INNOVATIVE, RELIABLE, HYDROGEN RISK MITIGATION SYSTEM FOR TRANSPORTATION OF RADIOACTIVE MATERIALS

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LOGISTICS

Reliable Hydrogen Risk Mitigation System for Transportation of Radioactive Materials

► Summary:

- RADIOLYSIS EFFECT IN TRANSPORT AND STORAGE CASKS
- TNI RADIOLYTIC HYDROGEN RECOMBINATION SYSTEM
- TNI / SNPE OXYGEN GENERATOR
- ELECTRONIC SEQUENCER
- RELIABILITY AND SAFETY OF THE HYDROGEN MITIGATION SYSTEM
- CONCLUSION

Radiolysis Effect in Transport and Storage Casks

► **Subject:**
- **Radioactive waste transportation**
- **Mixture of radioactive materials and water/organic waste leads to Radiolysis**
- **During transport, radiolytic gas builds up in the cask cavity**
- **Hydrogen amount to stay below the flammability limit of 4% in ambient air**
- **In conformity to safety regulations IAEA TS-R-1**

Radiolytic Hydrogen Recombination System

- Solution developed by TNI R&D:
  - TN® Comb-A+ Hydrogen recombiners
- Characteristics of TN® Comb-A+ hydrogen recombiners
  - H_2 recombination in dry conditions
  - Catalyst of hydrogen oxidation (exothermal reaction):

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

  - Presence of oxygen within the gaseous mixture is necessary
  - Note: Even if the recombiners are damaged in accidental conditions, which is unlikely, the accessible surface of the recombiners will not be decreased so that their efficiency will be maintained.

Qualification of TN®Comb-A+ Hydrogen Recombiners

- For qualification, laboratory tests on hydrogen recombiners were performed to determine:
  - Hydrogen recombination properties (quantity and kinetic)
  - The effect of different parameters on the hydrogen recombination :
    - Temperature up to 150°C
    - Irradiation from radwaste
    - presence of radiolysis gases other than hydrogen: CH_4, C_2H_6, CO, CO_2, HCl, I_2.
- TN®Comb-A+ has been especially developed for recombination of Hydrogen in presence of carbon monoxide

Qualification of TN®Comb-A+ Hydrogen Recombiners

- **Results of laboratory tests: Amount of TN®Comb-A+ needed to recombine 1 mole of H_2 in presence of carbon monoxide**

Temperature °C	25	45	65	>65
Amount of TN®Comb-A+ (grams) needed to recombine 1 mole of H_2 in presence of carbon monoxide	81	66	38	38

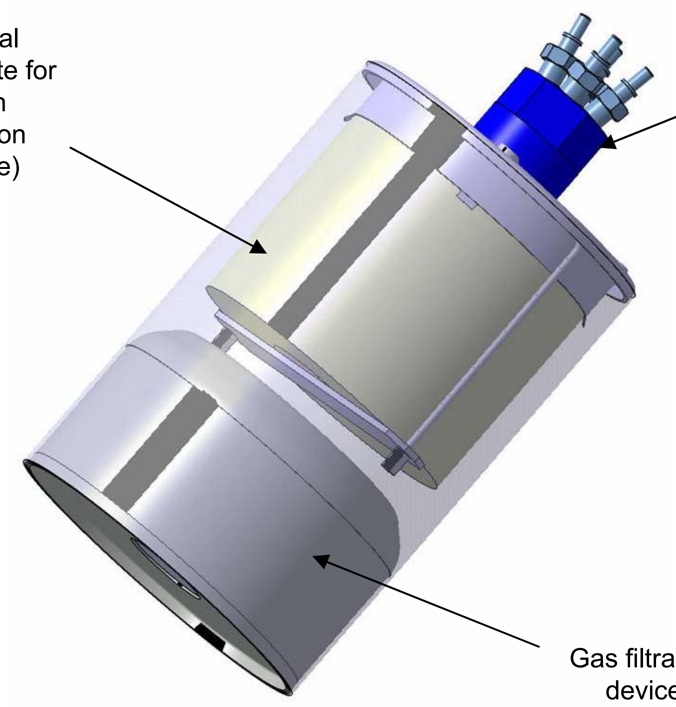
- **Easily compatible with the space available in the casks**

Limitation of the Recombination System and Research of Innovation

- Limitations of $TN^{®}$Comb-A+ recombiners
  - After some transport time all the oxygen is used
  - When insufficient or no oxygen is produced: i.e. radiolysis of organic waste, for example the H-C polymers
- Associated risk
  - Reaction $H_2 + ½ O_2 \rightarrow H_2O$ is stopped
  - Flammable mixture in containment vessel
- An innovative solution
  - Idea: Use another source of oxygen
  - TNI together with SNPE and ELTA has developed an oxygen generator

Oxygen Generator

- **Oxygen generator has been developed by SNPE**



Solid material

O_2 Capacity 600 l

Electrically activated

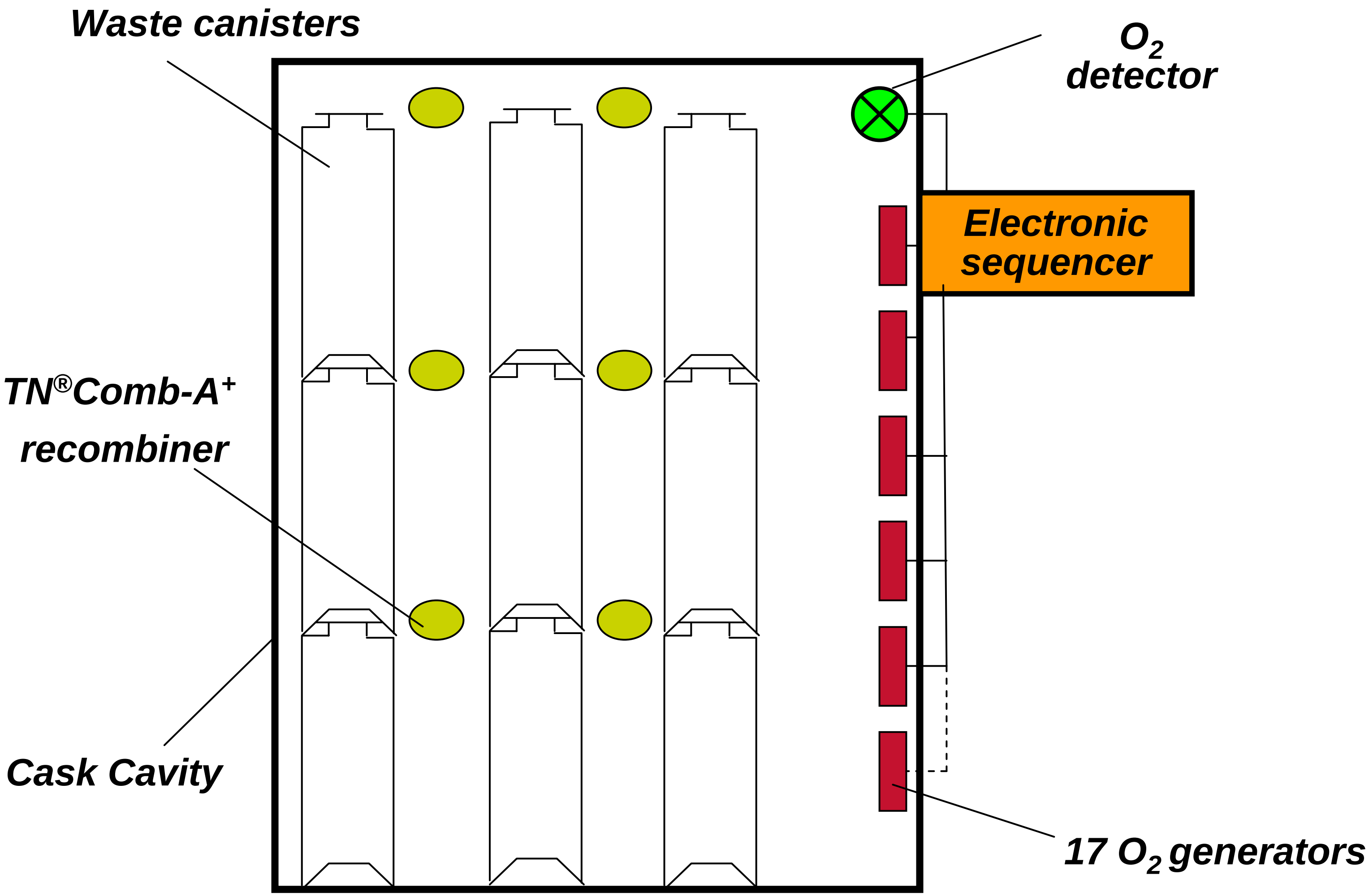
Oxygen Generator

- **Performance vs need**
  - **Case of 3 m^3 vessel, with H_2 production = 2.14 mol/day**
  - **1-year transport requires 17 Oxygen generators (17 generators of 600l correspond to 408 days of recombination)**
- **Tests and qualification**
  - **Resistance of the oxygen generator was tested under different preparation and transport conditions**
  - **Vibration, shock, temperature (-40°C to 135°C)**
  - **Low pressure (package leak tests)**
  - **Accident : no oxygen release**

Oxygen Generator System
General Design

- **How to cover 1 year of oxygen demand ?**
  - **Excess of oxygen not acceptable**
  - **Need to provide oxygen for recombination only**
- **Design of Oxygen generator system, main components :**
  - **Oxygen detector detects the minimum O_2 concentration below which, additional O_2 is required. Concentration 5% leaves sufficient time to react in case of accident.**
  - **Electronic sequencer links the detector to oxygen generators Rule : only 1 generator is initiated for each signal received**
  - **N oxygen generators in cask cavity; N depends of the need; in previous example, 17 generators are necessary to meet the need = 2.14 mol/day of H_2 production**

Hydrogen Mitigation System - Basic Design



Electronic Sequencer

▶ Example

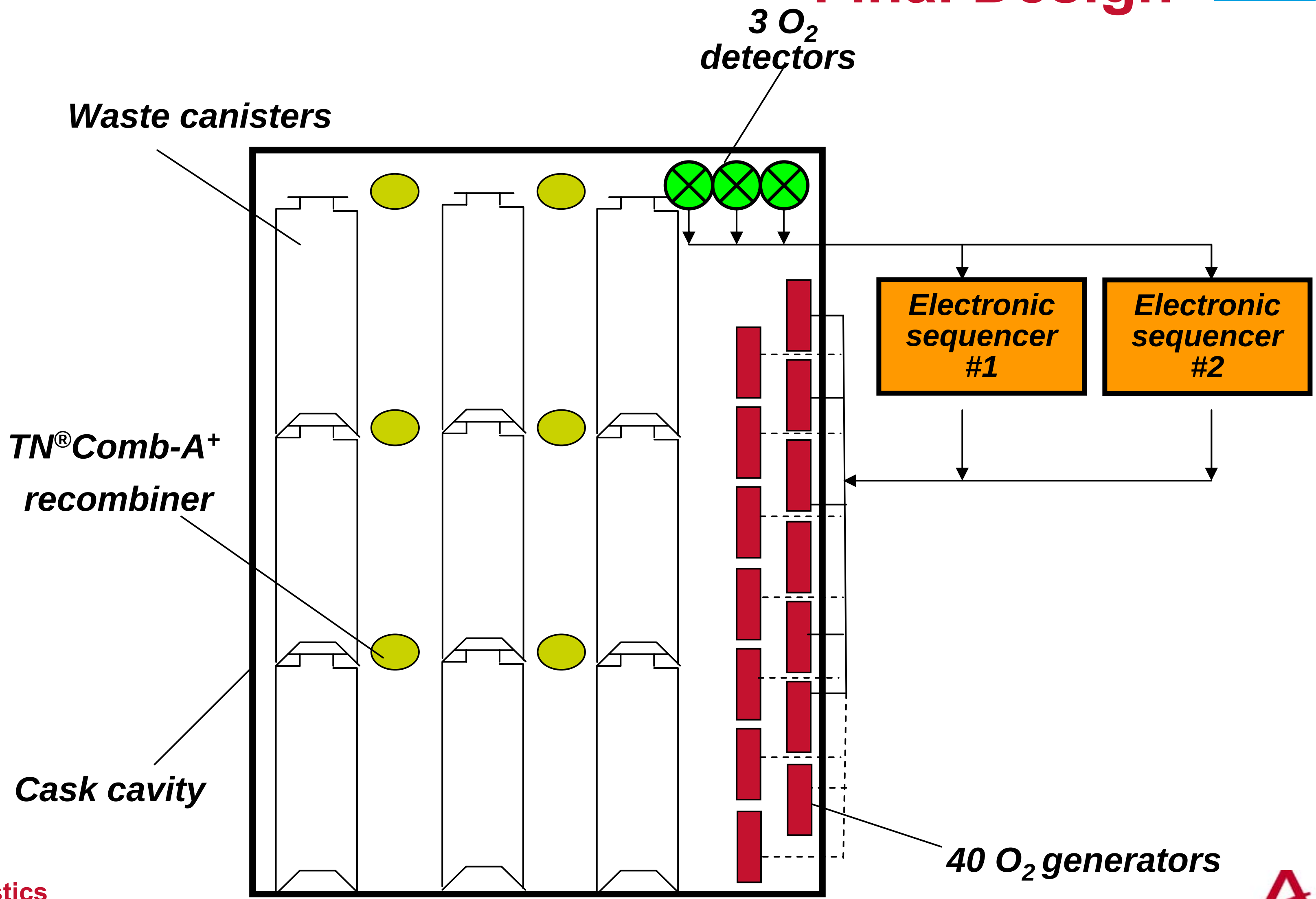
Gaseous environment	Oxygen detector	Oxygen generators								Sequencer indication
$[O^2]>5\%$	0									N
$[O^2]\sim 5\%$	1			i						N+1
$[O^2]\sim 20\%$	1									N+1
$[O^2]>5\%$	0									N+1

Reliability and Safety of the Hydrogen Mitigation System

▶Probability risk assessment method

- HAZOP method
- Failure : confinement vessel contains either too much hydrogen or too much oxygen
- Compliance with standard IEC/EN 61508 = failure probability less than 10^{-8}/h
- Failure probability of each component of the hydrogen mitigation system has been evaluated
- Consequently sufficient redundancy of oxygen generator in system architecture is required
- Final design after 1 year of transport, the probability reaches $6x10^{-8}$ which is still 3 order of magnitude below the requirement

Hydrogen Mitigation System - Final Design



Logistics

Innovative Hydrogen Mitigation System

▶ Conclusion

- Innovative hydrogen mitigation system dedicated to transportation with large amounts of hydrogen production by radiolysis
- Development and qualification of oxygen generator.
- Reliability and safety of the design of hydrogen mitigation system has been studied
- The probability of failure of the system is bellow standard safety integrity levels with comfortable margin

» If probability risk assessment were more commonly accepted in the area of transportation of radioactive materials, innovation would be enhanced and it would open large perspectives for risk mitigation and safety improvement.