Consistent criticality safety approach to nuclear sites, external transport and final disposal

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NCSD TOPICAL 12 SEPTEMBER 2017, CARLSBAD, NM

Overview

Safety Culture?

- Criticality safety principles
- Nuclear sites, external transport, final disposal
- Principles same, Implementations vary
- Technical basis of Transport Regulations
- Scope of Regulations: Shipment, not associated operations
- Subcritical system intended, not confinement system
- Criticality Safety Index (CSI) – A fairy tale method
- Temperature range from -40 ºC up to +800 ºC

Criticality safety principles

- Principles from theory, understanding and experience
- Expressed in consensus standards, e.g. ISO and ANSI/ANS
- What (objectives), where & when (scope), who (responsibility)
- Avoids reference to specific applications, methods and limits
- Stability over very long periods
- Traceability to origin of principles, preservation
- Criticality: Energy release, radiation only 5 %

Example: Identification and verification before and throughout operations (2.6)

“2.6 Items, fissile material properties and process functions of importance to criticality safety during operations shall be identified.

Their safety function before and throughout operations shall be verified.”

(from full paper, based on ISO 1709)

Compare with “confinement system” definition and application in Transport Regulations

Nuclear sites, external transport, final disposal

- Fissile material (not nuclides!) at nuclear sites. Usually:
  - Detection and alarm, trained staff, away from public
- External transport of fissile material,
  - International, close to public, no detection or trained staff
- Final disposal of fissile material, no human intervention
  - Direct disposal of used nuclear fuel
  - Nuclear sites (loss normal or accidental, MUF)
  - During transport (e.g. lost at sea)

Principles same, implementations vary

- Same criticality safety principles for sites, transport and disposal
- Varying implementation at different sites, transport, disposal
- Different regulations for different sites, transport, disposal
  - Technical basis builds on common principles?
  - Design-basis requirements for authorization
  - Safety of operations is management responsibility, required
  - Demonstration of subcriticality in transport is too complicated. 1961: Maximum Credible Accident had to be demonstrated

Technical basis of Transport Regulations

Safety Culture?

- IAEA is preparing a Technical Basis Document (TecBasDoc)
  - First attempt on criticality (ref. 2) replaced by IAEA June 2017
  - 2017 TecBasDoc contains many errors, gaps, lack of principles
- Real technical basis of the IAEA Transport Regulations:
  - Prepared in early 1960's, primarily by a few general specialists: Woodcock (UK), Paxton (USA) and Breton (France).
  - Based on general principles, including double contingency
  - Criticality safety basis has deteriorated substantially with time

Title of Regulations: Safe Transport!

Safety Culture?

- “SCOPE 106. … Transport comprises all operations and conditions associated with, and involved in, the movement of radioactive material; these include the design, manufacture, maintenance and repair of packaging, and the preparation, consigning, loading, carriage including in-transit storage, unloading and receipt at the final destination of loads of radioactive material and packages” (Complete packages unless unpackaged material complies with Regulations).
- “107. These Regulations do not apply to any of the following:
- (b) Radioactive material moved within an establishment that is subject to appropriate safety regulations in force in the establishment”

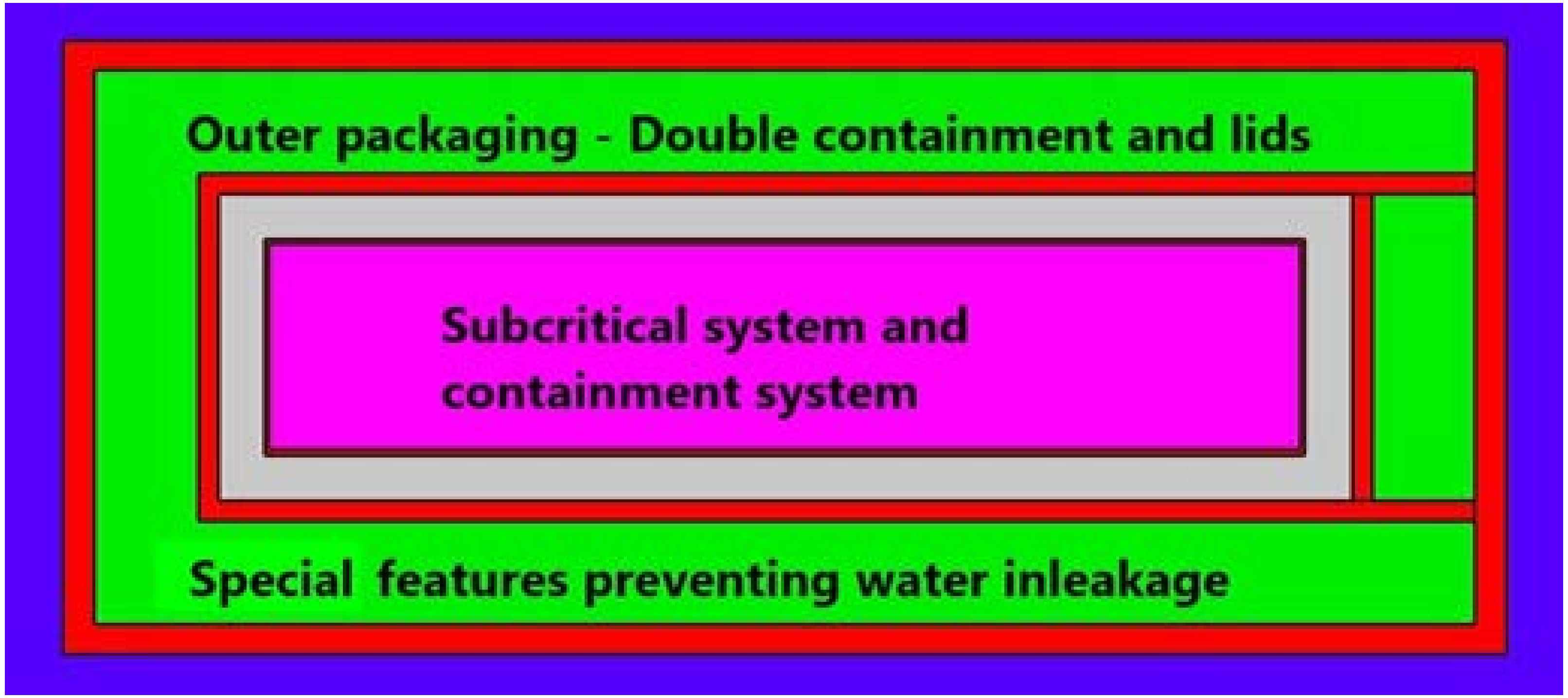
Criticality accident prior to shipment?

Safety Culture?

- Is “before shipment” within scope of Transport Regulations?
- Compliance with Regulations ensures criticality safety?
- Authority approval covers safety before shipment?
- Assume mistake causes criticality accident before shipment
- Are the Regulations really intended to prevent the accident?
- Criticality accident before shipment only delays transport (radioactive decay period required) – JCO accident 1999

Subcritical system for technical support

Containment vessel (purple) prepared outside, loaded into and out of the package, with inspection and maintenance possible interruptions during transport



Subcriticality of containment vessel with water reflection is a technical requirement: Intended for safety support, not for safety preservation

Multiple containment, subcritical systems

Safety Culture?

- Today a single package may contain:
  - Hundreds of containment systems in a single handling unit (e.g. fuel claddings in a fuel assembly)
  - Multiple subcritical systems handled separately
- <1973, subcriticality required for containment vessel
- Since 1973, subcriticality of package is required, with containment system reflected by water
- Subcriticality of containment system not required

Subcritical system –Proposed definition

“Intended to be subcritical, a separable assembly of one or more *containment system(s)* including *fissile material*. Applies to an individual package containing one or more *subcritical systems*. Additional components in the *packaging* or in the contents may be required (e.g. structural, spacing, neutron absorption) for a *subcritical system* containing multiple *containment systems*”

Discussed by IAEA criticality safety working group July 2017

Proposed requirement

- “Each subcritical system shall remain subcritical under the following conditions:
- The complete package shall have been subjected to accident conditions of transport
- The subcritical system shall be reflected by 20 cm of water or such greater reflection as may be present in the outer packaging
- Reliance on prevention of water in- or outleakage shall be specified.”
- Discussed by IAEA criticality safety working group July 2017

Current implementation (1996)

Safety Culture?

- "*Confinement system* shall mean the assembly of *fissile material* and *packaging* components specified by the designer and agreed to by the *competent authority* as intended to preserve criticality safety "
- Intent lost (editorial change!), Preserve safety (package), Term?, Fissile material (nuclides in 1996)?, Agreed by CA (required anyway)? Array (single package intended)?
- The definition is used to prepare a list of criticality safety features (as in ISO 1709!) The requirement in IAEA §681 is ignored by designers and competent authorities.

Criticality Safety Index (CSI) – A fairy tale

Safety Culture?

- CSI controls accumulation of packages with fissile material
- The CSI method allows mixing different systems in transport
- Each CSI is based on a configuration of identical packages
- The CSI method has not been and could not be validated
- CSI and similar methods fail for site storage as well
- Subcriticality is determined by conservative assumptions
- Subcriticality is not safety – Awareness is required
- The CSI method is a fairy tale to keep your eyes closed

Rounding CSI value down to zero

- IAEA recommends that CSI should **not be rounded down** but **rounded up to first decimal.**
- Proposal: Allow rounding CSI down to zero when safe (no fixed limit – depends on credibility of configuration).
- **Material with up to 0.25 g of ^{235}U in a package is not fissile**
- §674(a): 0.25 g of pure ^{235}U corresponds to a CSI value of 0.2
- **1800 simple packages, each with CSI of 0.2, are negligible**
- 1800 large, strong packages with CSI of 0.2 or less?
- **<1985: Subcriticality only for 250 "damaged" packages**

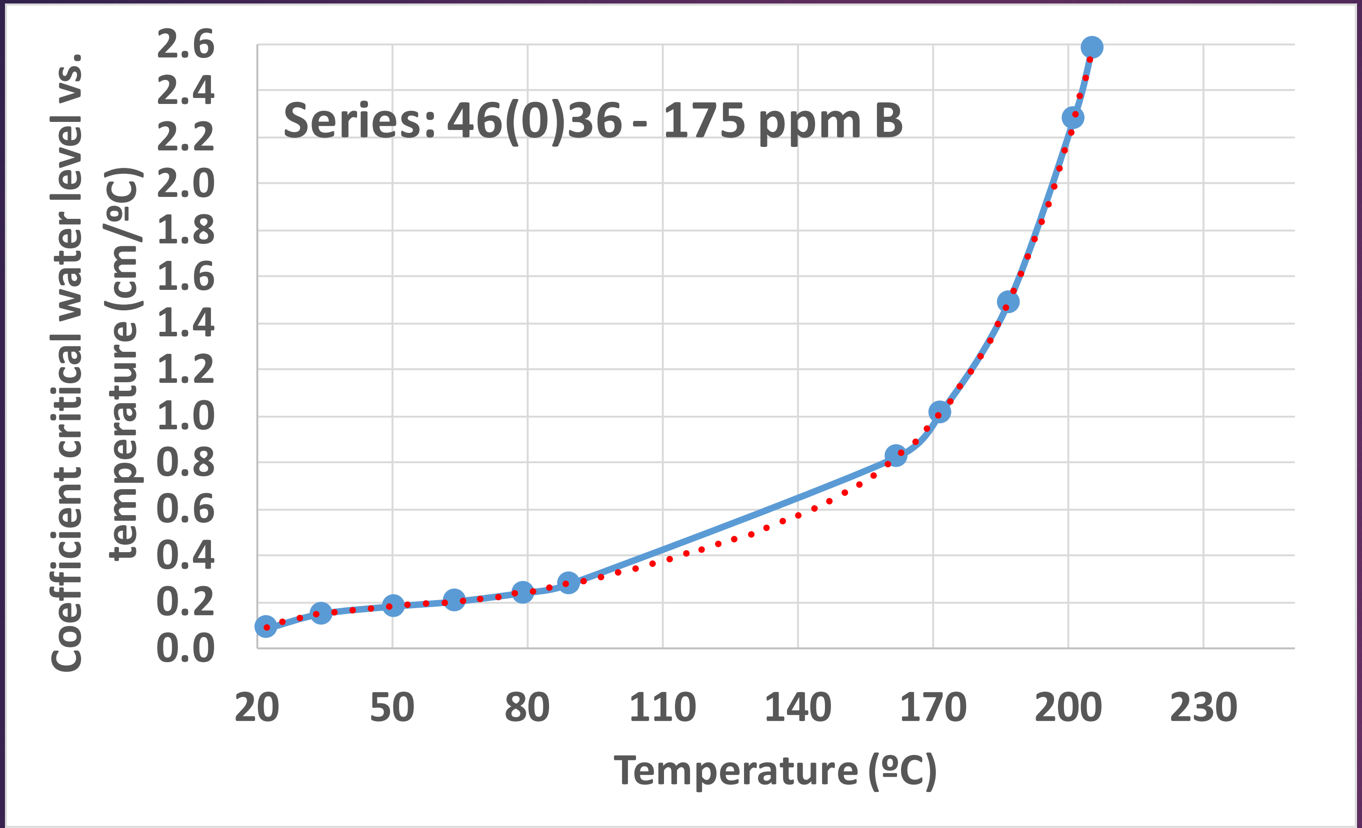
Temperature range from -40 ºC and upwards

Safety Culture?

- IAEA: Environment temperature range from -40 ºC to +38 ºC:
  - From 1985 for Type B package designs
  - From 1996 for package designs for fissile material
- Fire for 30 minutes at 800 ºC
- Burnup credit requires full power depletion calculations
- Nuclear data dependence (Doppler, thermal scattering)
- Methods and validation essential for temperature correction
- KRITZ critical experiments 1969-1975 appear to be valuable

KRITZ-1 experiments 20 ºC to 250 ºC

- **KRITZ was a zero-power critical facility, designed for temperatures from 20 ºC to 250 ºC, without boiling (pressurized)**
- **KRITZ allowed full length reactor fuel rods and assemblies**
- **Parameter in a single series: Temperature**
- **Results: Critical water height**
- **Parameters in multiple series: Boron concentration, design**
- **Experiment correlations reduce uncertainty of the measured reactivity change due to a temperature change:**
  - **Uncertainty** $= \sigma_1^2 + \sigma_2^2 - 2r\sigma_1\sigma_2$



KRITZ-1: Some measured results (preliminary)

Conclusions and Issues

Safety Culture?

- Principles come from early experience and understanding
- No fundamental difference between sites, transport, disposal
- Principles applied to 1960’s IAEA transport regulations. Now?
- Criticality before shipment? Responsibility, approval
- Subcritical system: Technical basis for site and transport safety
- Criticality Safety Index: Fairy tale that should allow flexibility
- Temperature: KRITZ benchmarks for validation
- A critical mess (self-sustaining chain-reaction of ignorance)