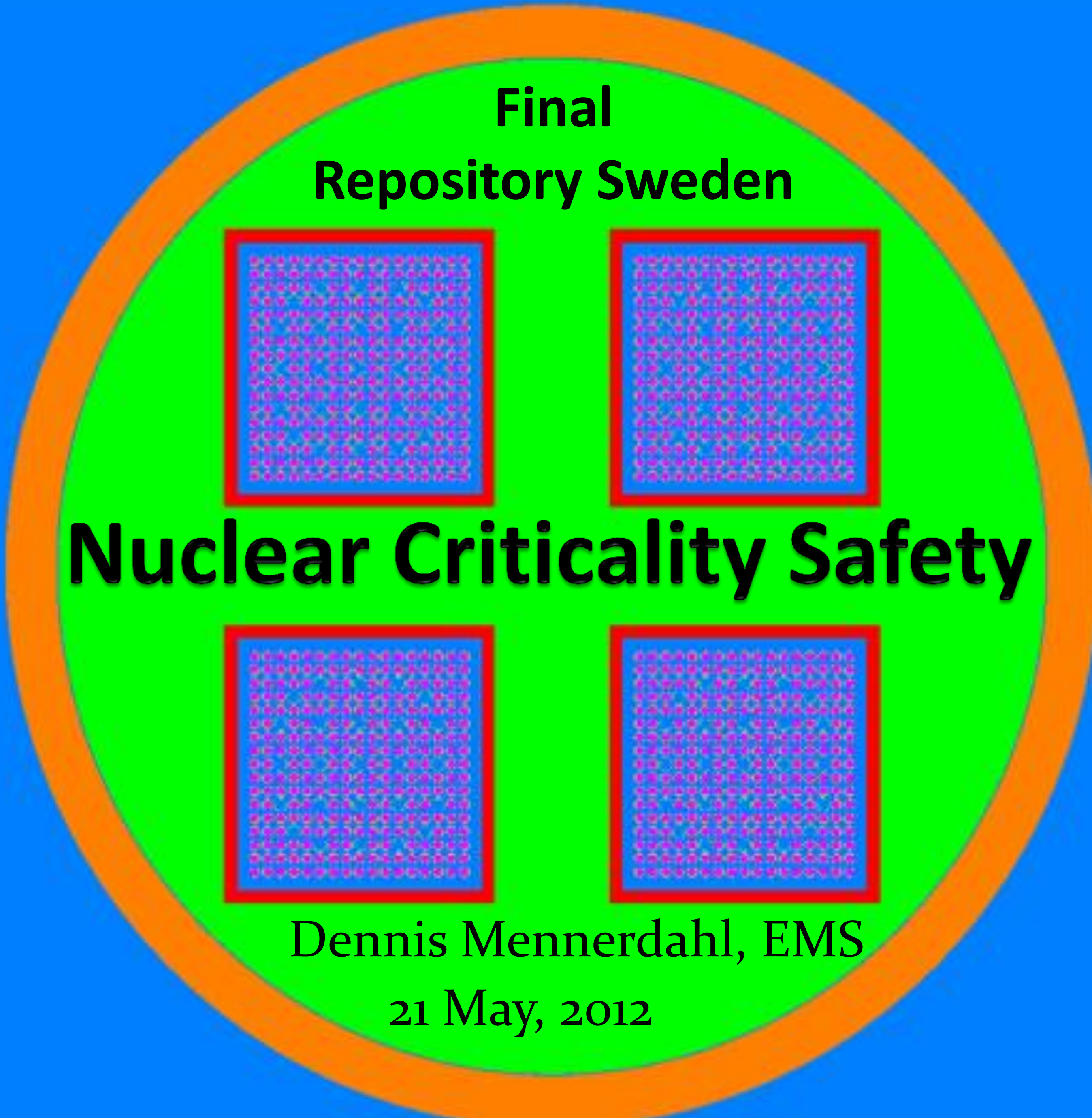

Final
Repository Sweden

Nuclear Criticality Safety

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Topics

- Nuclear criticality safety
- Burnup credit
- Fissile materials involved
- Copper canister
- Potential criticality scenarios
- Human intervention – Incentives
- Environmental law
- Nuclear energy and radiation protection laws
- Preliminary conclusions

Nuclear criticality safety

- Prevention is the traditional approach
- Shielding may be an acceptable mitigation
- Reactivity is essential, not radioactivity
- K-eff does not necessarily reflect safety
- Safety margin to be based on observable parameter
- Double-contingency principle is a recommendation
- Inherently safe materials, safe geometry, etc.
- Emergency preparedness, criticality alarm systems
- Validation of calculation methods

Burnup credit (BUC)

- A control method that accounts for fuel burnup
- "Burning" fuel eventually reduces its criticality hazard
- Used for Swedish research reactor fuel since the 1970's
- International studies have not been driven by utilities
- Swedish reactor physics methods have been available
- Validation benchmarks are available but commercial
- New utility efforts in Finland (TVO) and USA (EPRI)
- New NRC guidance from ORNL studies (NRC sponsor)
- ANS (2008) and ISO (2011) standards available

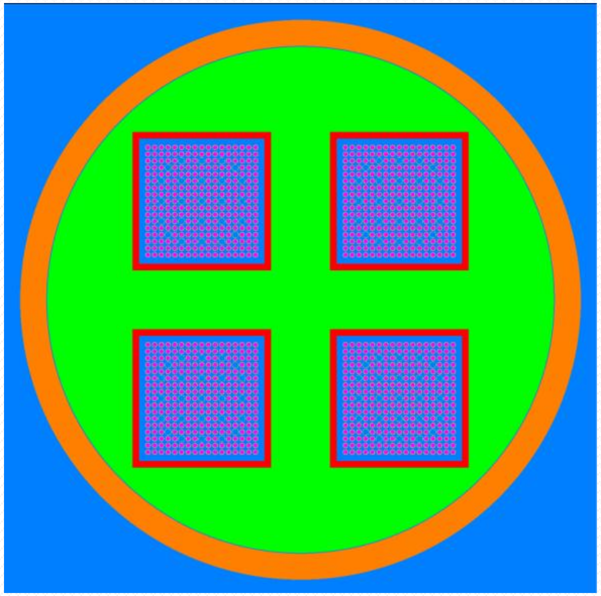
Fissile materials

- BWR UO_2 fuel
- PWR UO_2 fuel
- BWR MOX fuel, from reprocessed Swedish fuel
- BWR MOX fuel, exchange with Germany
- PWR MOX fuel, exchange with Germany
- Ågesta very low-enriched HWR fuel
- Some research reactor fuel and samples

Operations with fissile material

- Transport of UF_6
- Fuel fabrication (including UF_6 to UO_2 conversion)
- Fresh fuel transport
- Power reactor operation, fuel depletion
- Used fuel transport
- Storage at CLAB
- Encapsulation in copper canisters
- Transport of canisters with used fuel
- Final disposal – Influenced by previous operations

Copper canister



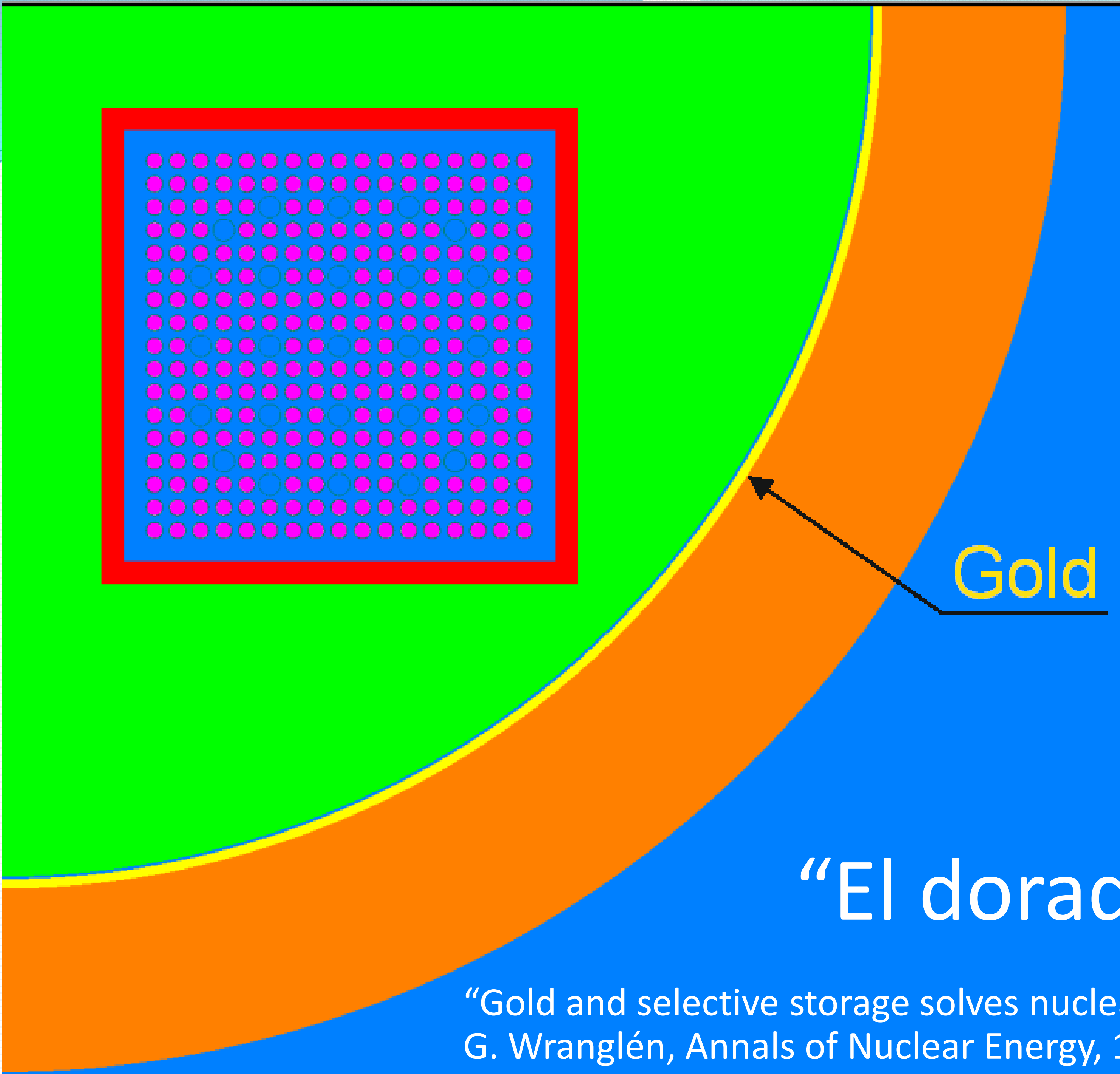
- Chemical integrity
- Mechanical integrity
- Heat conduction
- Shielding (gamma and neutron)
- Criticality prevention – No water
- Criticality potential – One fresh PWR assembly critical
- Water in-leakage and fissile material dispersal?
- “Shielded facility”?

Potential criticality scenarios

- Criticality is not possible without water
- Fresh PWR fuel and water in canister – criticality
- No criticality in canister with significantly used fuel
- With failed canisters, criticality can't be excluded
- With copper recovery, criticality is possible at surface
- Criticality is a "threshold" event, 0->100 Sv
- Annual risk 10^{-6} per individual for $1.4 \cdot 10^{-5}$ Sv/yr (SSM)
- Shielding of a criticality deep underground
- Criticality in encapsulation plant – Alarm system?

Human intervention

- A treasure (Cu, U, Pu), not waste - Will be recovered
- Cu recovery may result in radioactive waste dump
- Best available technique (BAT) increases treasure
- Double thickness of copper (5 cm to 10 cm)?
- “Gold … solves nuclear waste problem” (G. Wranglén)
- Recovery requires significant resources and time
- Recovery will not be needed for safety reasons
- Awareness of treasure needs to be maintained



“El dorado”

“Gold and selective storage solves nuclear waste problem”, G. Wranglén, Annals of Nuclear Energy, 1977

“Copper thieves cut off Sweden's main rail line”

“Rail traffic connecting Stockholm, Malmö, and Copenhagen was brought to a standstill on Tuesday after thieves severed the high-voltage overhead lines in order to steal the valuable copper wire inside.” [The Local, 4 April 2012]

Integral safety

- Criticality
- Other hazards
  - Non-proliferation
  - Contamination of large areas/volumes
  - Internal radiation sources
  - External radiation sources
  - Heat generation
- Overall: Criticality is major issue in Clink, minor issue in repository (proliferation, contamination dominate)

Environment code

- Criticality as a hazard is not mentioned
- Potential consequences of various criticality events?
- If criticality risk is dismissed, it should be supported
- Neutron radiation is dismissed, without support
- The incentives for recovery of Cu, U or Pu
- Storage, not disposal
  - Likely recovery within 100 years, certain in 1000 years
  - Siting consideration?
  - Resources required for recovery versus copper value
  - Non-proliferation – Today and in future

Acts on nuclear activities and Radiation Protection

- The potential consequences of a criticality
- Some criticality probabilities should be estimated
- Barriers from criticality should be defined
- Safety to be based on one or more parameters, not k_{eff}
- Burnup credit (BUC) method validation is important
- Recent BUC standards, guides and methods

Preliminary conclusions

- Criticality is not possible without water
- Burnup credit is required if water can enter canister
- Validation of burnup credit requires utility input
- The criticality risk can be made very low
- Shielding can be a mitigating factor in a criticality
- International studies support low criticality risk
- Alternatives, e.g. transmutation, may change situation
- Incentives for recovery of canisters? Keep ALARA
- If low likelihood of repository closure: Siting?

Questions?