Orano NCS – Use of SCALE in our R&D projects

2023 SCALE Users' Group Workshop

27 April 2023

orano

Orano NCS company overview

Orano NCS GmbH offers:

World-wide transportation services

> Radioactive material
> Front end, back end and research
> Own equipment for road and rail

Packaging development and services

> Complete design process
> Approval and validations
> Procurement and commissioning
> Packaging and lashing services on site

World-wide planning services

> Transportation feasibility studies
> Packaging studies
> Consulting services

Design and Technology dept. (AT)

> Design and supply of packagings

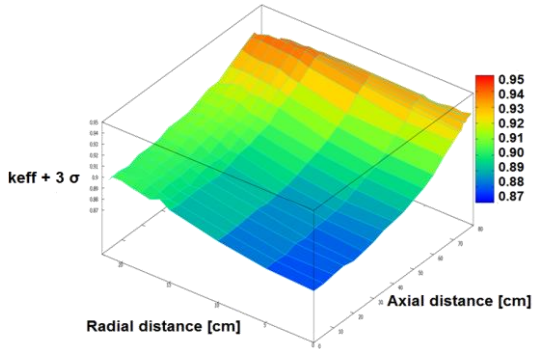
> Safety analysis

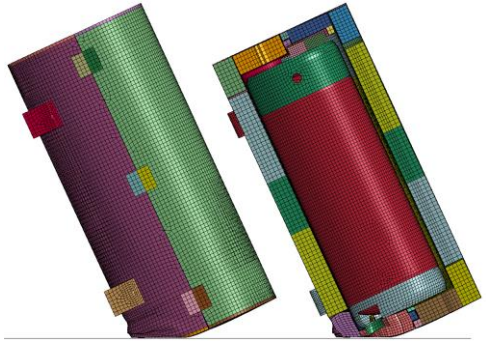
> Radiation protection

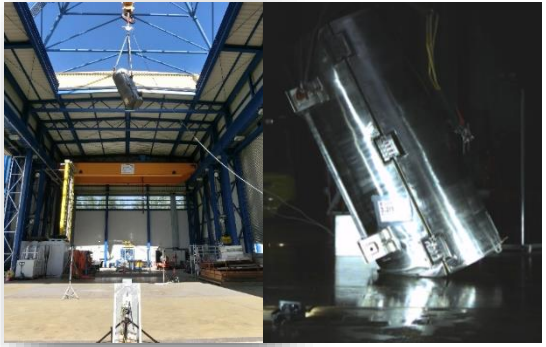
> Transport approvals

> Transports of irradiated fuel rods

> Storage and maintenance facilities







Engineering Team

Small but experienced team of technical experts

Successful licensing and license maintenance for several package designs

- National and international licenses and validations
- In-house creation of PDSR (Package Design Safety Reports)
    - Complete safety assessment
    - Documents and instructions for handling, testing, etc.

All safety analyses are carried out in-house

- Thermal and structural analysis (ANSYS and LS-DYNA)
- Criticality and shielding analysis (SCALE)
- Containment analysis (acc. to ISO 12807 / ANSI N14.5)

Team approach based on technical capabilities

- Project managers with technical background
    - Contribute to PDSR creation
    - Able to guide technical discussions and design decisions
- Direct communication between experts and authorities
    - Clear exchange of technical questions
    - Very good feedback from authorities for this approach

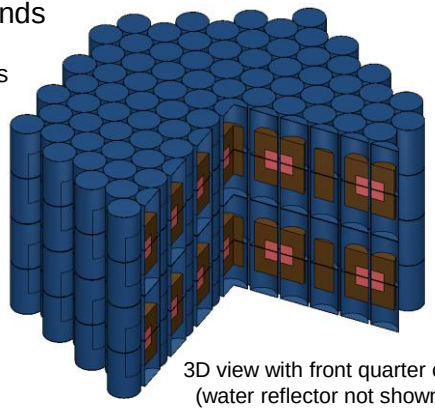
Safety analyses with SCALE (1)

Criticality safety analyses

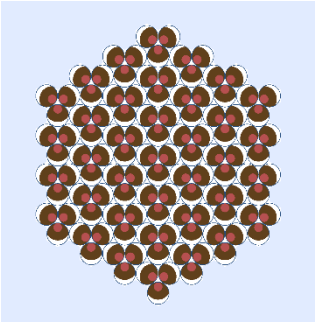
Safety assessments for our package designs

- DN30 and DN30-X for UF_6 transport
  - presented in detail later
- NCS 45 for intact or damaged irradiated fuel rods
  - transport capability for fast-breeder MOX fuel or research reactor fuel rods with 93 wt.% ^{235}U
- Simple drum package designs for unirradiated Uranium compounds
  - e.g. BU-D or EB3 licensed packages
  - low fissile mass per package, neutronic interaction between packages

Feasibility studies for new designs or content extensions for existing designs



3D view with front quarter cut
(water reflector not shown)



horizontal cut through a layer

steel
fissile mixture
carbon
water

Safety analyses with SCALE (2)

Shielding analyses and dose rate determination

Safety assessments for our package designs

- DN30 and DN30-X for UF_6 transport
  - presented in detail later
- NCS 45 for intact or damaged irradiated fuel rods
  - lead/tungsten shielding
- Final storage containers for medium active waste
  - large spectrum of radioactive nuclides needs to be taken into account

Irradiation/decay calculations

Determination of radiological and heat source terms

- Usually, rough approach with ORIGEN-ARP is sufficient for our needs
- no applications of burn-up credit (yet)

Overview DN30 package

30B cylinder

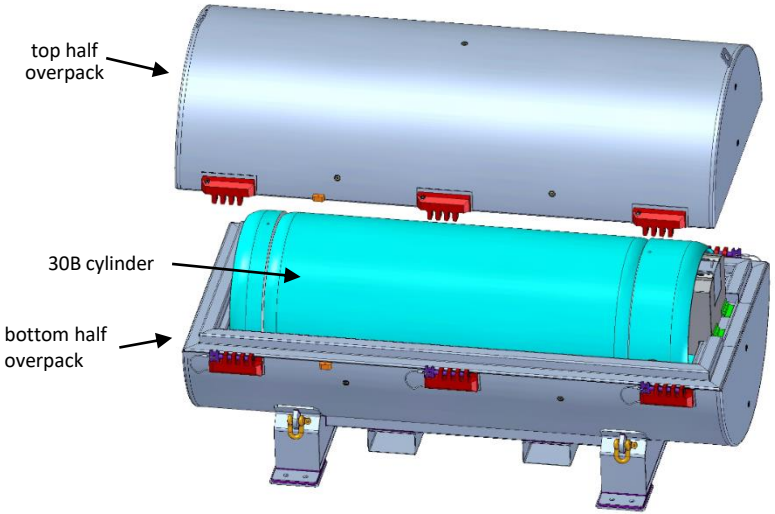
Cylindrical steel vessel for transport and storage of UF_6 (ISO 7195 and ANSI N14.1)

UF_6 content

- Up to 2277 kg of commercial or reprocessed UF_6, max. enrichment 5% ^{235}U
- Up to 11.4 kg of heels content for ‘empty’ cylinders

DN30 PSP (Protective Structural Packaging)

Two half shells with inner and outer steel shell filled with foam material



DN30 Shielding analysis (1)

Source term considerations

Low amount of neutron emitters in UF_6

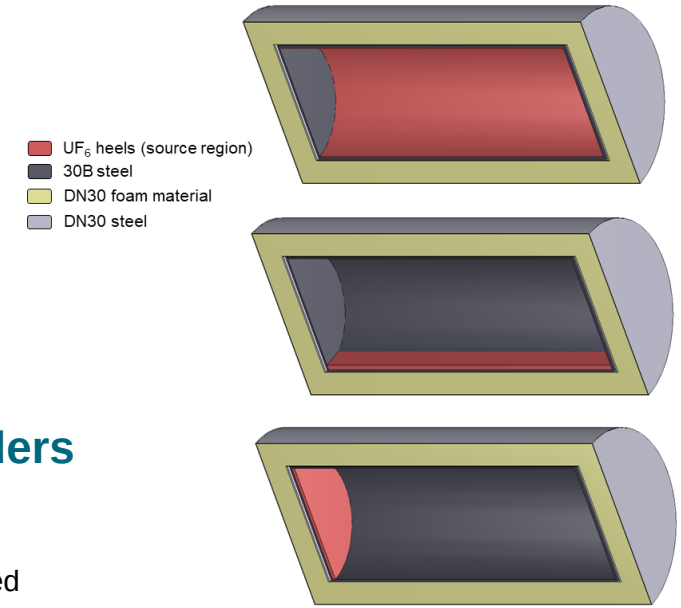
- Neutron contribution to total surface dose rates generally < 2 µSv/h

Commercial grade UF_6

- Main source term contribution from uranium daughter products
  - increase of dose rate over time

Reprocessed UF_6

- Additional contribution from fission products and higher actinides
- External dose rates usually dominated by ^{232}U daughter nuclide ^{208}Tl
  - permitted ^{235}U concentration depends on storage time after processing



Heels have higher dose rates than full cylinders

No self-shielding from UF_6 content

Strong gamma emitters form non-volatile compounds

- remain in the cylinder during emptying when the UF_6 content is liquified

DN30 Shielding analysis (2)

Dose rates for cylinders with reprocessed UF_6 heels

Relevant factors for external dose rates

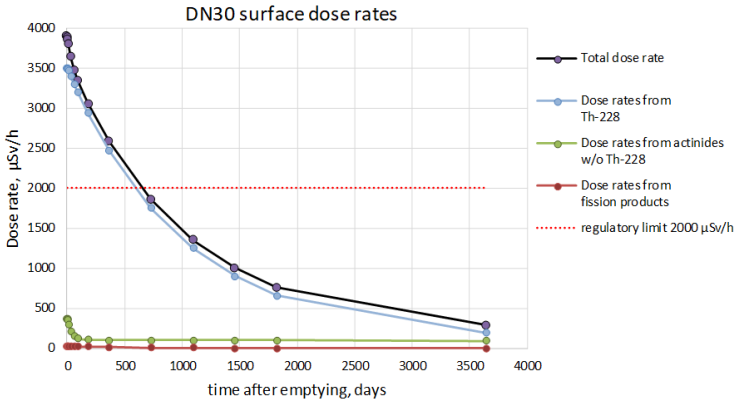
- No refilling of cylinders with reprocessed UF_6 without prior cleaning
  - source term is based on a single UF_6 filling
- Main source term contribution from ^{232}U daughter nuclide ^{228}Th
  - initial ^{232}U content (higher concentration → higher dose rate)
  - build-up of ^{228}Th between processing and emptying (longer time → higher dose rate)
  - decay of ^{228}Th between emptying and transport (longer time → lower dose rate)

Calculation approach with MAVRIC/MONACO

- Source terms are varied and complex → group-wise calculations
  - seperate calculation for each energy group (V7-27N19G library structure)
  - evaluation of dose rates with time-dependent source terms via excel

Example results

- UF_6 with 0.03 µg/g_U ^{232}U, 180d storage after processing
  - Dose rates dominated by ^{228}Th and its daughters
  - Decrease over time with the 1.9 years half life of ^{228}Th
  - Regulatory limit of 2000 µSv/h met after ~2 years



DN30 criticality safety analysis

Absence of water leakage for the individual package

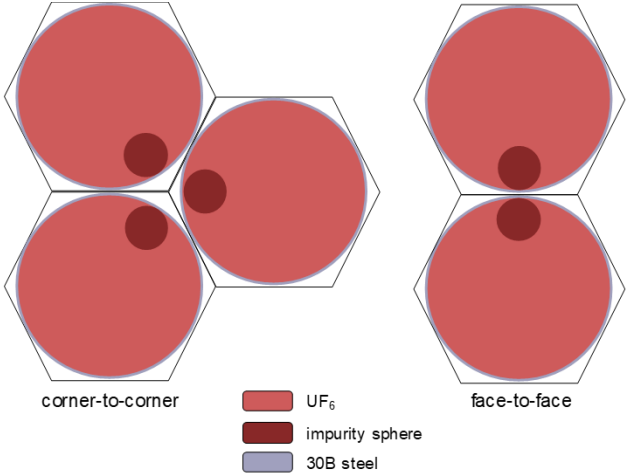
‘Special feature’ under IEAE SSR-6 para. 680 / 10 CFR 71.55

(b) For *packages* containing uranium hexafluoride only, with a maximum *uranium* enrichment of 5 mass per cent uranium-235:

(i) *Packages* where, following the tests prescribed in para. 685(b), there is no physical contact between the valve and any other component of the *packaging* other than at its original point of attachment and where, in addition, following the test prescribed in para. 728, the valves remain leaktight;

Covering scenario is the infinite (CSI=0) ACT package array

- No significant water in-leakage (valve remains leaktight after ACT tests)
- Relevant moderation from impurities in UF_6
  - up to 0.5 wt.% homogeneously distributed HF
  - Hydrogenated uranium residues (HUR): conservative assumption 11.4 kg



Calculation results

HUR sphere at the 30B wall (close to adjacent cylinders)

- approximates realistic scenarios (HUR will accumulate in a lump)
- no significant k_{eff} difference for corner-to-corner or face-to-face orientation

Overview DN30-X package

Transport solution for HALEU (up to 20 wt.% ^{232}U) UF_6

Required for new LWR fuel designs and many SMR concepts

- 30B cylinder is limited to 5 wt.% ^{235}U
- No licensed transport overpack for UF_6 with higher enrichments

DN30-X package conceptual design

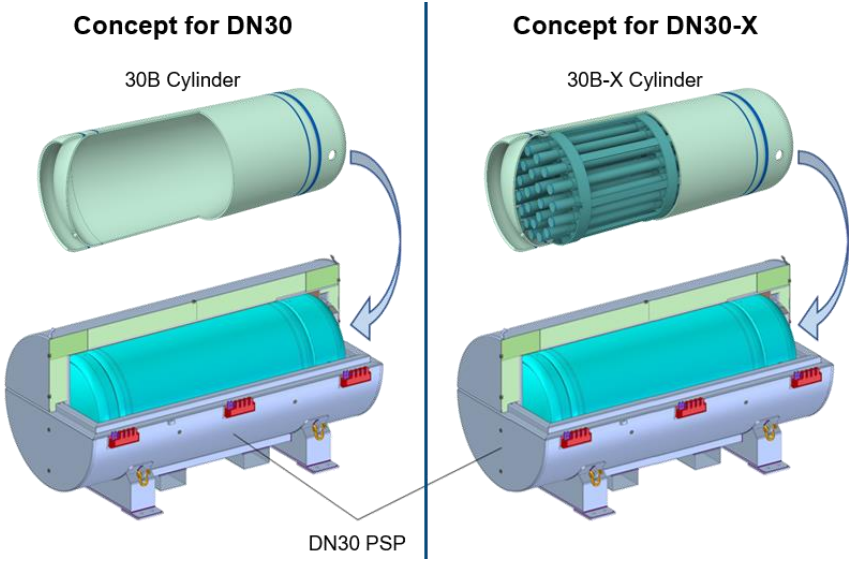
- Unmodified DN30 PSP
- 30B-X cylinder instead of standard 30B cylinder
  - internal lattice of steel rods with B_4C filling
  - same loaded mass for both cylinders
  - identical operation and handling

DN30-X package safety assessment

- Structural analysis for the PSP mostly covered by DN30
  - new analysis for the internal criticality control system
- Thermal, shielding and containment covered by DN30
- New criticality safety analysis

Licensed by US NRC in March 2023

- Application was submitted in June 2021



30B-X cylinder

Internal Criticality Control System (CCS)

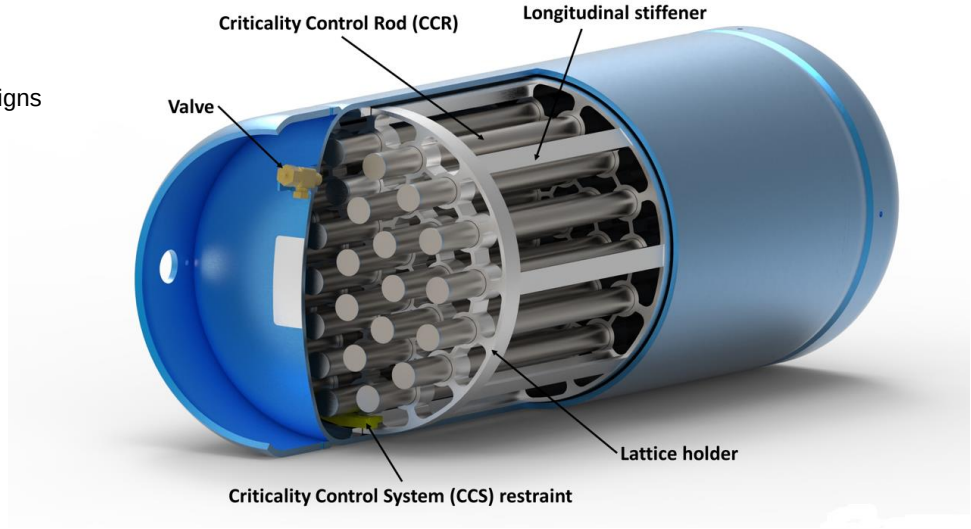
- Higher reactivity from increased UF_6 enrichment
- No exemption for SSR-6 para. 680
  - optimal moderation for the single package
  - standard 30B with 5 wt.% ^{235}U and optimal moderation: k_{eff} = 1.29
- Steel CCRs with B_4C filling, positioned by lattice holders

Two versions: 30B-10 and 30B-20

- Optimized CCR lattices to increase UF_6 capacity
  - 30B-10 with up to 10 wt.% ^{235}U for new LWR fuel designs
    UF_6 capacity 1460 kg (33 CCRs)
  - 30B-20 with up to 20 wt.% ^{235}U for SMR fuel
    UF_6 capacity 1271 kg (43 CCRs)
  - For comparison, 2277 kg UF_6 in a standard 30B

Cylinder shell identical to standard 30B

- Identical dimensions, valve and plug
  - no changes in handling and operation
- Identical carbon steel material
  - Same carbon steel is used for the CCS
- Inclusion in UF_6 cylinder standards is planned
  - ANSI 14.1 for US, ISO 7195 for elsewhere



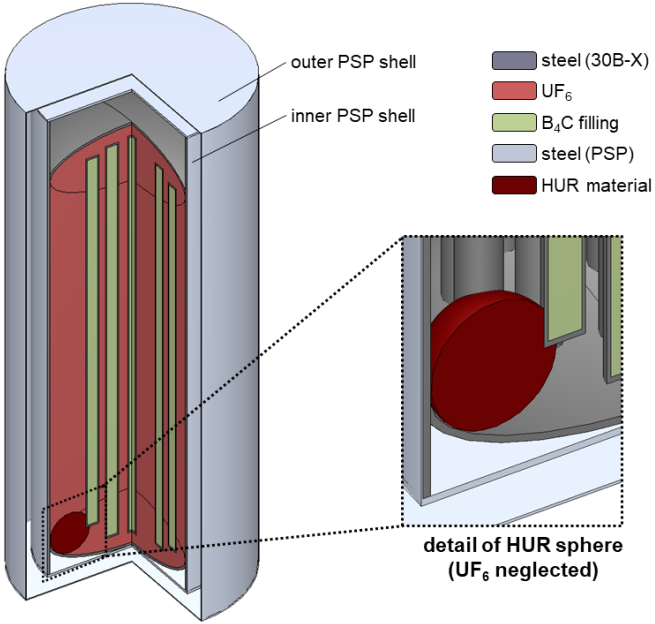
Full criticality analysis

Single package in isolation

- Determination of covering assumptions for the proof of safe subcriticality
  - Manufacturing tolerances of the cylinder and the internal CCS (Cylinder Ø, wall thickness, CCS position, CCR length, Ø and wall thickness)
  - B_4C taken into account with < 90% specified density (NUREG-2216)
  - Deformations from HAC drop tests (CCS position, CCR position changes)

Infinite package array

- Similar assumptions as for the DN30 analysis
  - HF content of 0.5% evenly distributed
  - 11.4 kg HUR sphere
- In spite of pessimistic assumptions, lower k_{eff} than the single package



Code validation via TSUNAMI

Covering application of the single package is challenging to properly validate

- System with optimally moderated HALEU UF_6 and B_4C rods
  - no directly comparable benchmark experiments
  - apparently dissimilar U/H systems can actually correlate well
  - neutron spectrum (i.e. EALF) and enrichment are central parameters

- TSUNAMI study with 76 cases from 11 benchmark series
  - Correlation coefficient $c_k > 0.90$ for most cases, minimum $c_k = 0.823$
  - Explicit sensitivity studies to validate TSUNAMI models
  - Other conclusions from the TSUNAMI study
    - High similarity possible for large differences in ^{235}U enrichment
    - Impact of boron is not crucial
    - U compound/solution has little impact for optimal moderation with H
    - Similar EALF is a good indicator for further candidates

	^{235}U (in mixture)			H (in mixture)			B_4C (in CCRs)		
application	direct	model	rel. Δ	direct	model	rel. Δ	direct	model	rel. Δ
DN30-10	0.219	0.226	3.3%	0.405	0.413	2.0%	-0.047	-0.056	15.5%
DN30-20	0.173	0.180	3.9%	0.453	0.450	-0.7%	-0.050	-0.060	17.2%

		^{235}U (fuel)			H (moderator)		
series	case	direct	model	rel. Δ	direct	model	rel. Δ
LCT-022	3	0.184	0.180	-2.2%	0.342	0.324	-5.6%
LCT-023	1	0.237	0.244	2.9%	0.239	0.247	3.2%
LCT-024	2	0.178	0.172	-3.5%	0.297	0.295	-0.7%
LCT-032	6	0.226	0.232	2.6%	0.256	0.256	0.0%

- Calculational bias $\Delta k = 0.0081$, USL = 0.9419

CCS of the 1st 30B-10 prototype

orano

Giving nuclear energy its full value