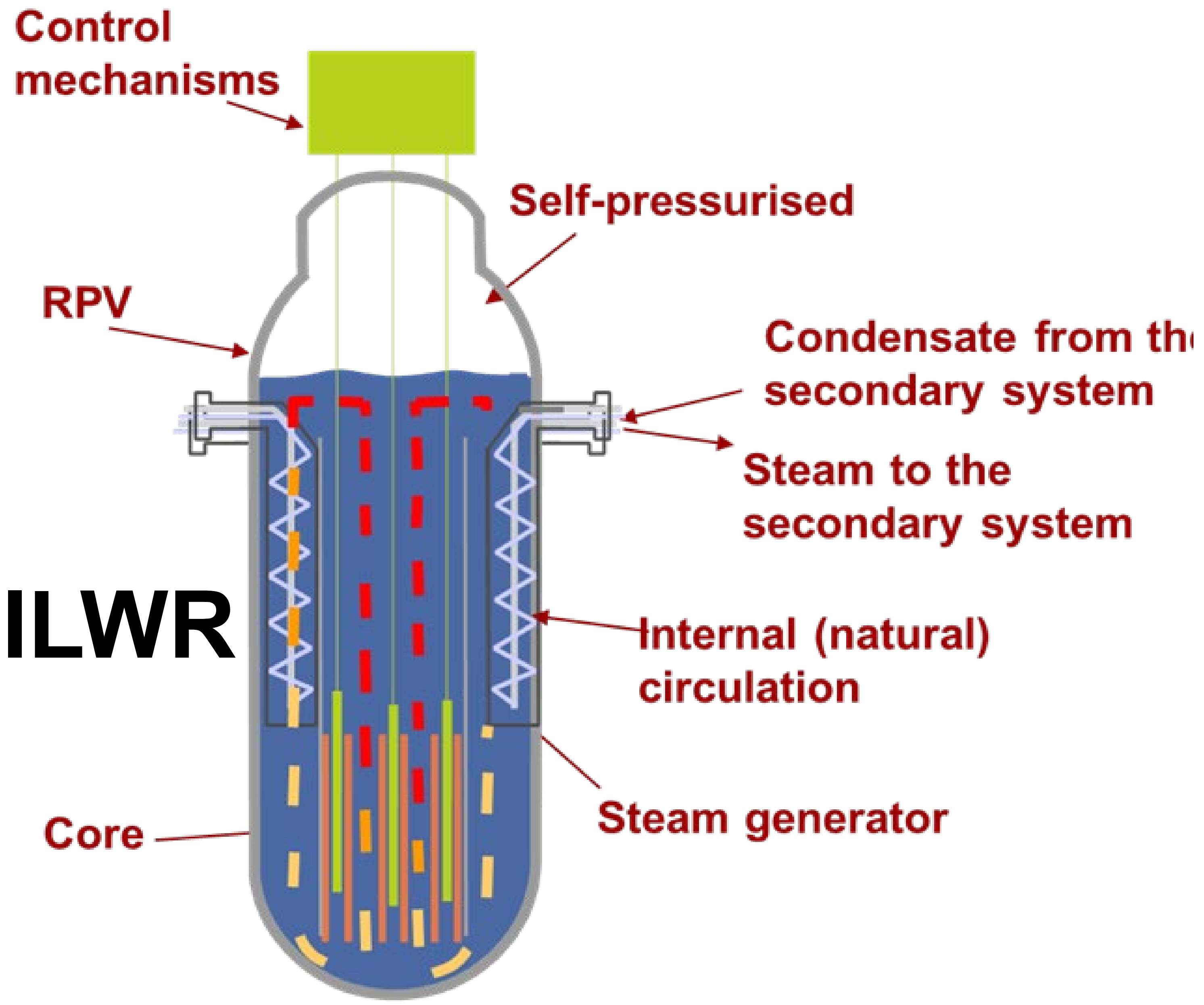
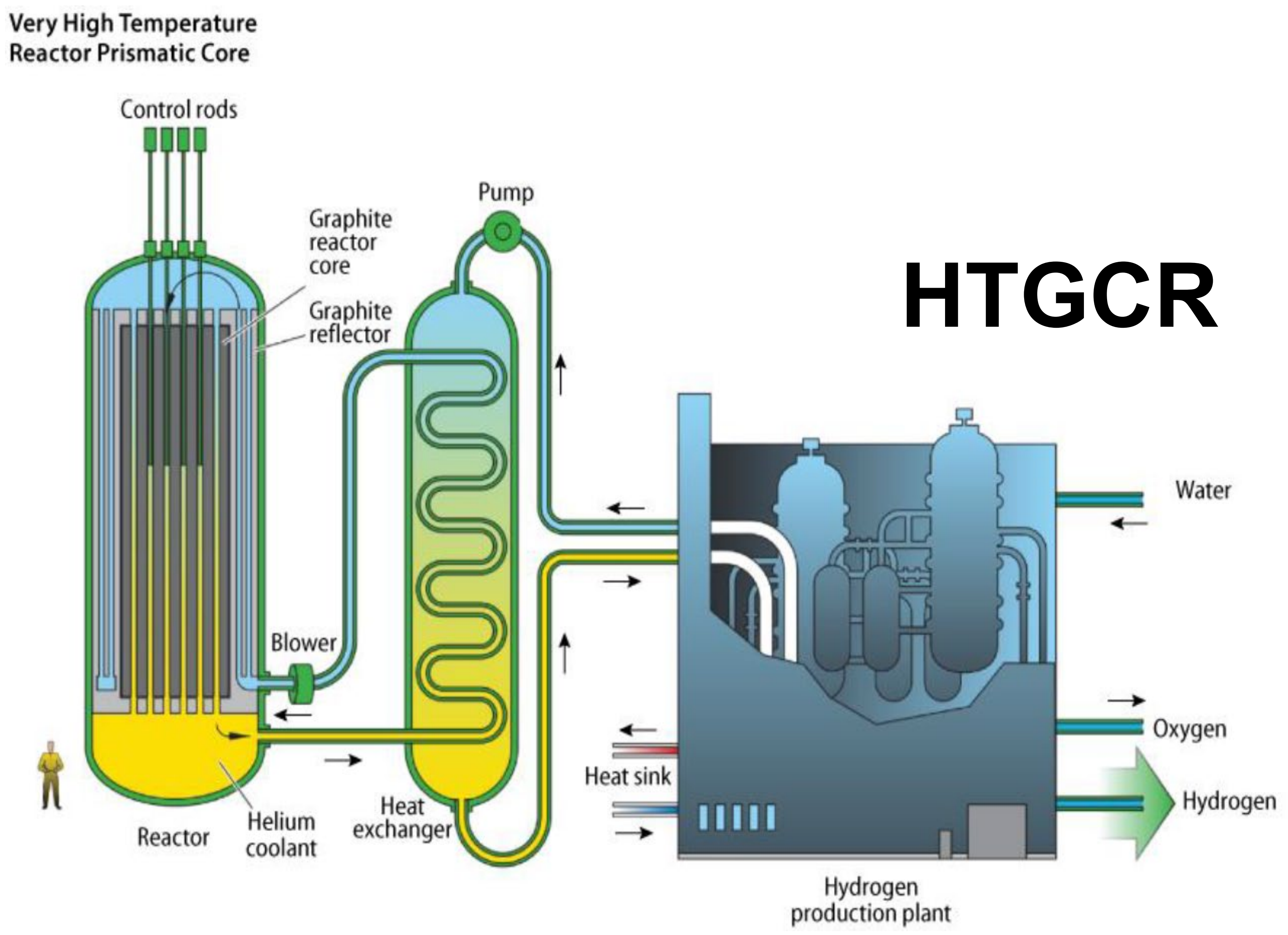
ILWR




HTGCR

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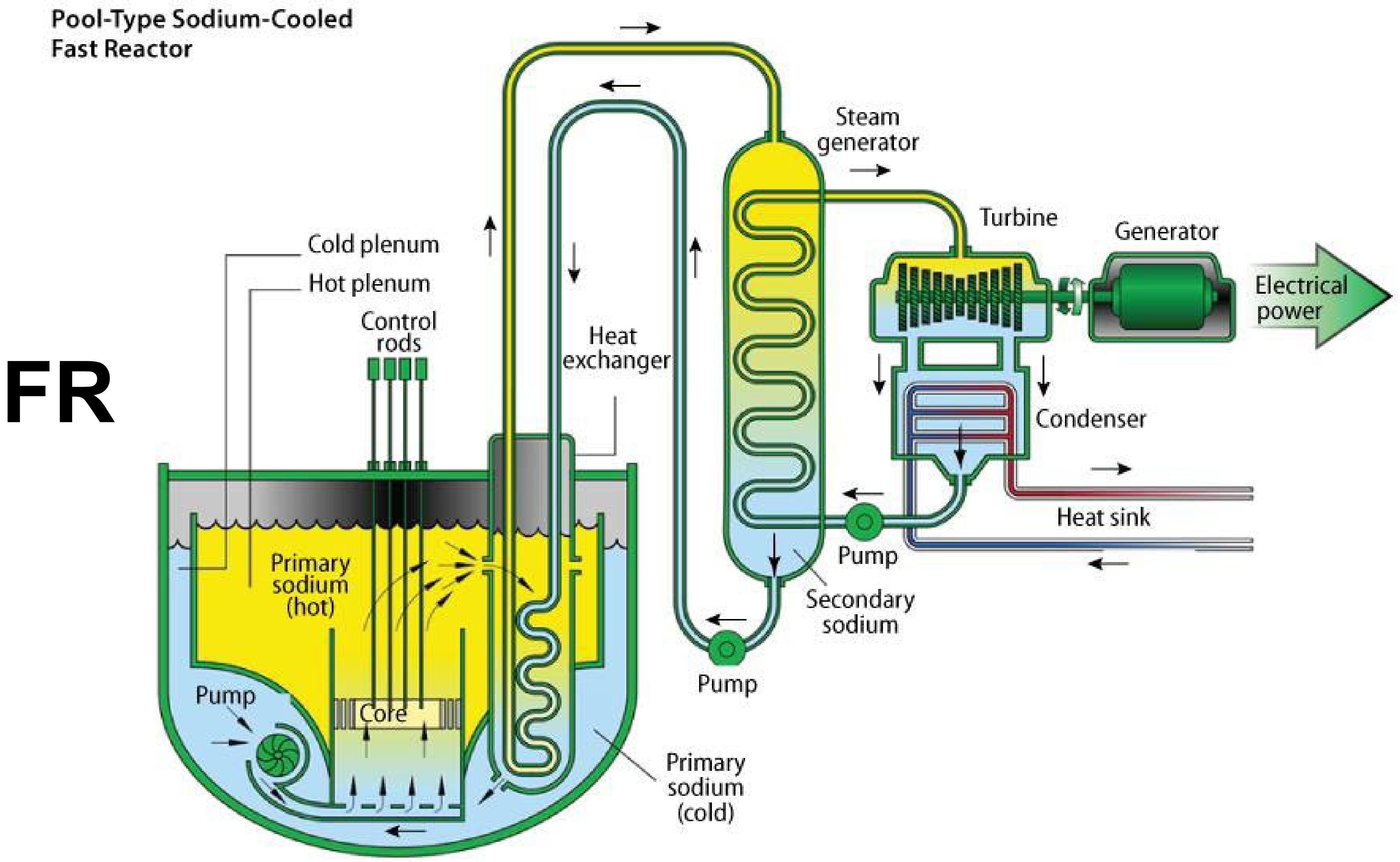
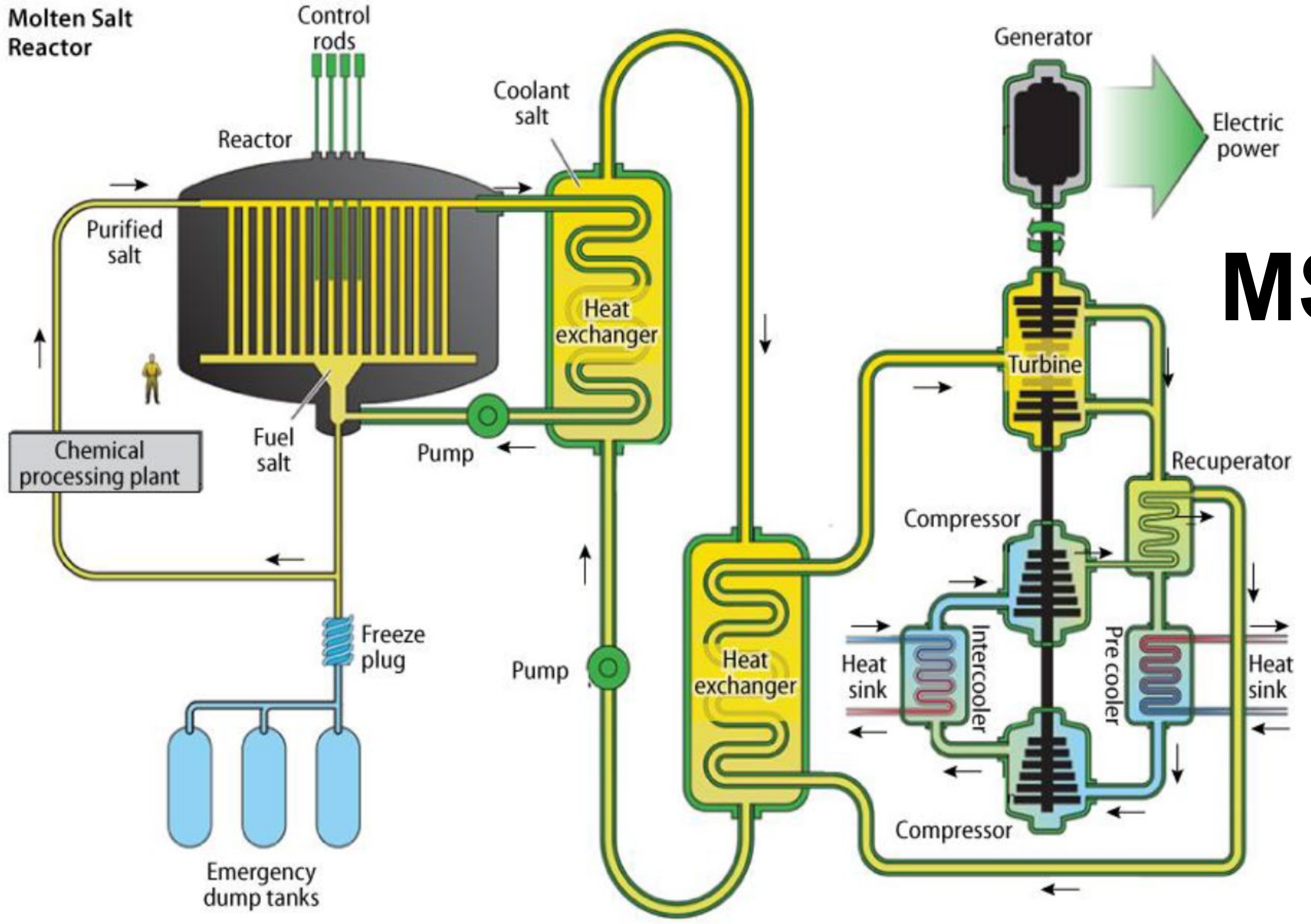



MSR

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# COMPARISON OF PHYSICAL BARRIERS FOR DIFFERENT INNOVATIVE REACTORS

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| Barrier | LWR | HTGCR | FNR | MSR |
|---|---|---|---|---|
| 1 | Fuel matrix | Fuel kernels | Fuel matrix | None (liquid fuel) |
| 2 | Zr-alloy cladding | Coatings<br>Graphite blocks | Steel cladding | None (liquid fuel) |
| 3 | RCS high pressure boundary | Helium circuit as high pressure boundary | High temperature low pressure reactor coolant system<br>High temperature low pressure confinement (guard vessel) | High temperature low pressure reactor coolant system<br>High temperature low pressure confinement (guard vessel) |
| 4 | Airtight high-pressure containment | Reactor building (vented or full pressure) | Containment (reactor building) resistant against external hazards | Containment (reactor building) resistant against external hazards |



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# TECHNOLOGICAL ISSUES ASSOCIATED WITH IMPLEMENTATION OF INNOVATIVE DESIGNS

- At research and development level infrastructure is available for variety of coolant, for both fast neutron and thermal neutron spectra
- At industrial level infrastructure available mainly for pressurized water reactors
- Innovative reactors feature mostly unproven innovative technologies (except water cooled reactors)
- Possible material challenges
- Difficult estimation of component/plant life time
- Innovative fuel cycle
- Security and proliferation issues not completely clear
- Limited knowledge of transient and material behaviour
- Limited set of validated computer codes available
- Limited technological benefit for recipient country in case of factory made facility

# SAFETY/LICENSING ISSUES ASSOCIATED WITH IMPLEMENTATION OF SMALL REACTORS

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- Regulations developed mainly for existing NPPs, to large extent light water reactors
- Looking for new sites may be a difficult task, unless the legislation will be changed
- Limited experience with new reactor types, available regulations based on experience with light water reactors
- Development of technology neutral international safety standards not sufficiently advanced
- Only few of small reactors can be considered as of "proven design" as one of basic safety principles
- Limited interest both from the regulatory body as well as future operator side to risk building a prototype
- These issues can be successfully resolved in case of strong and stable political and public support

# ECONOMIC ISSUES ASSOCIATED WITH IMPLEMENTATION OF SMALL REACTORS

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- Factors contributing to increasing the cost
  - First of a kind cost
  - Delays in licensing due to limited familiarization
  - Lack of verified designs
  - Uncertainty of life time predictions
  - Small plant output
- Factors contributing to reducing the cost
  - Relatively low total investment
  - Rapid construction
  - Possibility for factory made modules
  - Easy transportation of components, mostly by railway
  - Reduced requirements on emergency planning
- Most probably higher investment cost per installed kWe

# ADVANTAGES IN DEFENCE IN DEPTH APPLICATION FOR INNOVATIVE DESIGNS (SMR'S REGULATORS FORUM)



- Reduced risk of fuel damage and consequential release of fission products
- Reduction in the dominant radiation hazard as the radiation hazard is roughly proportional to power level
- Air is readily available for residual heat removal (for some designs)
- Heat can be removed heat passively in all operating plant states and accident conditions;
- Barrier performance enhanced (e.g., lead-bismuth – lead will solidify when released so fission products are contained in lead)
- Enhanced safety margin
- No fuel melt and therefore a reduction in types of accident scenarios rated as potentially severe
- Allows inherent fission product confinement at high temperature and fuel burnup
- Reduction in potential source term for single unit accident sequences

# CHALLENGES IN DEFENCE IN DEPTH APPLICATION FOR INNOVATIVE DESIGNS (SMR'S REGULATORS FORUM) 1 OF 2

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- Vendor desire for reduced barriers (e.g., confinement or containment requirements)
- Fewer possibilities for physical separation for internal and external hazards
- Uncertainties in natural circulation (cooling) performance in certain conditions;
- Possibility of power oscillations
- Heat loads must be adequately understood in accident conditions
- Less operating experience available for non-water cooling media
- Functional failure is possible without mechanical failure (e.g., small driving forces, higher level of uncertainties, etc.); no rules for safety assessments, no reliability data, no statistics
- Less operating experience with passive safety systems
- Weak driving force may lead to lower reliability under harsh environmental conditions; passive system needs to be activated; activation is important for system reliability

# CHALLENGES IN DEFENCE IN DEPTH APPLICATION FOR INNOVATIVE DESIGNS (SMR'S REGULATORS FORUM) 2 OF 2

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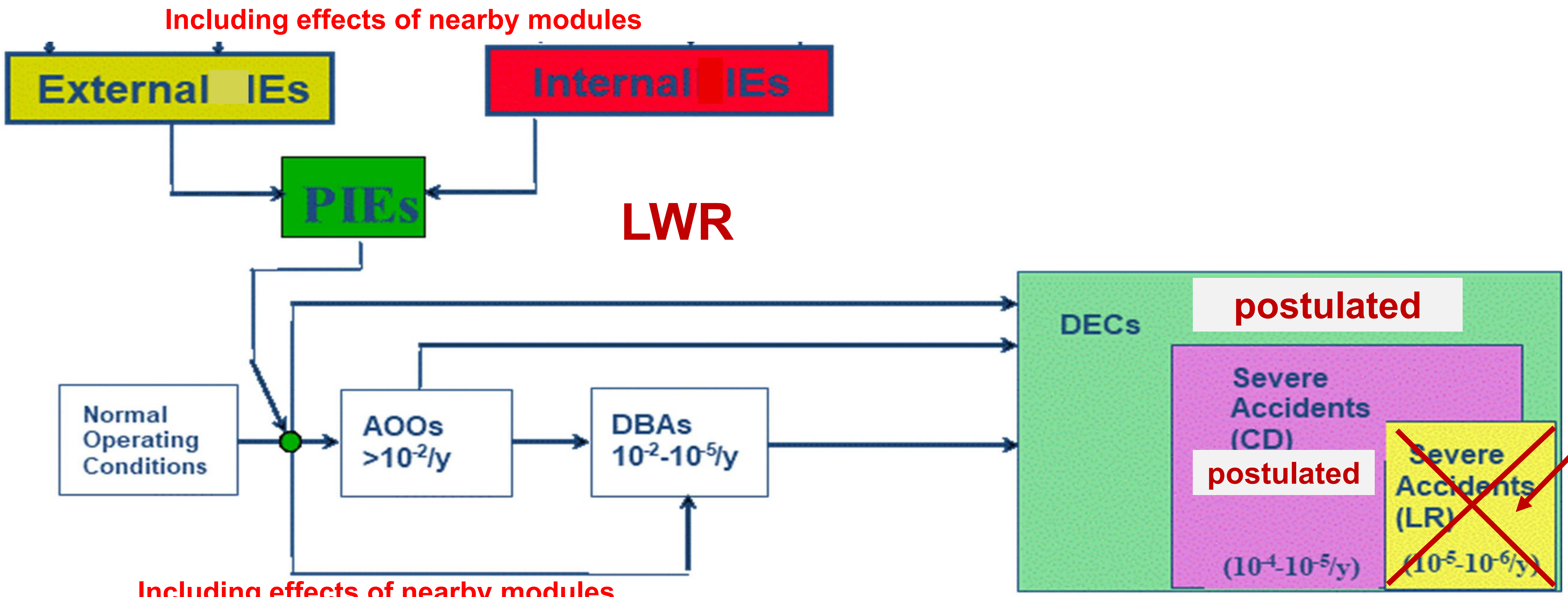
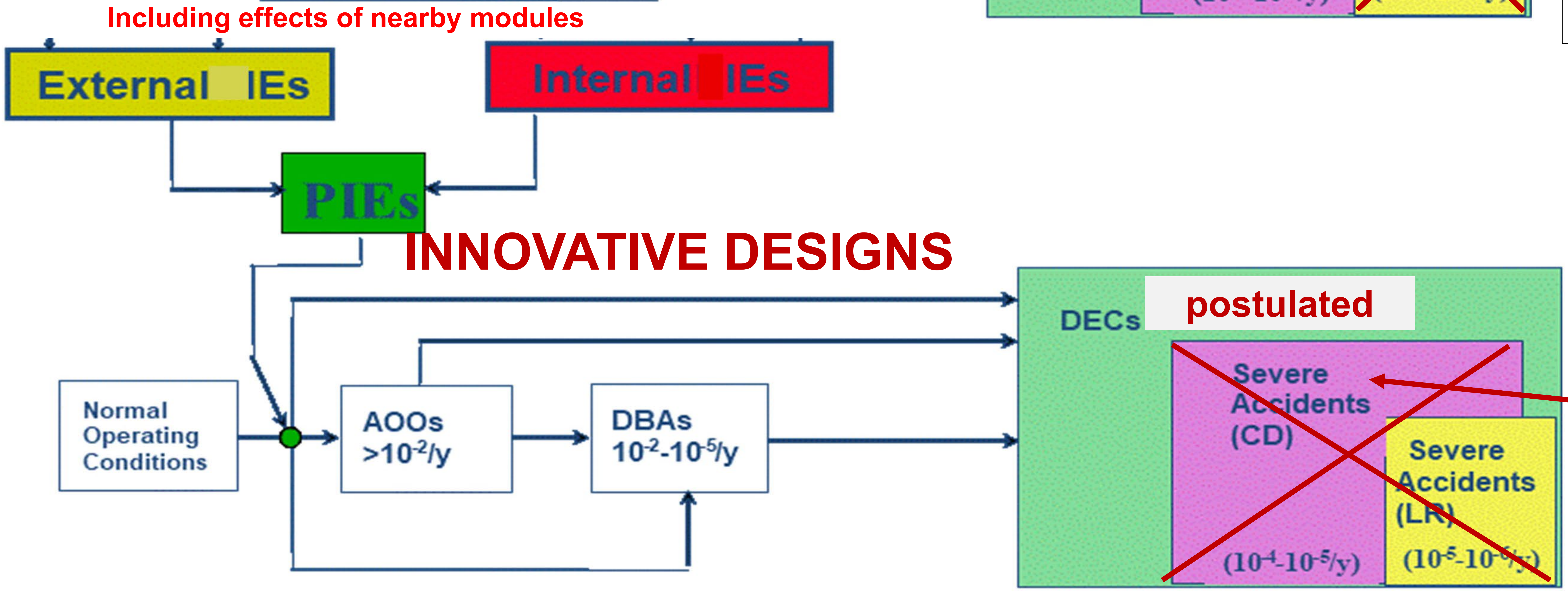
- Information for the operator for safety function performance
- How will the qualification be done?
- A high temperature gas-cooled reactor unit capacity below ~600 MWt as necessary condition to ensure long-term passive heat removal from the core
- Increased possibility of common cause failures
- Control room staffing; operator may need to perform emergency response simultaneously on multiple modules
- Accumulative radionuclide inventory in more units
- Increased complexity in accident sequences and responses
- Less external response capability
- Lack of local infrastructure
- Challenges with the remote operation

# SPECIFIC TECHNICAL ISSUES

# PRACTICAL ELIMINATION OF CERTAIN PLANT CONDITIONS




Measures implemented, demonstration of practical elimination with high confidence, very low residual risk




Measures implemented, demonstration of practical elimination with high confidence, very low residual risk

# LIMITED SIZE OF EMERGENCY PLANNING ZONE

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- In principle, in innovative designs with capability to prevent and mitigate severe accidents it may be claimed to eliminate the need to establish any emergency planning zone.
- **A solution could be determining the size of the emergency planning zone based on the dose criteria associated with certain non-negligible frequency.**
- It would be appropriate to limit the size of the zone to the nuclear site itself or to its close proximity.


**Overview of the size of EPZ in different European countries**

# ROBUSTNESS AGAINST EXTERNAL HAZARDS TO BALANCE RISK

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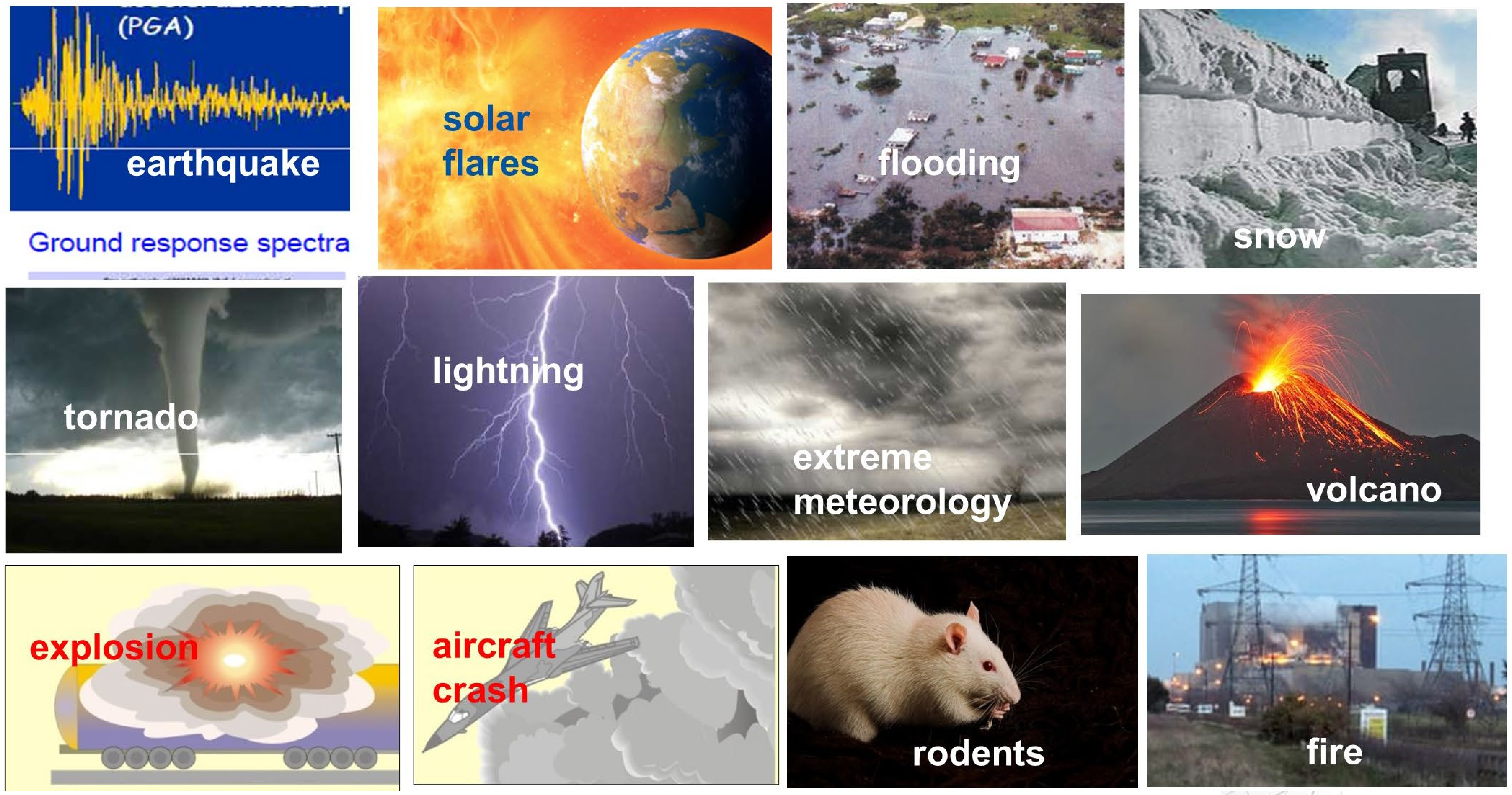
- With simplification of the design and extensive use of passive safety features it is achievable that return period of severe core damage due to internal events is comparable with the age of universe;
- Under such conditions the dominant role for safety will have the robustness against external hazards (since cut-off frequency for practical elimination is usually taken as $10^{-7}$/year, while design basis external events are usually determined for frequency $10^{-4}$/year).
- External hazards have no strict upper limit of the intensity, limitation by frequency is necessary
- Hazards induced by neighbour modules need to be considered



# QUANTIFICATION OF INDEPENDENCE OF LEVELS OF DEFENCE IN DEPTH: SSM RESEARCH, 2015:04, DID-PSA: DEVELOPMENT OF A FRAMEWORK FOR EVALUATION OF THE DID WITH PSA

| | |
|---|---|
| DiD level 1-5 | PSA level 3 – Society risk (fatalities and cancer) |
| DiD level 1-4 | PSA level 2 – Source term frequencies |
| DiD level 1-3 | PSA level 1 – Core damage frequency |
| DiD level 1-2 | PSA Initiating event (?) |
| DiD level 5 | Conditional probability of society risk given release |
| DiD level 4 | Conditional probability of release given core damage |
| DiD level 3-4 | Conditional probability of release given IE |
| DiD level 3 | Conditional probability of core damage given IE |
| DiD level 2:2 | Conditional probability of IE given abnormal operation |
| DiD level 1:2 | Frequency of abnormal operation – Frequency of failures of normal operating equipment |
| DiD Level 1:1 and 2:1 | Dependability of components in terms of the original quality and quality of surveillance/maintenance activities – represented by failure data – data investigation can identify the root causes and what went wrong. |

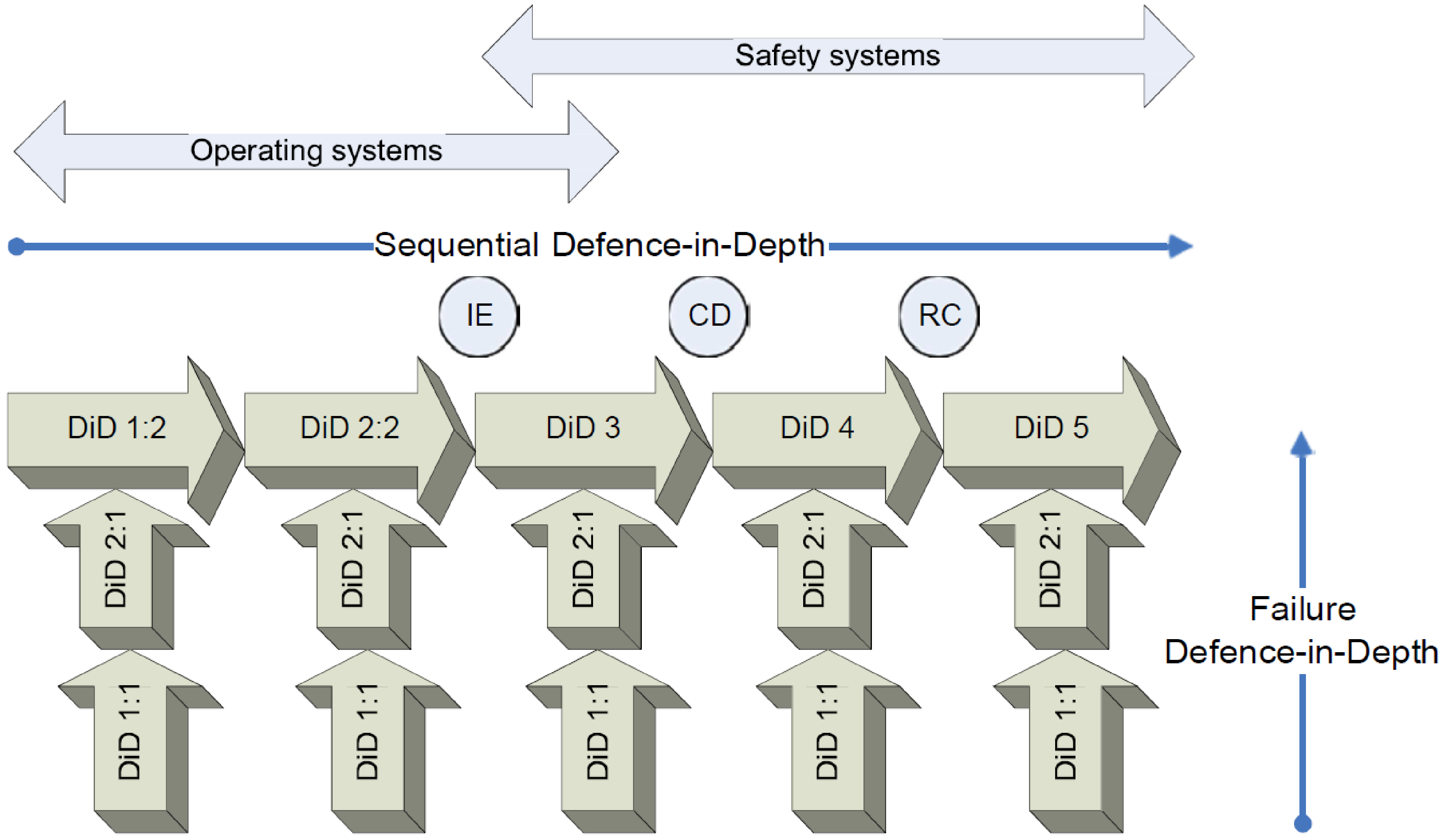
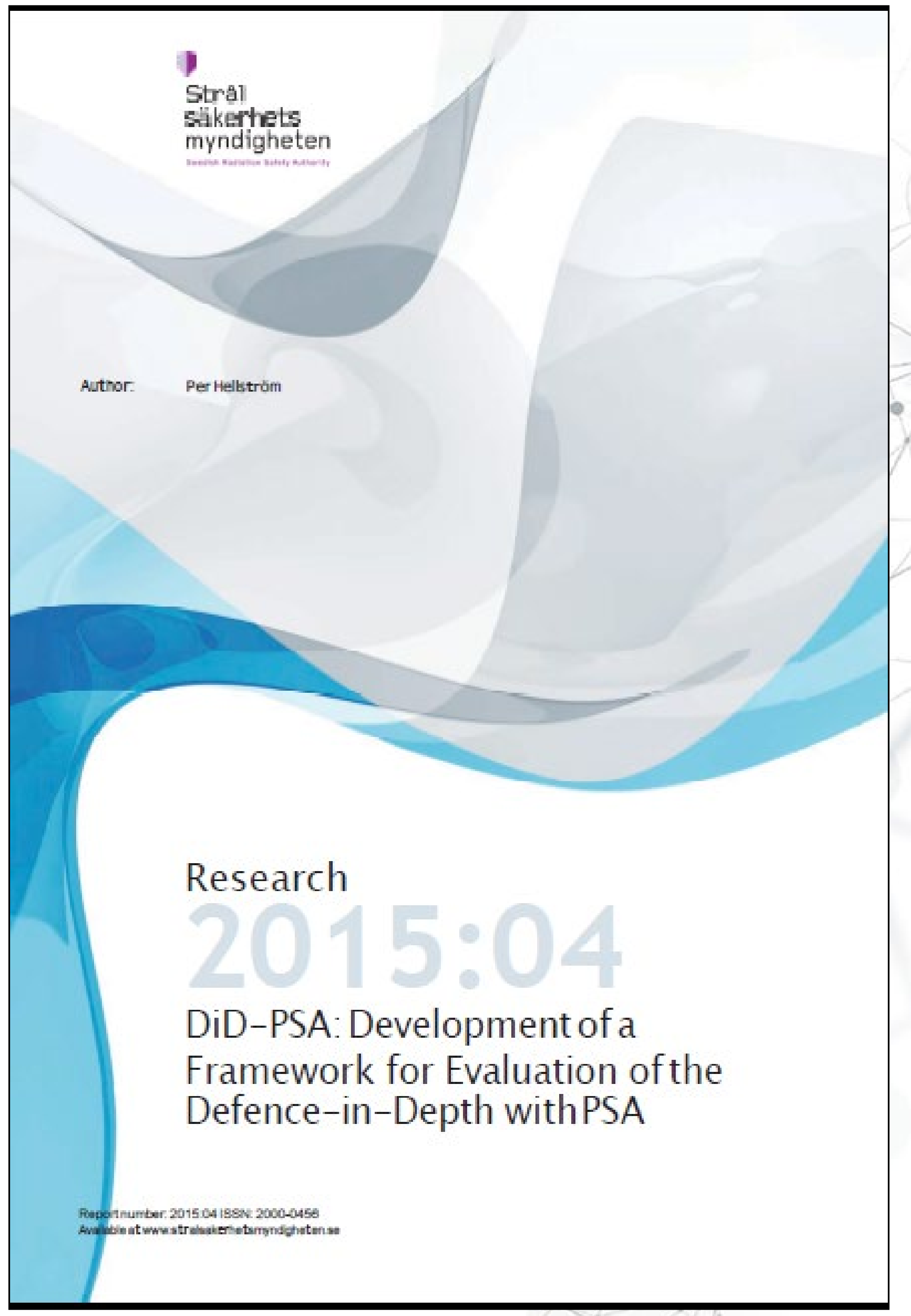



**Figure 16: The New Elaborated DiD Framework**

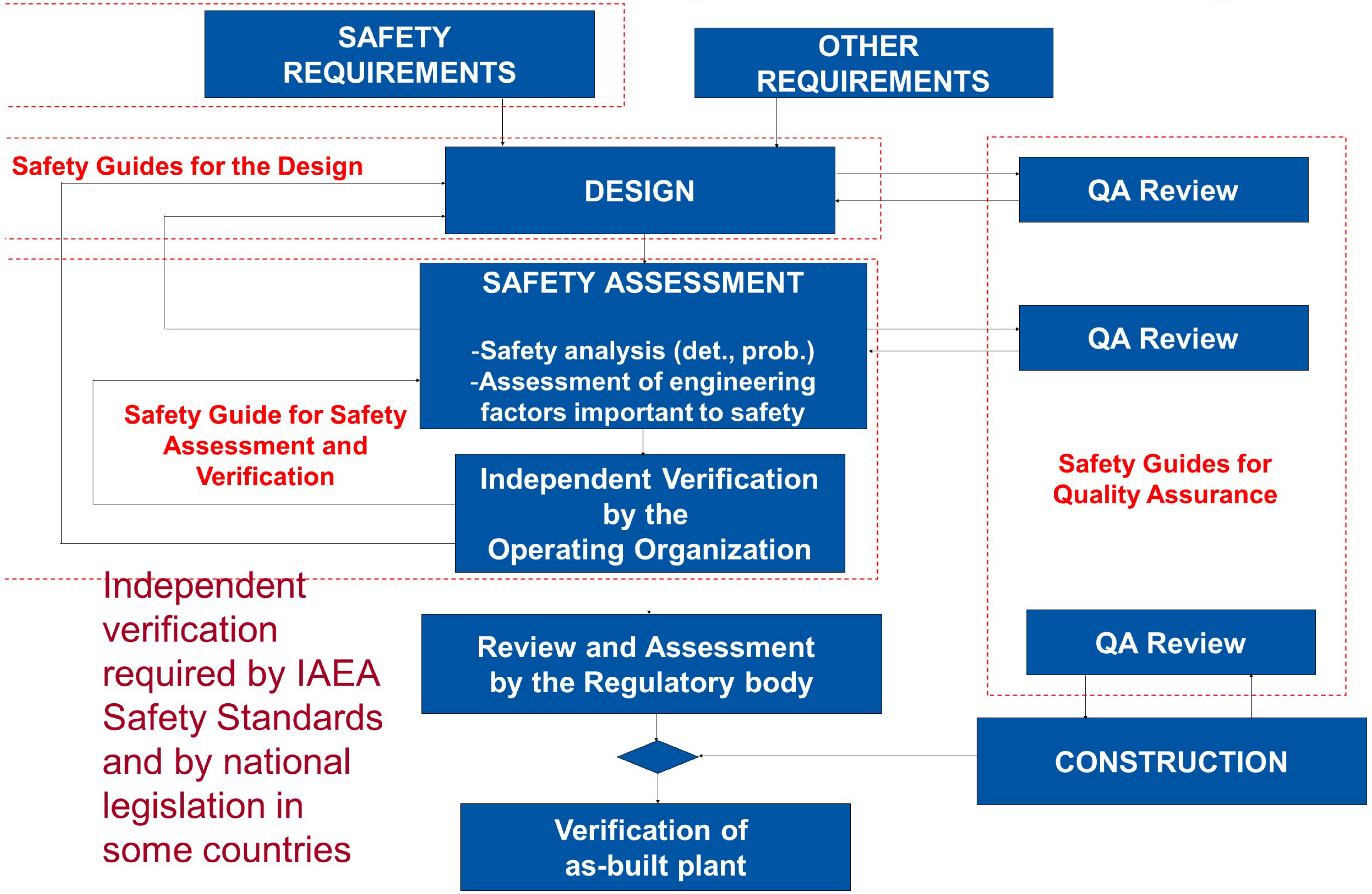



## Summary of Probabilistic Measures for DiD Levels

The absolute frequencies (CDF, LRF) represents a measure of all DiD levels (1:2-3, 1:2-4, 1:2-5)

# SPECIFICS OF INNOVATIVE DESIGNS FOR INDEPENDENT VERIFICATION BY OPERATING ORGANIZATION

- Because of many novel design features of innovative designs, independent verification of safety analysis is more important than for the existing designs
- Due to novel design features and limited experimental demonstration, adequate validation of computer codes as well as validation of input models may be the issue
- Experience with performing reliable safety analysis may be limited
- Knowledge accumulated by individual vendors has commercial value, may be subject of some kind of confidentiality regime and dissemination of that knowledge may be restricted
- In consequence, it may be difficult to find another qualified organization with capability to preform independent  verification analysis



# Thank you for your attention

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