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Management of Damaged Fuel and Fuel Debris Resulting from Severe Reactor Core Melt Accident

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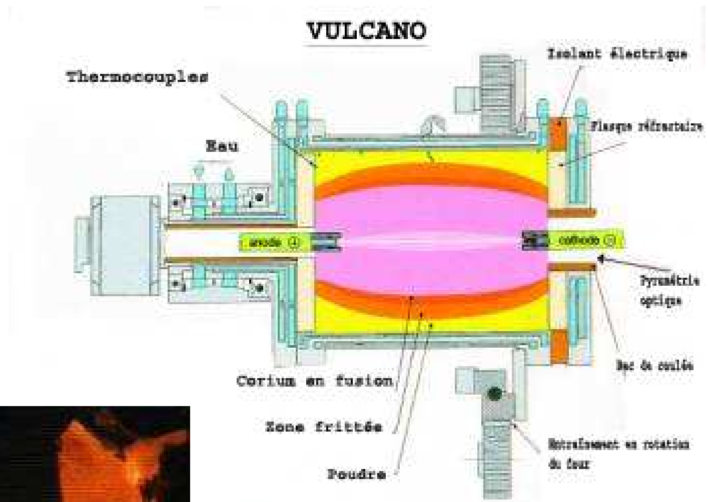
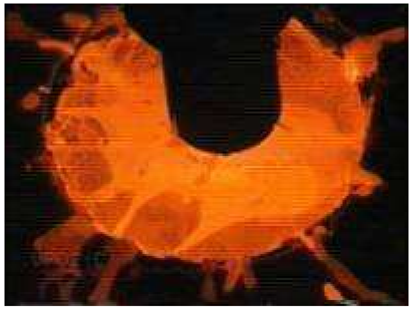
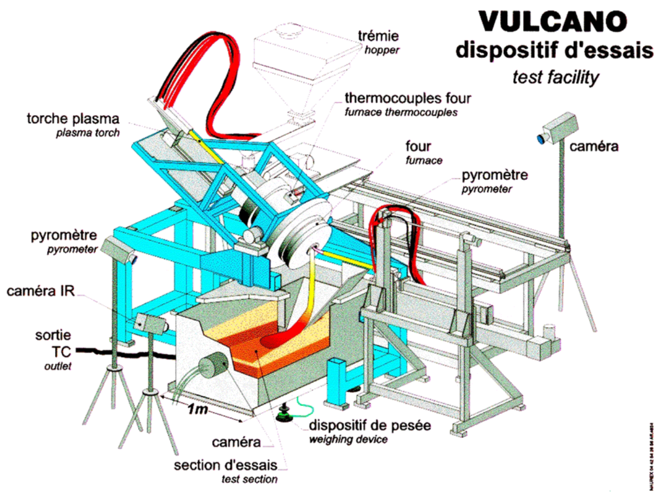
- The operational questions
- The main scientific issues
  - estimation of debris and MCCI products for Fukushima's conditions
  - experimental and simulation studies on debris/MCCI products under Fukushima's conditions
  - stability in geological environment of both fuel debris and MCCI products
  - waste stabilization or conditioning processes.
  - Treatment, reactivity towards aqueous or molten slat media
- Conclusions

CEA activities on damaged fuel

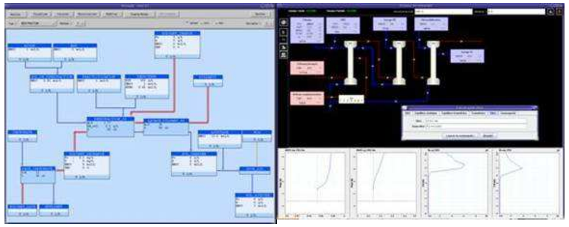
- **Vulcano facility**
  - Production of corium and MCCI products
  - Study of melted fuel solidification
  - Fuel/concrete interactions
  - Thermohydrolics of corium
  - Corium formation in fuel debris
  - All associated characterization and modelling/simulation tools



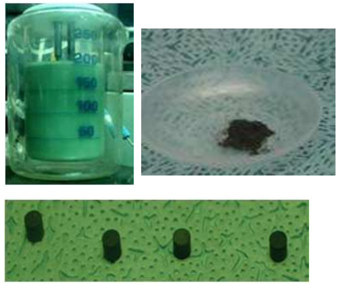




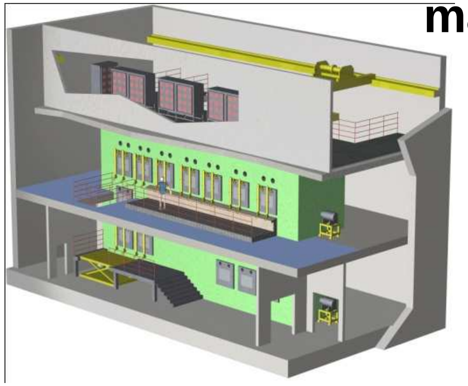
CEA Activities in back-end fuel cycle

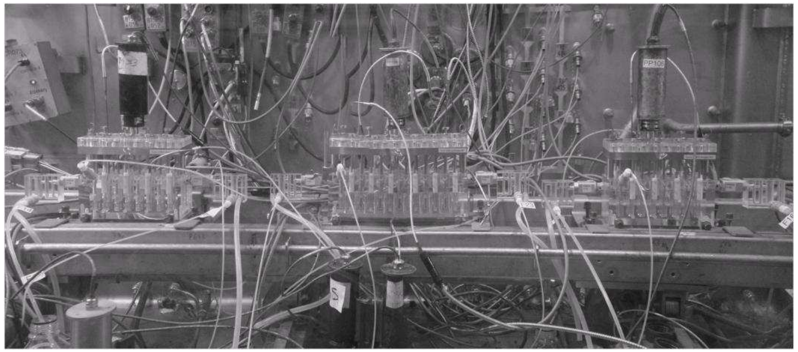


- **Spent fuel reprocessing**
  - Dissolution
  - Process development
  - From liquid to solid for fuel re-fabrication
- **Waste conditionning**
  - Vitrification
  - Confinement of metallic waste
  - Long term performance assessment



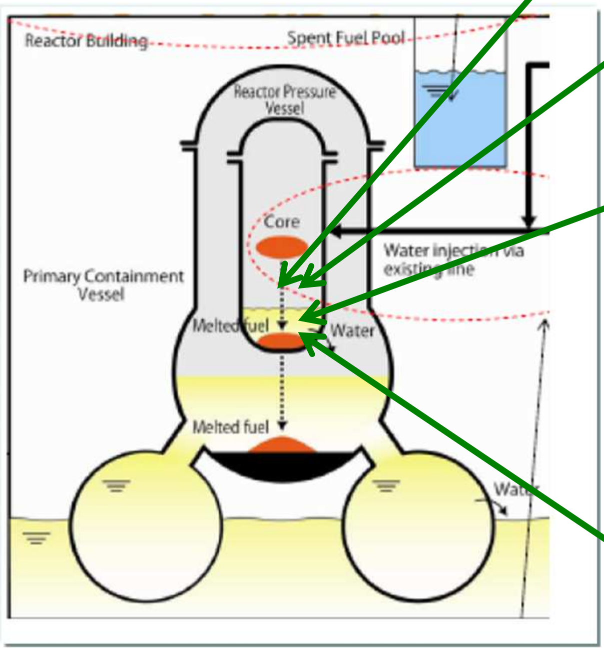
- **ATALANTE – a unique facility for handling high active materials, including irradiated fuels**





The operational questions

The operational questions belong to the industrial operators but we have to define the drivers for the subsequent R&D program prior technical decisions



❶ How to recover the fuel debris to treat them ?

Specific remote-handling/sampling tools

❷ How to characterise the fuel debris ?

- Based on the theoretical knowledge of the system and previous experiments

- Development of specific in-situ tools

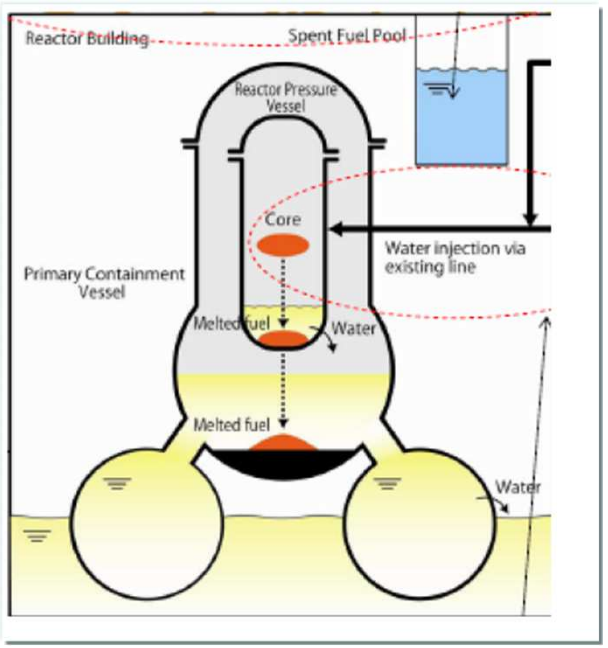
❸ How to condition the fuel debris? What kind of long term performances?

- *What kind of relevant canisters? What kind of relevant matrices?*
- *What about their long-term performances? Is it suitable for a deep repository?*

❹ Is it possible to increase performances and reduce toxicity by implementing a treatment?

- *Relevant treatment processes to develop? Is it worth to recover the actinides?*
- *Relevant hydro- or pyro-chemical processes?*

The main scientific issues – Fuel debris characterization



What do we need?

Initial conditions of the reactor mass of nuclear fuel, zircalloy mass, composition and mass of structural materials, source term, concrete composition and amount of steel bar, time and amount of eventual mitigation, pit geometry,

1F exact conditions ("Best Estimate") during the first days of the progression of severe accident: water temperature, pressure, injection of water

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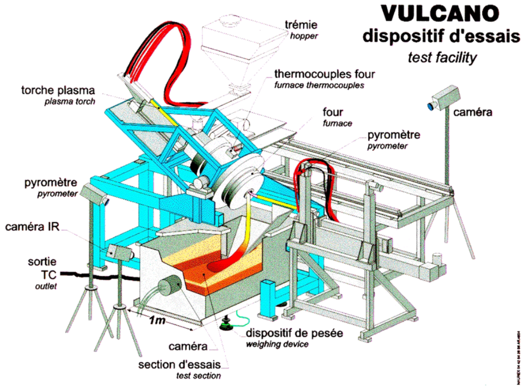
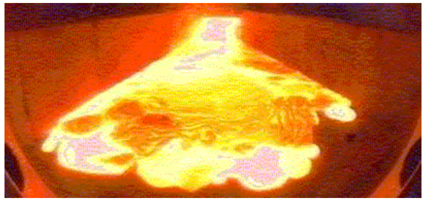
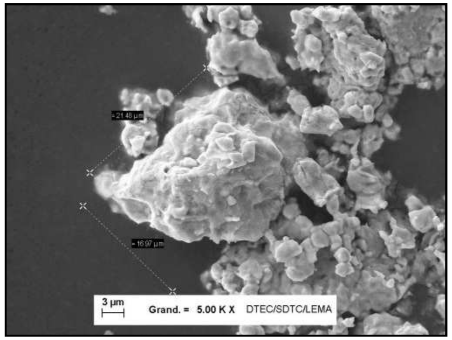
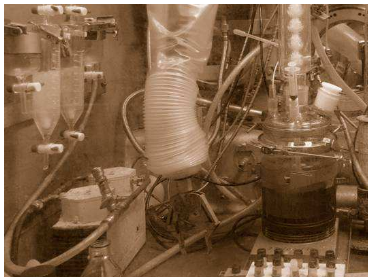
The main scientific issues –
Fuel debris characterization





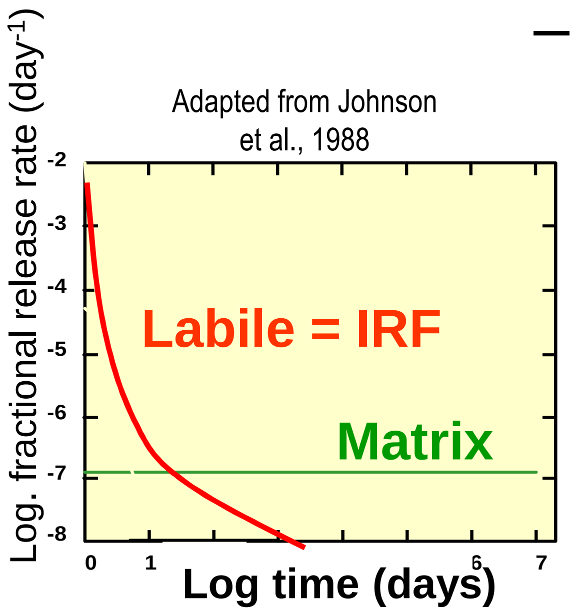
- **Physical characterization**
  - For a better knowledge
- **Chemical composition**
  - Representatitivity of the samples
  - Total dissolution
  - Will help to select the processing conditions
- **Modelling, simulation**
  - MAAP or/and MELCOR evaluations





The main scientific issues – fuel debris conditioning (1/2)

- **Long-term performances:**
  - Assessment of the anticipated performances in a deep repository
    - Necessary to develop a source term model to perform the performance assessment of the deep repository.



  - First trends could be derived from the current knowledge on spent nuclear fuel performances (french PRECCI project):
    - Main issues to address: assess the respective Instant Release Fraction (IRF – which inventory?) and matrix contribution (which release rate?).
      - IRF anticipated to be very low for corium (Grambow & Poinssot, 2012) but what about MCCI products?

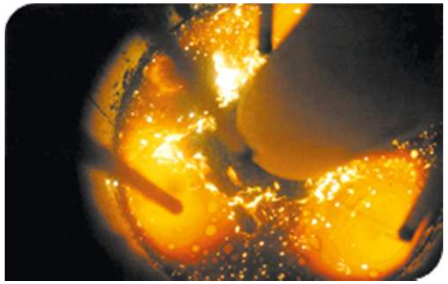
The main scientific issues – fuel debris conditioning (2/2)

- **Conditioning: wasteform to be defined**
  - Direct conditioning of fuel debris debris and MCCI products in dedicated canisters?
  - What kind of blocking matrices?
  - Core samples to be embedded in a specific matrix?

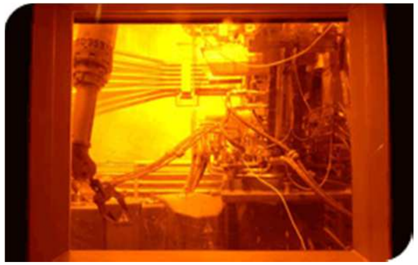
- **Pretreatment to reduce the fraction of waste with very low performance?**

The main scientific issues – fuel debris treatment (1/5):

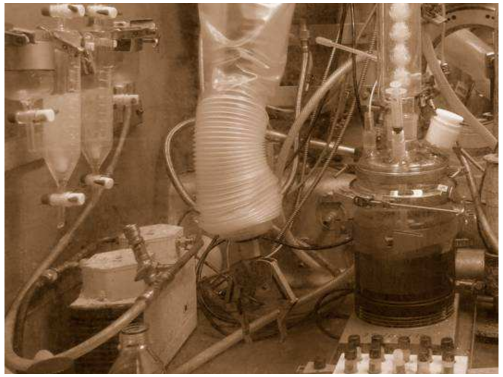
- **fuel debris treatment can meet two objectives**
  - Replace low-performance and ill-known debris by a highly-confining matrix : nuclear glass (key issue)
  - Decrease the radiotoxic inventory to be disposed of (added value)

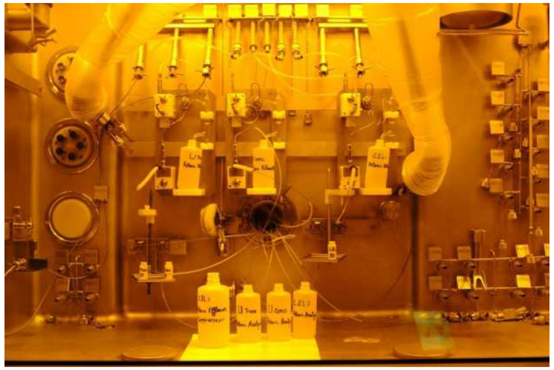


- **Two options have to be considered**
  - Specific process to develop
  - Specific head-end process to develop to allow subsequently using the existing processes (such as PUREX, UREX…)



The main scientific issues – fuel debris treatment (2/5):



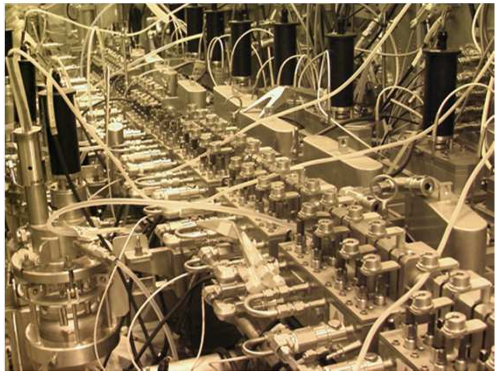


Several steps to consider specifically

- Head-end steps
  - Quantitative dissolution
  - … Or a selective one…
  - Oxidation/reduction
- Core process
  - Selective recovery of main components (uranium)
  - Further separation?
  - Derive a specific separation scheme from the current experience and skills in actinide separation science

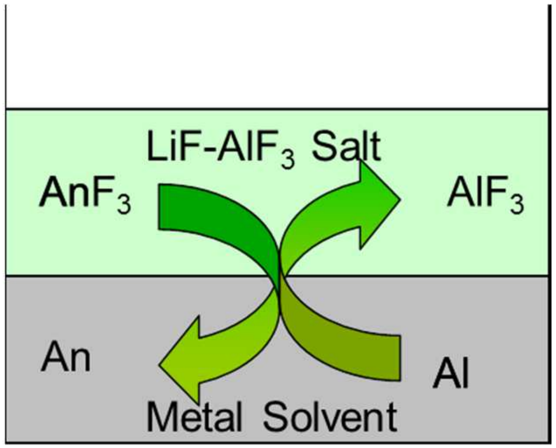
The main scientific issues – fuel debris treatment (3/5):

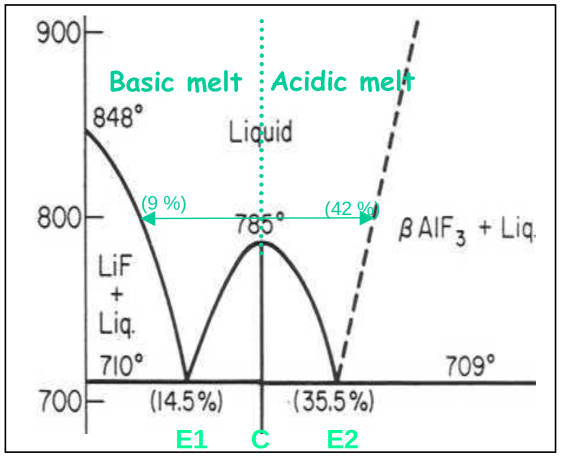
- **Aqueous treatment:**
  - processes developed for U-Zr or CERMET fuels could be applied: NIFLEX, ZIRFLEX processes…
  - Corrosion issues to be addressed !
  - Compatibility with further U separation processes to be addressed



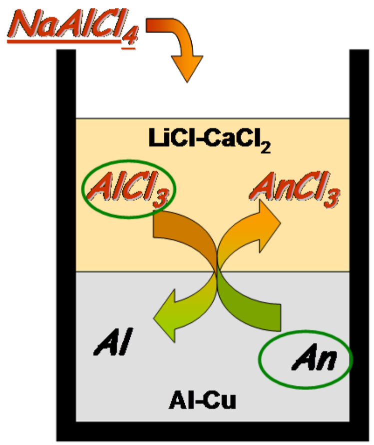
The main scientific issues – fuel debris treatment (4/5):

- **Pyrochemical treatment**
  - Lab-scale test performed at ANL in the 90's on synthetic sample: reduction by Li followed by U refining.
  - Electrochemical pre-reduction?
  - An alternative process in fluoride based on reductive liquid-liquid extraction?

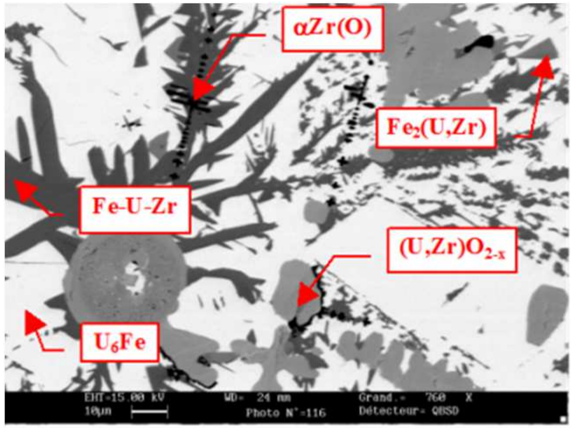




LiF-AlF_3 system, J.L Holm and B.J Holm, *Thermochim. Acta*, 6 [4] 375 (1973)



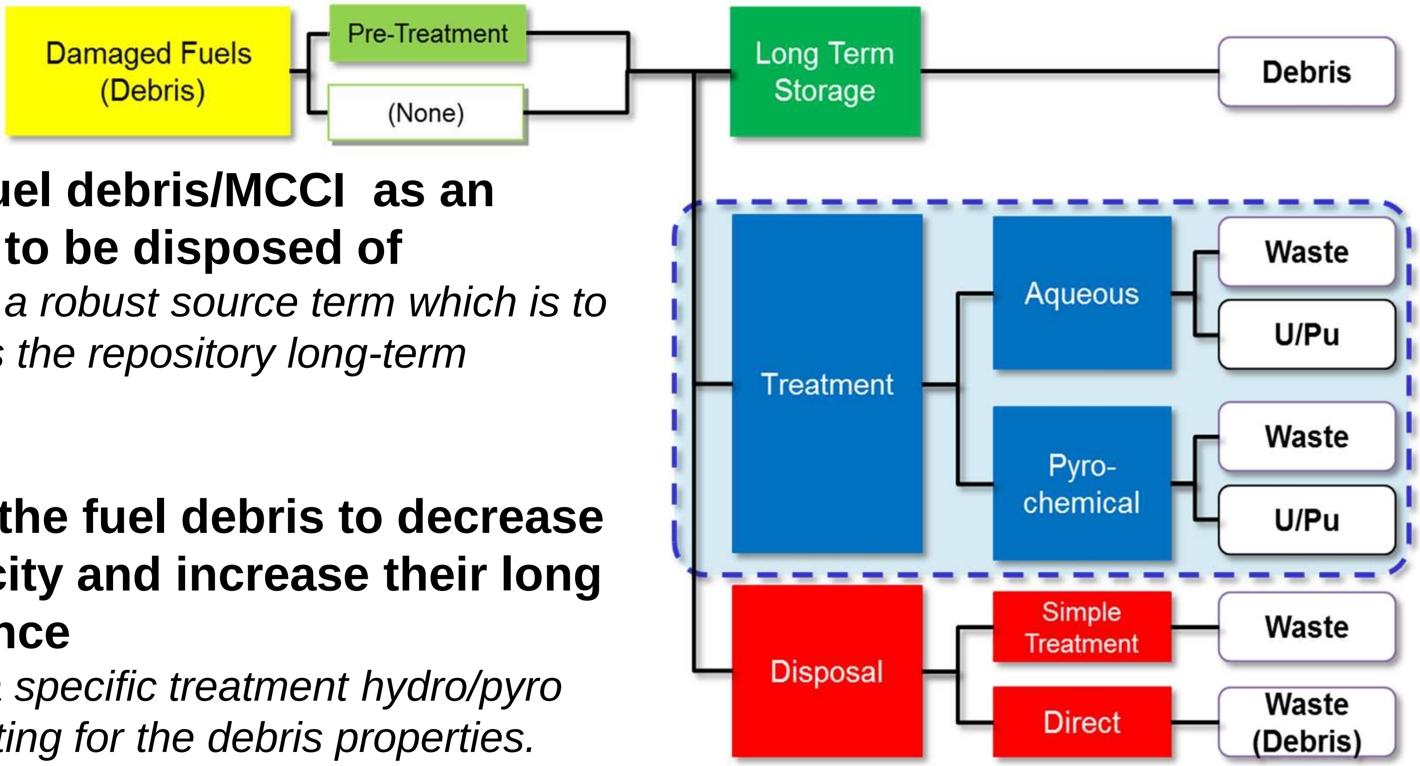
The main scientific issues – fuel debris treatment (5/5):



- **Some specific issues to address**
  - Zirconium chemistry and impact of metallic elements
  - Impact of the elements produced by the interactions with concrete
  - Influence of sea salts on the chemical processes
  - Ensure the safety and the non-criticality

Conclusion

Two main options have to be considered for the long term management of fuel debris, each of it requiring specific R&D programs:



Courtesy of JAEA

- **Consider the fuel debris/MCCI as an ultimate waste to be disposed of**
- *Needs to develop a robust source term which is to be used to assess the repository long-term performance*

- **Chose to treat the fuel debris to decrease their radiotoxicity and increase their long term-performance**
  - *Either develop a specific treatment hydro/pyro process accounting for the debris properties.*
  - *Either develop a specific head-end steps to allow the coupling with the current PUREX process*

Conclusion

Whatever the selected option or combination of options,
they should remain as simple as possible
in order to **produce waste suitable for**
long term repository or deep geological disposal,
and not to lead to the development of very complex options
for the recycling of these materials,
which will never be applied.

Thank you for your kind attention