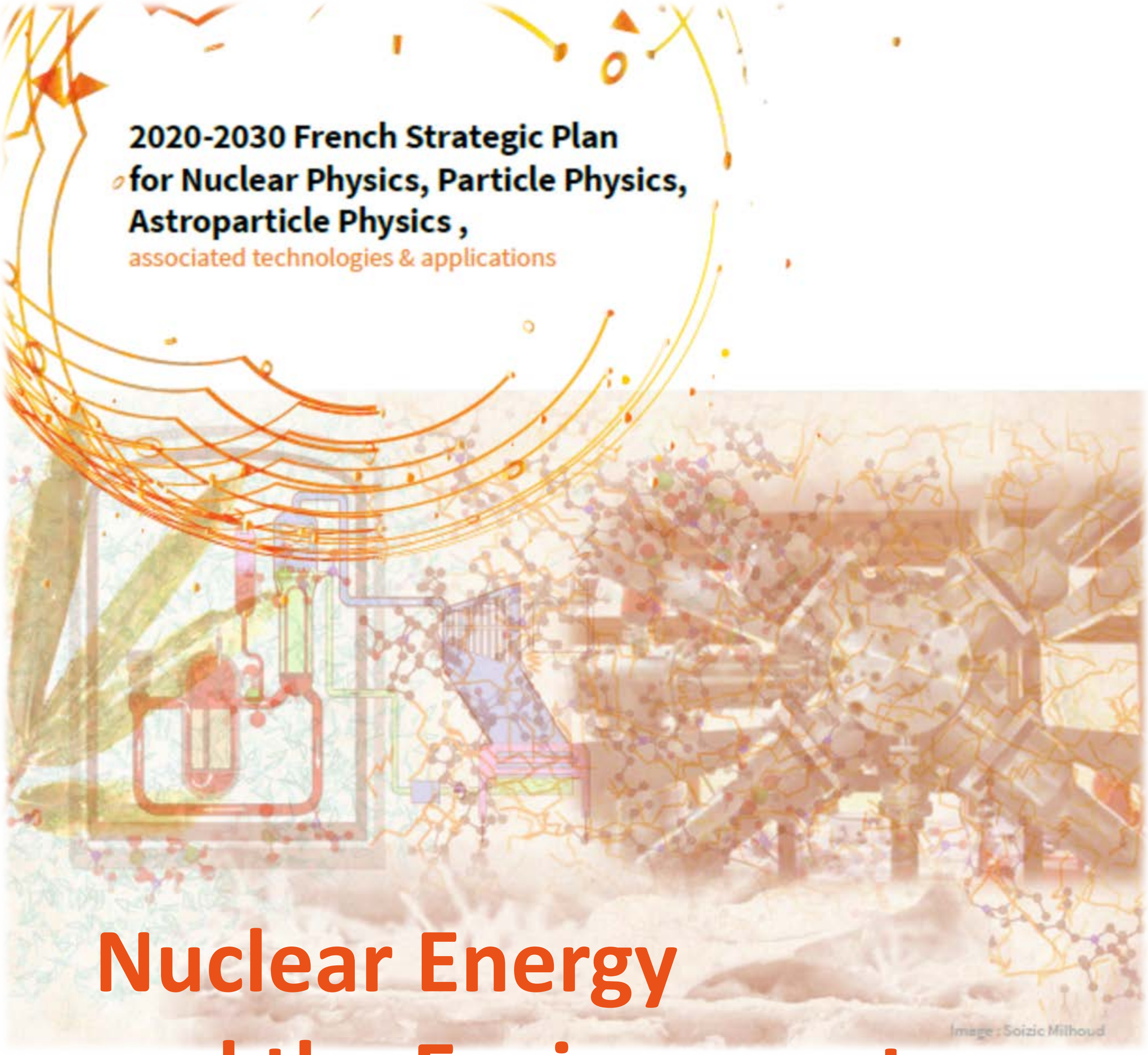

Nuclear Energy and the Environment

GT11 working group

" Facing the present and future nuclear energy challenges "

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Summary

1. **Introduction:**
   Nuclear Energy and the Environment at IN2P3
   The GT11 work

2. **The prospective exercise:**

   2.1 Reactor physics and scenarios

   2.2 Nuclear materials, radiochemistry and chemistry of the nuclear fuel cycle

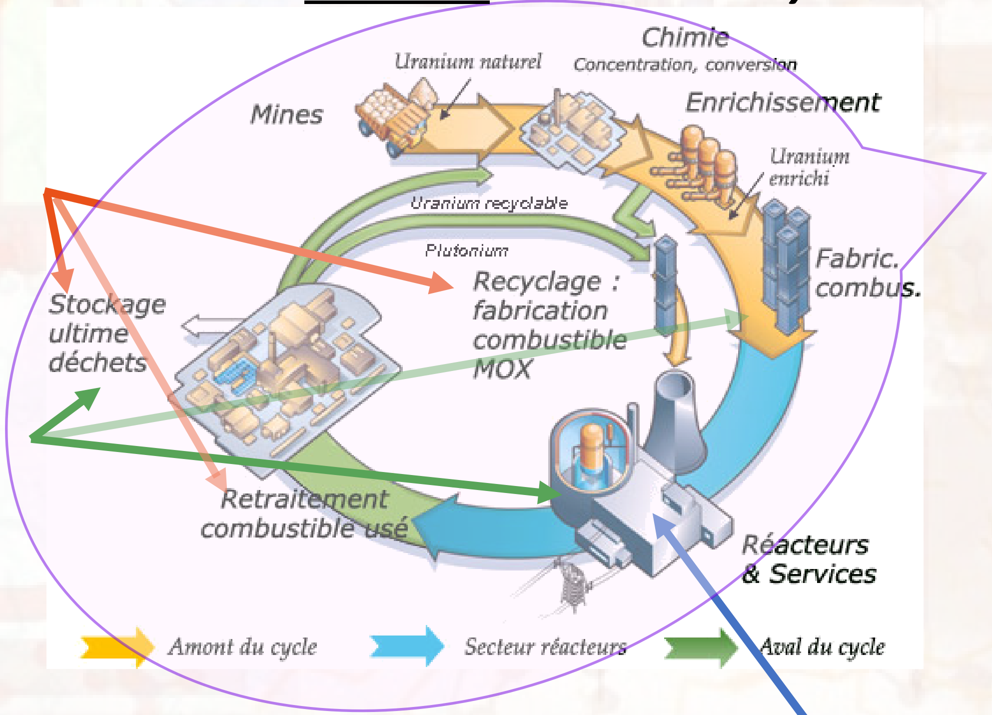
   2.3 Radioactivity and the environment

3. **Conclusions and recommendations**

1. Introduction:
Nuclear Energy and Environment at IN2P3

Perimeter addressed and main associated fundamental topics:

Present & Future nuclear industry



Nuclear materials, radiochemistry and chemistry of the nuclear fuel cycle

- Radiation damage mechanisms - Understanding of microstructural evolution
- Material behavior at solid/liquid, and liquid/gas interfaces (radiolysis, corrosion, dissolution)
- Physico-chemistry of actinides

Behavior and impact of radionuclides (RN) in the environment

- Measuring / mapping radioactivity
- Speciation of radioelements
- Mechanistic description of the behavior of radioelements

Nuclear reactors and associated nuclear data

- Nuclear data measurement, modelling, evaluation
- Neutronics and thermohydraulics models, sensitivity analysis
- Interdisciplinary scenarios

➔ Programme : Sciences Nucléaires pour l'Energie et l'Environnement

Who at IN2P3

- physicists, physico-chemists, chemists (radiochemists, theoretical chemists) ~100 researchers+ 75 docs & post-docs
- technical staff involved in our experimental tools and facilities (design, construction, operation, maintenance), *GT7, GT8*

Our collaborators (France)

- **CNRS**: INC, INP, INEE, INSU + **Universities**
- **CEA, IRSN, EDF, FRAMATOME, ORANO, ANDRA,…**

…But also with foreign labs !

- Not listed here…

Frames (& funding agencies)

- France: NEEDS, MITI, Institut Carnot, ANR, PIA4
- International: EURATOM, IAEA, OECD/NEA, Rosatom, Forum Gen IV

➡ **70% of the funding provided by agencies external to IN2P3**

National federation

- Creation of the **GDR SciNEE** (Sciences Nucléaires pour l'Energie et l'Environnement) in 2018
- Atomistic modelling : Interaction between the IN2P3 players, creation of the RCT MP and involvement in the creation of the **large-scope FR ThéMoSiA in 2021**
- EMIR accelerator Research Federation since 2014, **EMIR&A renewed as RI in 2021 !**

We share:

- **Scientific approach:**
    - **Need to acquire fundamental data**: nuclear data, chemical and physical properties,…
    - Improvement and development of modelling : **multi-scale and multi-physics**, moving towards **predictive models**
    - Model **verification and validation** thanks to experiments, case studies, benchmarks

- **Requirements:**
    - Access to **calculation/computing tools** and software (*GT9*)
    - **Experimental facilities** (irradiation and characterization platforms and instruments, workshop zone) and related network (EMIR&A)
    - Access to **national and international facilities** (JRC Geel, GANIL, GSI, SOLEIL, ILL, …)
    - **Multi-disciplinary cross view** inside the GDR SciNEE (Sciences Nucléaires pour l'Energie et l'Environnement)

1. Introduction: Nuclear energy and the environment at IN2P3

French context and more: topic with a high societal impact

- **The context around nuclear energy research has changed since the end of the 90's:**

- Piloted by the 1991 and 2006 laws, **related to the nuclear waste management strategy** : partitioning, transmutation, waste packaging, surface storage, deep geological repository

- Post Fukushima (2011)
- LTECV + SNBC (Loi de Transition Energétique pour la Croissance Verte, Stratégie Nationale Bas Carbone, 2015): **nuclear energy is a key energy to lower the CO2 emissions**
- Regain of control from CSFN (Comité Stratégique de la Filière Nucléaire)
- PNGMDR (French public debate)
- Stop of the project ASTRID (2019) restructuring of the CEA/DEN ➔ CEA/DES …

- **Academic approach**:
  - Our labs started with studies on innovative systems (Accelerator Driven System, Molten Salt Reactor) and a strong involvement on transmutation and the nuclear waste disposal issue
  - ➔ Today's activities are **more versatile and upstream to meet the evolution of the needs**
  - ➔ Also a strong national issue on high level training & education in nuclear energy: **IN2P3 UMRs are strongly involved in engineering schools, bachelors, masters**

Future challenges are many:

- Nuclear waste: still an issue: conditioning and confinement
- Safety: ageing of current reactor
- Spent fuel reprocessing
- MOX multi-recycling chemistry
- Impact of cycle discharges on the environment (from the mine to the disposal facility)
- Future nuclear fuel cycles
- Nuclear systems beyond current PWRs
- Innovative materials for future reactors
- Place of nuclear power in an energy mix in transition
- Dismantling and remediation

To play a role in meeting these challenges we need:

- To deepen understanding and modelling of **fundamental processes**
- To **address specific needs** of current and future issues (still evolving !)
- To keep **high degree of flexibility and versatility with regard to the objectives**, and therefore to improve the method to respond to variations in objectives

➔ **Approach reflected in the proposals**

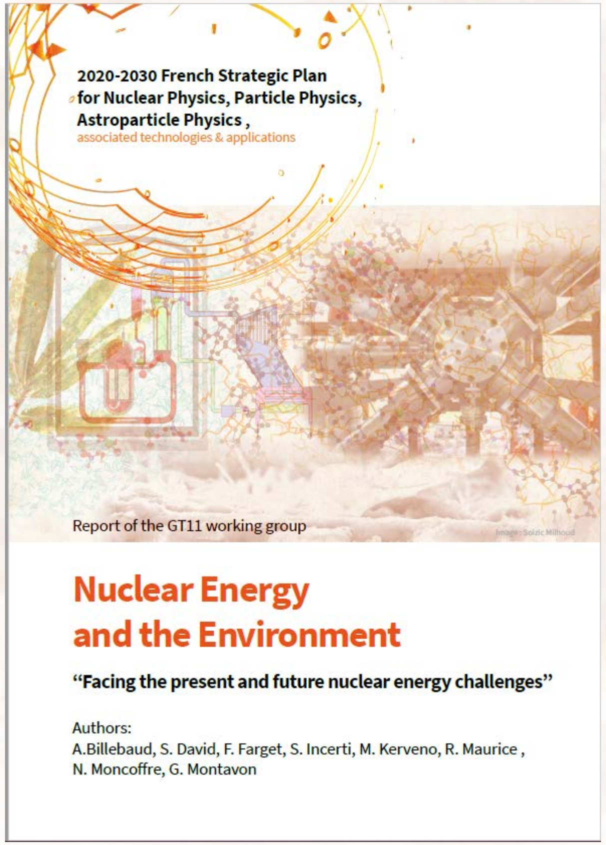
- **Following the call we received 18 contributions**
  - Reactors physics: 4 (2 of them resulting from a collective work)
  - Materials and radiochemistry : 6
  - Environment: 6
  - Others (new energy, communication) :2

- During the GT11 seminar (February 5-6, 2020, IPHC, Strasbourg) we tried to identify the main scientific objectives that may be addressed on the different topics within the 10 years time frame.

- The report issued summarizes the identified areas of work that will drive the new projects and the associated recommendations to carry them out (April 2020).

➔ **To follow: presentation of this synthesis work, associated stakes and recommendations.**

(but does not pretend to represent an exhaustive list of team's activities !)



2. The prospective exercise

Summary:

2.1 Reactor physics and scenarios:

SD11.1: Exploring the potential of nuclear energy for the future and its impact on resources, wastes and costs

2.2 Nuclear materials, radiochemistry and chemistry of the nuclear fuel cycle

SD11.2: Understanding the behavior of current and future nuclear materials in extreme conditions, contributing to nuclear waste management safety and developing innovative methods for fuel reprocessing

2.3 Radioactivity and the environment

SD11.3: Studying the behavior, fate and impact of radionuclides in the natural environment

2.1 Reactor physics and scenarios:

Exploring the potential of nuclear energy for the future and its impact on resources, wastes and costs (SD11.1)

Stakes

- Exploring the potential of nuclear energy for the future and its impact on resources, wastes and costs by
  - building nuclear databases as complete and accurate as possible
  - building relevant modelling of neutron fields at all reactor scales
  - to deepen the safety aspects of innovative concept (MSFR) and adapt the concept to different applications
  - building a modern and interdisciplinary modeling of nuclear scenarios

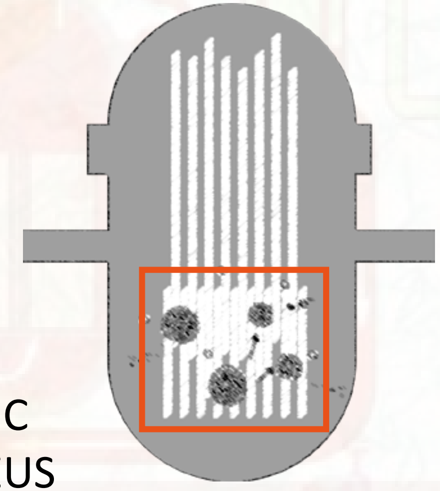
Associated fundamental issues

- Better knowledge of nucleon-nucleus interaction and decay properties of atoms (exp. and theo.)
- Better knowledge of neutronic, thermodynamics, and coupled models… and associated numerical methods
- Innovative reactor physics experiments
- Optimization of reactor models, quantification and propagation of nuclear data uncertainties in scenarios
- Coupling of physical models with a global economic model

Scientific approach: 4 levels of physics scale

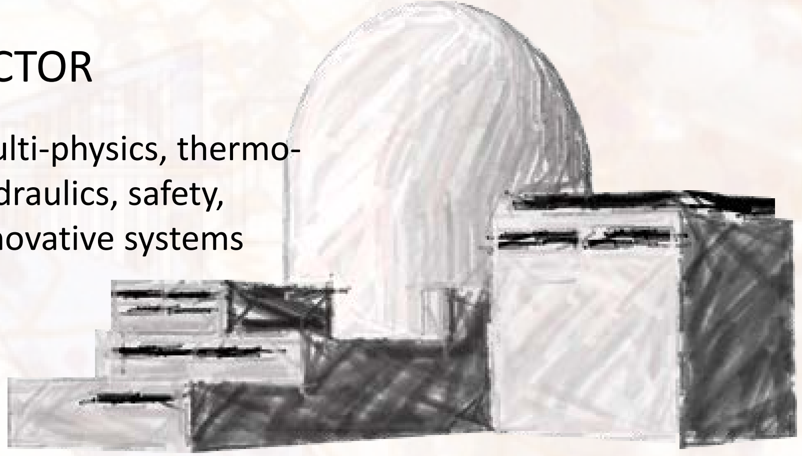
REACTOR CORE

Neutronics, kinetics (exp. & model.)



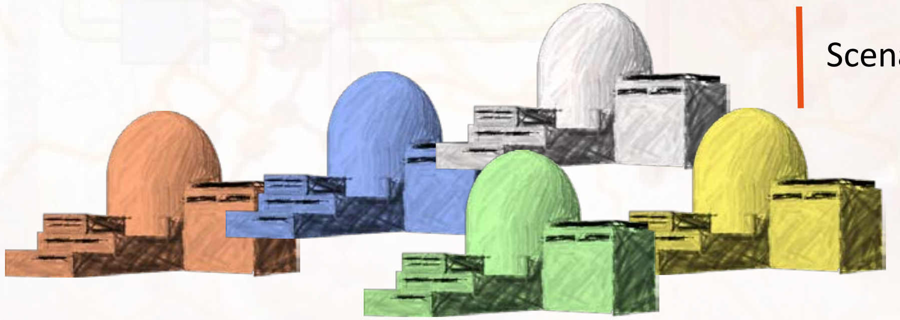
REACTOR

Multi-physics, thermo-hydraulics, safety, innovative systems



REACTOR(S) IN THE FLEET

Scenarios



ATOMIC NUCLEUS

Particles-nucleus interaction and decay studies (exp. & model.)

➔ IN2P3 has the skills and know-how in all these areas : a real asset

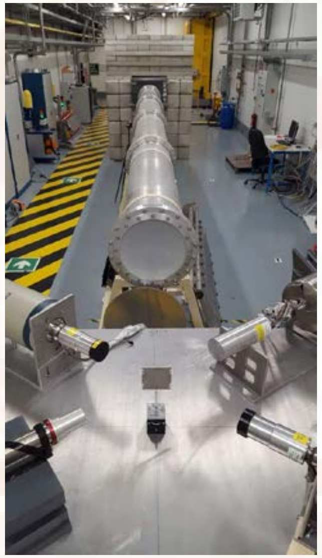
Main axis for the future

- **Nuclear data *(collective proposal)***
- **Reactor physics: open access computing platform of physics models and validation experiments *(collective proposal)***
- **Liquid fuel reactors**
- **Energy and nuclear scenarios**

- **Atomic nucleus: nuclear data**

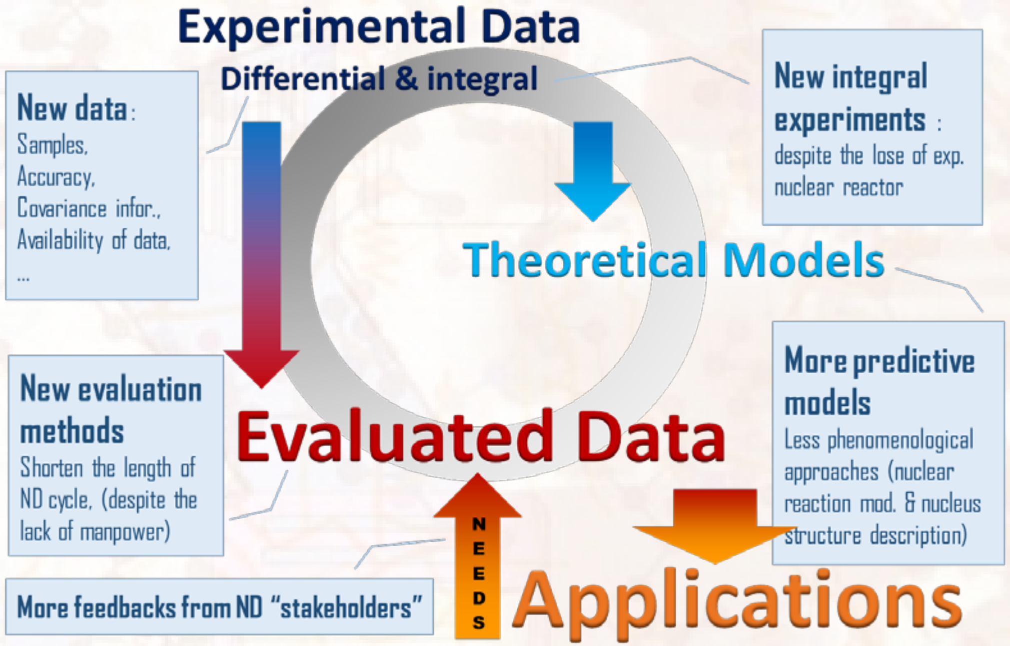
Significant contribution in **Nuclear data measurements** by taking advantage of new facilities (ex NFS) and existing or developing setups.

SPIRAL2/NFS



Contribution in **evaluation** by reinforcing collaborative work with CEA, NEA, and AIEA

Nuclear Data Cycle Issues

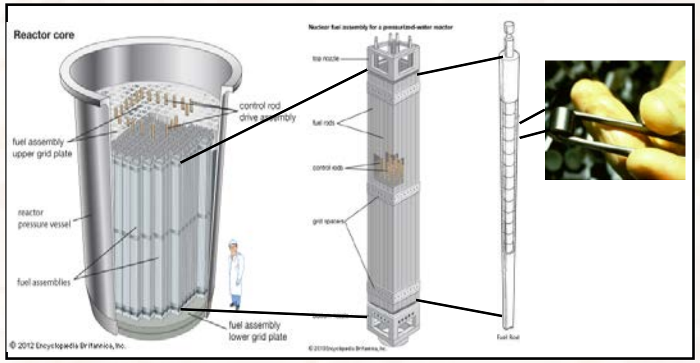


Contribution by taking advantage of collaborative work on **uncertainty sensitivity analysis** with IN2P3 reactor physicists

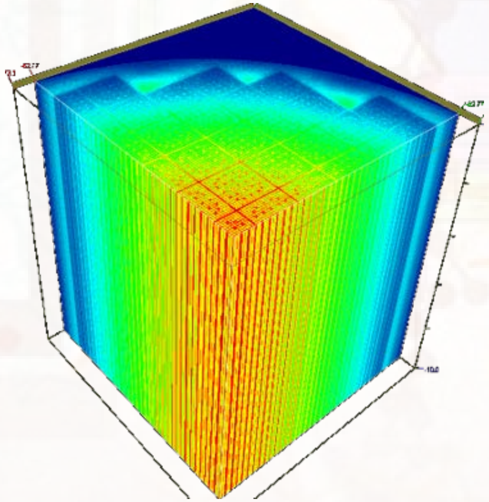
➔ **Nuclear data proposal focusing on measurements, evaluation and sensitivity studies**

- **Reactor physics**

  - **Objectives and associated challenges are evolving**
  - **Needs for versatile tools capitalizing all the know-how acquired so far**



Development of numerical codes: unitary "bricks" of reactor modelling (neutronic, thermodynamics, and coupled models, etc.).

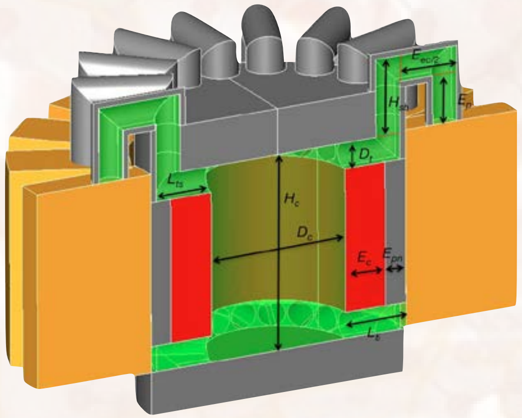


- **Validation** via experiments (in reactor or platform), benchmarks, model to model comparisons (PIA4/BPI SPATIAL project, FEST platform)

- **Feedback** through applied studies (innovative reactors, evolution analysis,…)

➔ **Proposal for building an open access computing platform** which gathers physics models and **validation experiments**

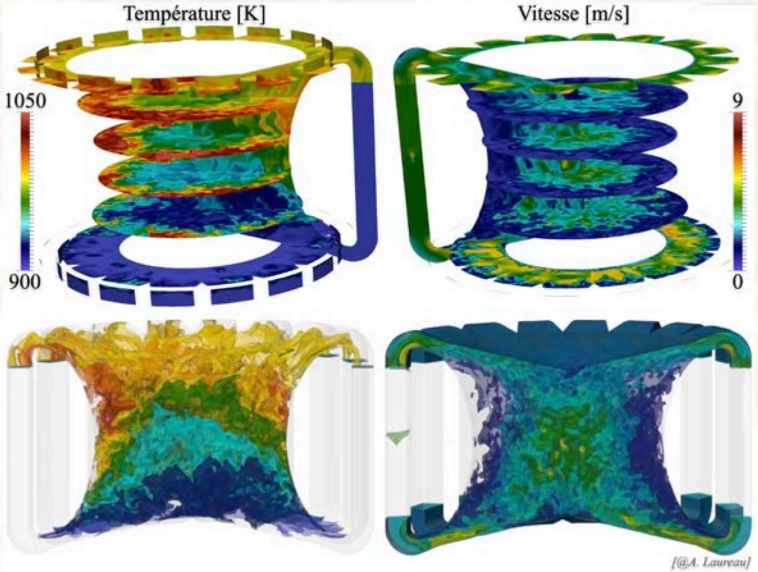
- **Reactor design : Molten salt reactor concept**



- To deepen the **safety aspects** of the concept and adapt it to several **applications**

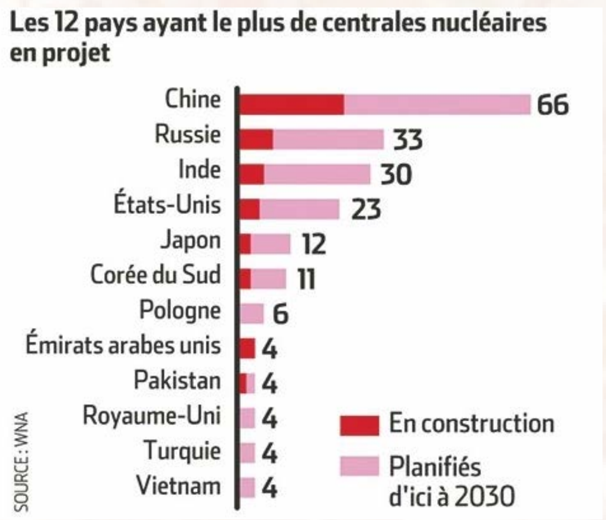
  - Study of severe accident, chemical reactivity of salts, corrosion of structural materials

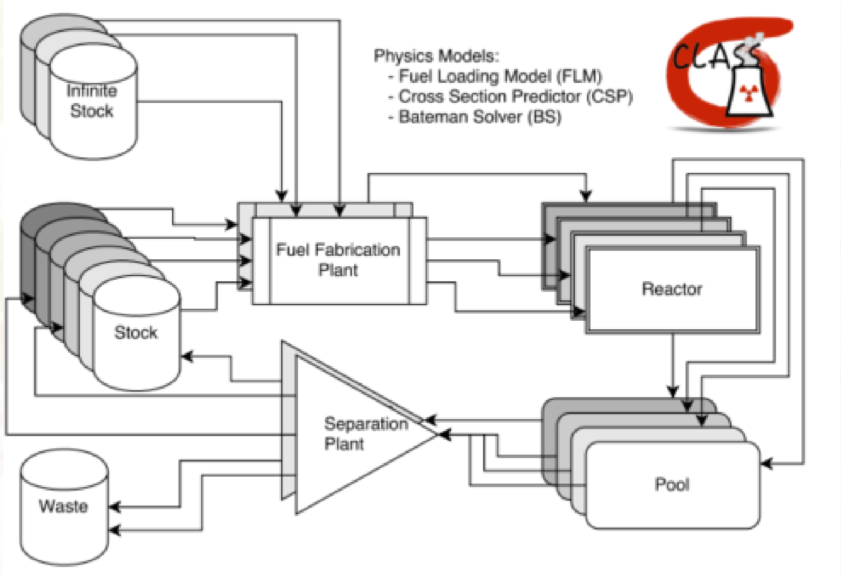
  - Extend the concept to new applications: small MSFR (reduced power), actinides incinerator (PIA4/BPI ISAC proposal)



- **Scenarios**

  - **Modelling the interaction of nuclear power with the rest of the energy mix**
  - **Exploration of the cycles according to societal choices for nuclear power** (resources, waste and Pu management)
  - Refine the **roles and uses of the scenarios**





- Development of Nuclear Scenarios (Reactor and Cycle Physics)
  - Study of nuclear power scenarios with CLASS®CNRS
  - Propagation of uncertainties in cycle studies

- Interdisciplinary workshop
  - on nuclear temporality and political decision making (sociology and physics)
  - to achieve the coupling of physical models to economic models (physics and economics)

2.1 Reactor physics and scenarios

Assets/Strengths

- **Academic approach of the nuclear issue: credit in a societal issue**
- **Collaboration with the main actors (close collaboration with CEA, IRSN) and industrial players**
- **Internationally recognized expertise**

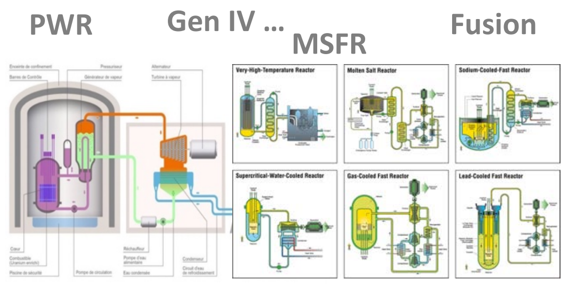
Specific recommendations:

- Maintain instrumental investments and facilitate access to facilities: **JRC Geel, NFS@GANIL, reactors, others…**
- Maintain/consolidate IN2P3's place in European projects
- Manpower:
    - replacement of experimentalists and need for evaluation skills
    - need for reinforcement in numerical physics applied to nuclear energy
- Need for interdisciplinary funding (scociology/economy)

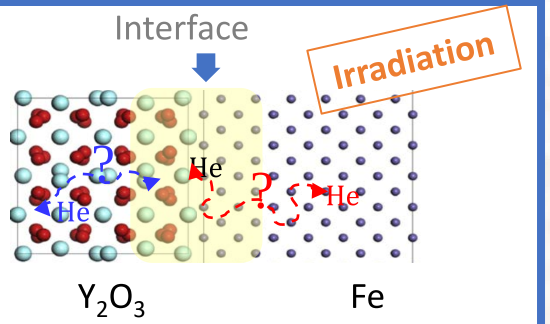
2.2 Nuclear materials, radiochemistry and chemistry of the nuclear fuel cycle

Understanding the behavior of current and future nuclear materials in extreme conditions, contributing to nuclear waste management safety and developing innovative methods for fuel reprocessing (SD11.2)

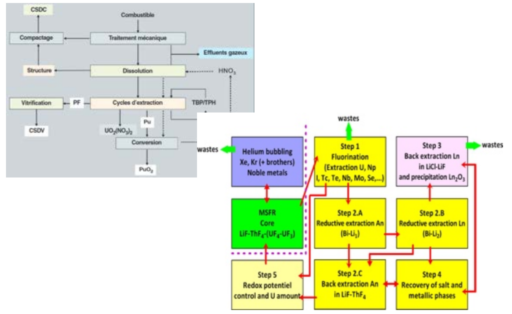
Current and future reactors



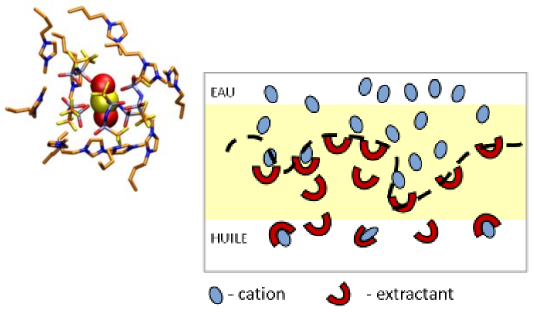
Nuclear materials
Fuel, structures, matrix



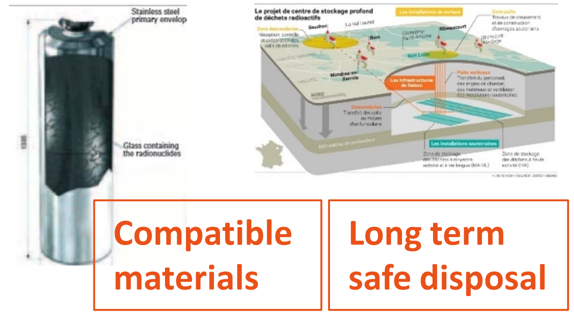
Spent fuel reprocessing



Radiochemistry
Fuel (re)processing



Waste management: Confinement and disposal



Stakes

- Lifetime extension of current PWRs (safety) → Controlling the ageing processes of the present structural materials
- Developing innovative materials for future fission and fusion reactors
- Waste management and recycling of new doped fuel
- Direct disposal: spent fuel chemistry at the interface with Engineered Barrier Systems (EBS)

Associated fundamental issues

- Detailed understanding of the radiation damage mechanisms in solids →Microstructural evolution of materials submitted to irradiation
- Deep knowledge of the material behaviour at the solid/solution, solid/gas interfaces (diffusion, radiolysis, corrosion, dissolution)
- Understanding the dissolution processes in innovative conditions
- Deep knowledge of the physico-chemistry of actinides

Main axis for the future

- **Understanding the behaviour of nuclear materials**
- **Improvement and understanding of waste conditioning for storage safety**
- **Innovative methods for nuclear fuel reprocessing**
- **Instrumentation challenges**

• Understanding the behaviour of nuclear materials under irradiation

Scientific approach

- Experimental simulation of irradiation effects in nuclear materials by using **ion beams**: parametric studies in model systems
- Importance of ***in situ* characterization techniques** at the atomic scale **(Equipex+ DIAPASON 2020)**

Experimental simulation of irradiation effects by using ion beams

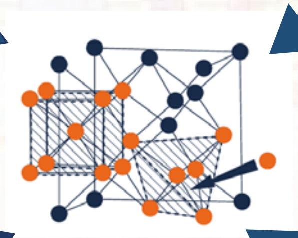
Understanding radiation effects by coupling experiments and modelling

Irradiation effects
- Fission products
- α particles
- Recoil nucleus
- Radiolysis

Irradiation

Low and high energy ions
(100 KeV -100 MeV)

Solid



Modelling

Molecular dynamics, Density functional theory, Kinetic Monte Carlo, Simulation of experimental signals

Irradiation-induced defects, atomic diffusion, physical and chemical properties

Fundamental mechanisms
Diffusion & release
- Gas
- Fission products
- Impurities

Nano-precipitates synthesis

Doping

Stable and radioactive elements

Parameters
Fluence
Flux
Temperature

Characterization (*ex* & *in situ*)
- *Ion Beam Analysis (RBS, channelling, ERDA, ...)*
- *Transmission Electron Microscopy (dual beam)*
- *Thermo-Desorption Spectroscopy, Raman*
- *X-Ray Diffraction*

2.2 Nuclear material, radiochemistry and chemistry of the nuclear fuel cycle

Challenging issues

- **Combined and Synergetic effects**
  - Electronic and nuclear energy deposition on the atomic lattice of materials
  - Between irradiation, temperature and gases
- **Elementary mechanisms** involved in the ion-matter interactions and the processes of reorganisation of solids under extreme conditions
- **Developing innovative multi-scale models**

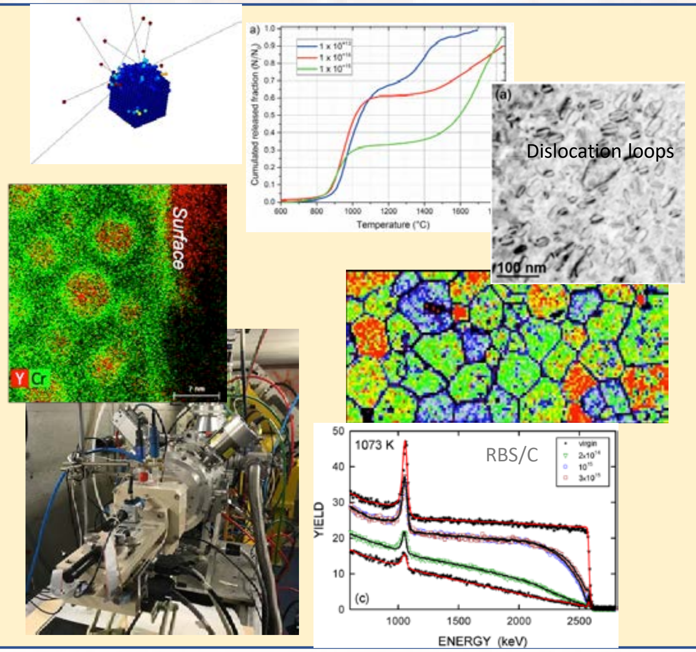
➢ **Coupled irradiation-temperature effects in ceramics**

Fuel, cladding, confinement materials, coatings, *e.g.* UO_2, AlN, fluorapatite, SiC, B_4C, HfB_2…

➢ **Behaviour of steels under ion irradiation - role of surrounding environment (gas, T°C, …)**

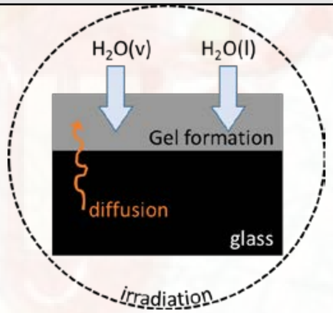
Structural materials *e.g.* advanced ferritic and austenitic steels, stainless steels, oxide dispersed strengthened (ODS) steels, high entropy alloys, …

➢ **Ion beam synthesis of model materials**

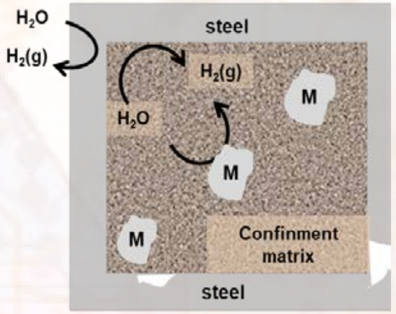


• Improvement and understanding of waste conditioning for storage safety

- Performance duration of the waste package from interim storage to post-closure stage
  - Radio-Physico-Chemical durability
  - Kinetic/Thermodynamic control
  - Dissolution/corrosion mechanisms



- Physico-chemical reactivity of metallic wastes and chemically reactive wastes in conditioning matrices



Mechanisms and kinetics of corrosion of metallic waste M (Al, MgZr, U, Be) and steel drum.

• Improvement and understanding of waste conditioning for storage safety

Existing and new materials
Minimisation of uncertainties

- Characterization and measurement of RNs
  - RNs **d**ifficult **t**o **m**easure (DTM)
  - Refine RNs inventory

- Behavior of gases in the waste packages
  - Diffusion (coefficients, mechanisms)
  - Speciation & Migration
  - Ex: C14 (g), H_2

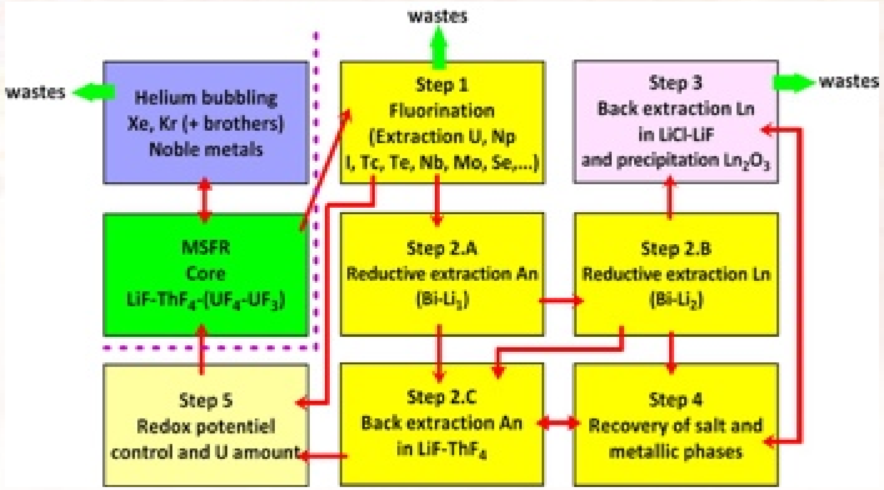
- Modelling from atomic scale to geochemical scale
  - Complex systems including multi-interfaces for RNs migration and transport from waste package to environment

- **Development of innovative methods for nuclear fuel reprocessing** (w.r.t. PUREX):

- In aqueous medium :
    - **Improve** the PUREX (Pu U Recovery by EXtraction) process

- In unusual non-aqueous media :
    - **Molten salts at high temperature** : high solubilization potential, low radiosensitivity of inorganic salts: possible on-line treatment of fuels as soon as they are unloaded
    - **Ionic Liquids at low temperature** (< 100°C) instead of kerosene or dodecane

In particular:
- Study of the chemical behavior (complexation, solvation, redox properties) of radionuclides, in particular lanthanides and actinides, in these media
- Make their selective separation by liquid-liquid extraction, electro-deposition or pyrochemical means.

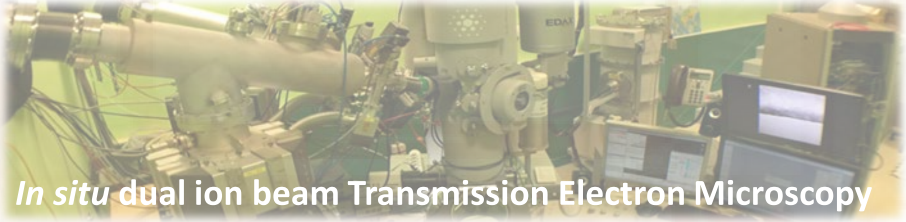


• Instrumentation challenges

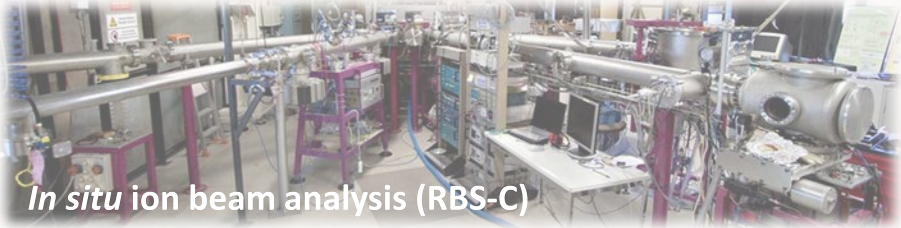
- To keep and improve the **radiochemistry and chemistry facilities**
- To keep irradiation facilities and analysis platforms at **a high level of technical performances** for simulation of irradiation in materials (fission products, alpha particles, recoil nucleus, radiolysis)
- To improve the ***in*** and ***ex-situ*** **microstructural and chemical characterization tools** to study on-line the ion-induced damage and material microstructure evolution

In situ characterization of materials @ JANNuS-SCALP, IJCLab

simultaneously or sequentially during ion irradiation



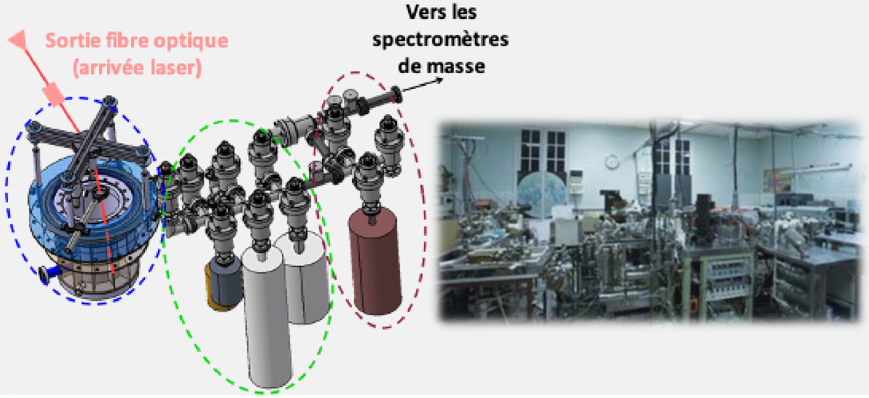
In situ dual ion beam Transmission Electron Microscopy



In situ ion beam analysis (RBS-C)

Ex situ characterization of materials @ CENBG, IP2I, IJCLab

- Raman spectroscopy @ IP2I
- Ion beam analysis (IBA) @ CENBG & IJCLab, Transmission and Scanning Electron Microscopies (TEM, SEM) @ IJCLab
- Elemental and isotopic analysis of rare gases using TDS – AITNA/PIAGARA, CENBG



2.2 Nuclear material, radiochemistry and chemistry of the nuclear fuel cycle

Assets/Strengths

- **Scientific background and technical know-how**
- **IN2P3 advanced irradiation and characterization tools**
- **Existence of hot laboratories**
- **Development of theoretical chemistry in complementarity with experiments**
- **Internationally recognized expertise**

Ion energy

keV — few MeV — few 10s MeV — 100s MeV

JANNuS SCALP — ALTO (Accélérateur Linéaire et Tandem à Orsay) — GANIL SPIRAL2 (laboratoire commun CEA/DRF CNRS/IN2P3)

IRMA, ARAMIS	Tandem beam line	CIRIL@GANIL (IRRSUD and SME beam lines)

EMIR&A — Réseau national d'accélérateurs pour l'irradiation et l'analyse des molécules et matériaux

+ use of other French irradiation facilities:
JANNuS-Saclay (CEA), CEMHTI (INC), LSI (INP-X-CEA), …

Specific recommendations

- Maintain the **technical know how** specific to IN2P3 (chemistry, irradiation and characterization instruments and platforms)
- Support to the **EMIR&A accelerators federation** for irradiation and analysis of molecules and materials (INP-IN2P3-INC)
- Creation of a **joint research infrastructure** (RI) between IN2P3 and INC for the **handling and study of radioactive materials**

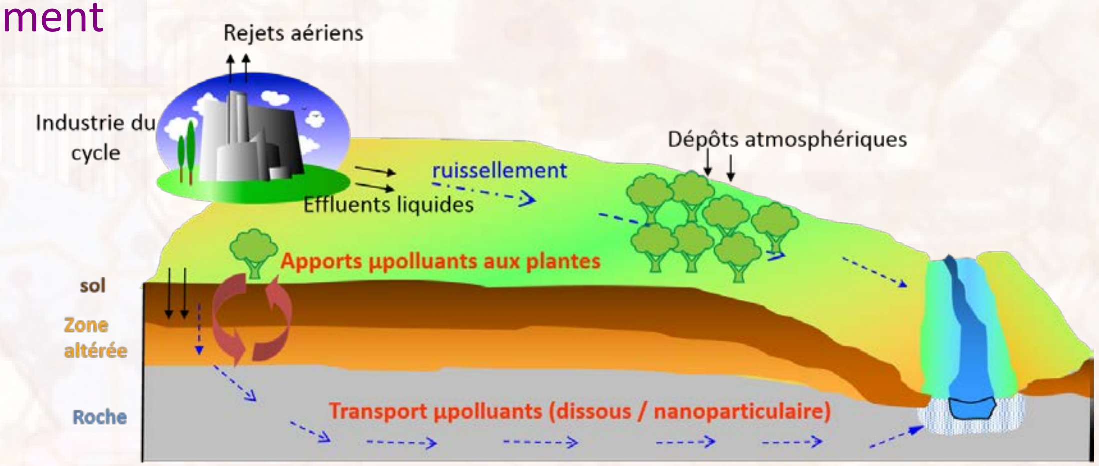
2.3 Radioactivity and the environment

Studying the behavior, fate and impact of radionuclides in the natural environment (SD11.3)

Stakes

Understanding the behavior and impact of RN in/on the environment

- Prediction of the impact of nuclear accidents
- Evaluation of the effects of low dose on life
- Contribution to safety analysis of nuclear storage sites
- Remediation



Associated fundamental issues

- Measuring / mapping radioactivity
- Speciation of radioelements
- Mechanistic description of the behavior of radioelements

Scientific approach

- Development of **experimental and modelling methodologies** related to the study of radioactive elements and of **specific databases**

- Linking the **model system to the real system** (from the lab to the field) with, in particular, the need to develop ***in-natura* instrumentation**.

- Develop **multi-scale and interdisciplinary** studies with the help of structuring initiatives (ZATU, OHM Fessenheim, OSUNA)

2.3 Radioactivity and the environment

Main axis for the future

- **Data bases and modelling**
- **Testing the databases : from the lab to the field**
- **Instrumentation**
- **Evaluation of the effects of low doses**
- **Remediation**

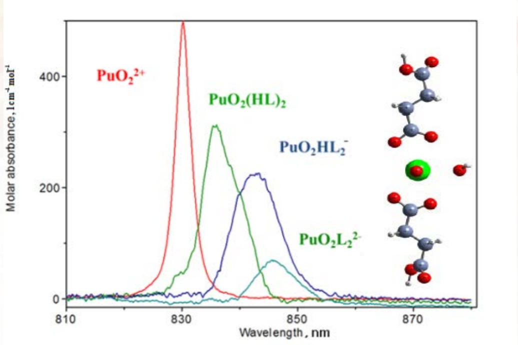
• Data bases and modelling

- Determine **fundamental data on the chemical properties (thermodynamics, kinetics, structural)** of radioelements / radionuclides
- The coupling of **experimental and theoretical approaches is fundamental**; the contribution of molecular modelling tools may prove to be indispensable for radioelements studied at the trace scale (Pa, Po, Ra...).

➔ For the next 10 years, a focus on actinides (Pa, Th, Np, Pu and U), Ra and Po

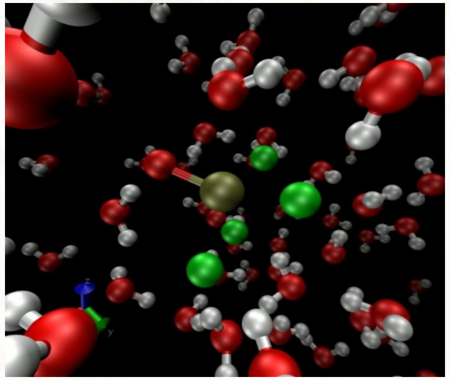
Confrontation between experiment and theory

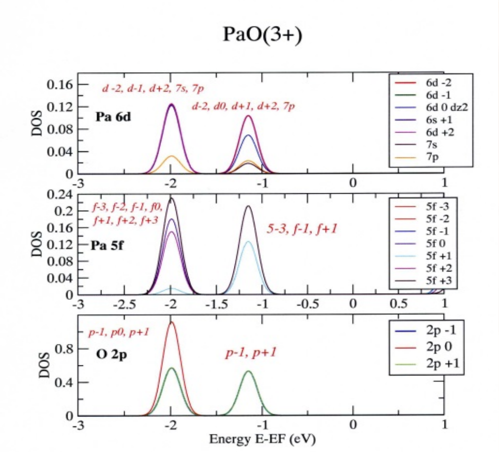
Pu(VI)-dicarboxylate
UV-Vis =>complexe 1:2
Theory => Pu coordinated by 2 ligands and a water molecule



Predictive calculations

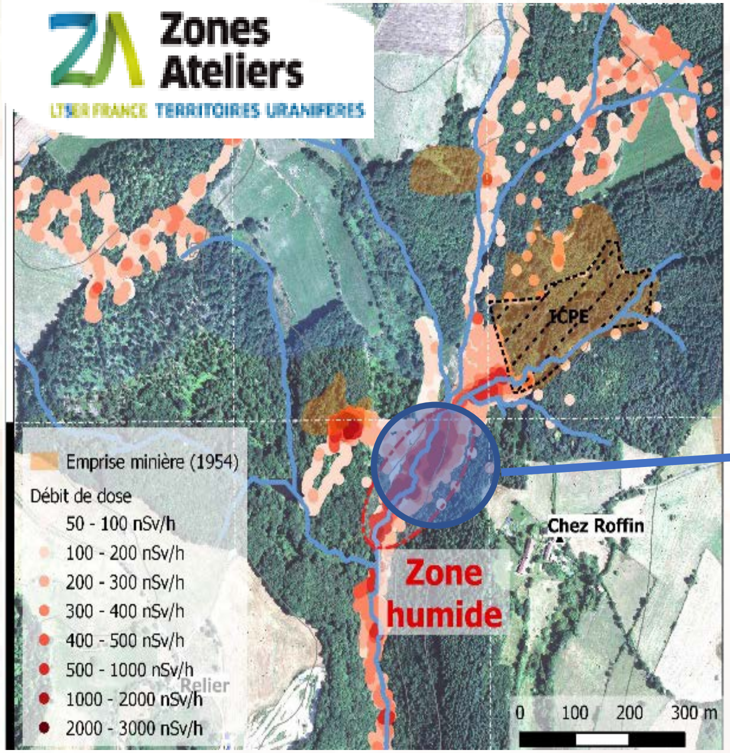
Pa: versatile mono-oxo bond

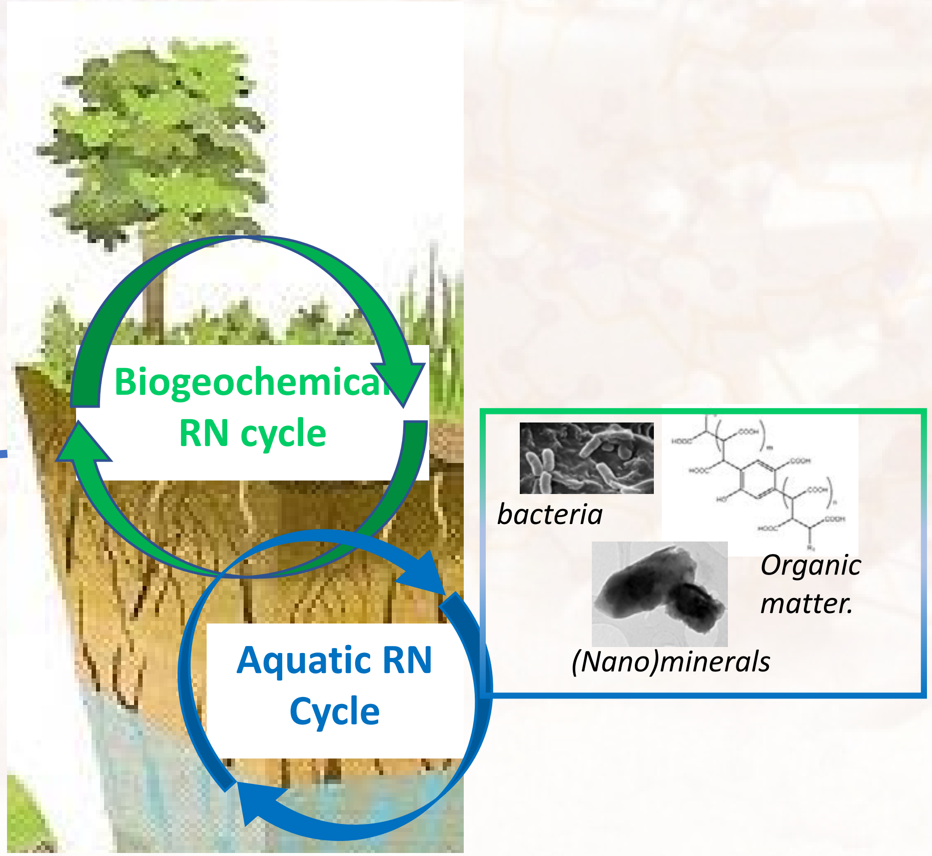




- **Testing the data bases**

An inter-organizational approach (CNRS/universities, CEA, IRSN, BRGM, ANDRA) in a European context (EURAD/FUTURE (2019-2024) and RADONORM (2020-2025))





• Instrumentation

- To go further in the sensitivity of the techniques (analysis, speciation)
- To address the problems of small and medium scale mapping
- To develop in-natura sensors
- High-frequency data acquisition

➔ A strong link with the industry (Labcom TESMARAC, P2R, LabCom avec AERIAL, AI4R, expertise activities of the Bq network)

PIA 3 / Equipex TERRA FORMA (RZA + OZCAR) 2022-2029

Airborne environmental gamma mapping by drone

IN2P3 contribution: Innovative sensors for contaminants and Communication network (from the sensor to the server)

- **Evaluation of the effects of low doses**

A multidisciplinary approach (INEE, INSU, IN2P3, INC)

➔ **A focus on natural radioactivity and the microorganisms present in mineral springs**

Study of biodiversity

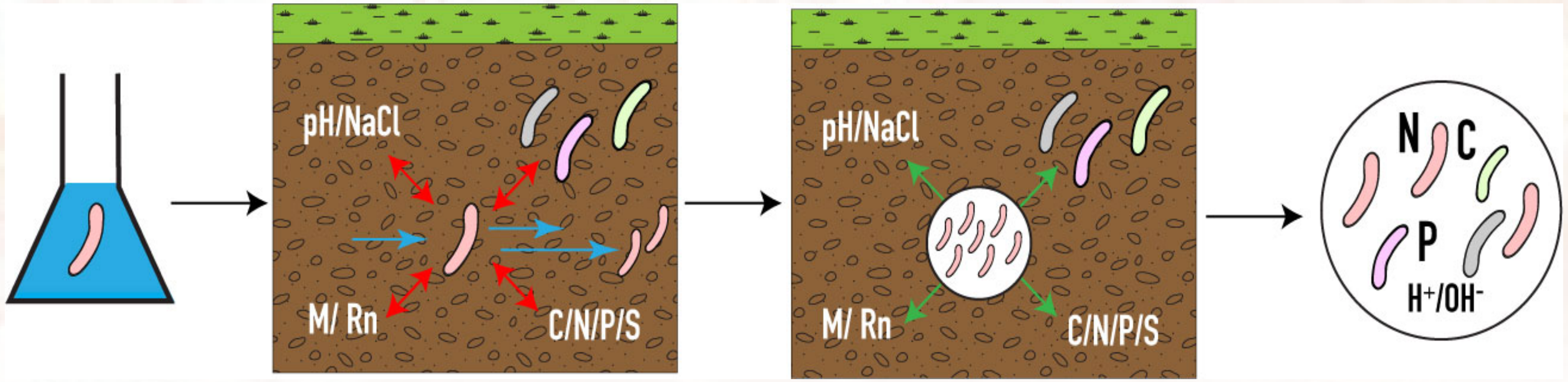
Evaluation by Monte-Carlo simulation at the microdosimetric scale

Interaction of radioelements with micro-organisms

• Remediation

Issue: diffuse contamination and large volumes of contaminated waste (e.g. decommissioning and decontamination of nuclear facilities).

- Known potential of certain bacterial strains to clean up metals and RNs
- Bio-depollution, at lower cost
- Concept of encapsulation by polymers



2.3 Radioactivity and the environment

Assets/Strengths

- Expertise at IN2P3 on key issues (instrumentation, speciation, modelling, Bq)
- A unique infrastructure adapted to the study of radioelements / radionuclides

Opportunities

- Interdisciplinarity within the CNRS and structuring organizations (ZA, OHM) to envisage academic research **over the long term**
- New emerging issues (TE-NORM, dismantling...)
- Link between research teams and Bq network

Specific recommendations

- Support for IN2P3's participation in national interdisciplinary tools CNRS « Zone Atelier » (ZA Territoires Uranifères) and « Observatoire Hommes Milieux » (Fessenheim), OSUNA (Observatoire des Sciences de l’Univers et Nantes Atlantique) ….
- Support to the IN2P3 **Becquerel network**

3. Conclusions & recommendations

Science Drivers

➔ **Reflects our involvement in societal issues**

- SD11.1: Exploring the potential of nuclear energy for the future and its impact on resources, wastes and costs
- SD11.2: Understanding the behavior of current and future nuclear materials in extreme conditions, contributing to nuclear waste management safety and developing innovative methods for fuel reprocessing.
- SD11.3: Studying the behavior, fate and impact of radionuclides in the natural environment

General and specific recommendations

Strategic orientations and manpower (targeted profiles)

- **Maintaining IN2P3's leadership in the field of nuclear data** and ensuring good investment in innovative projects requires constant support from human resources. The ambition to develop a line of research towards **evaluation** will require one **dedicated position.**

- **Capitalizing the IN2P3 long-term effort in reactor modelling** in order to have high-performance tools in the form of a digital platform would benefit the entire reactor physics community: to do so a **reinforcement in numerical physics applied to nuclear energy and neutronics** is necessary.

- **Developing multi-scale modelling**
  - by combining molecular and materials approaches in order to study increasingly complex systems;
  - of radionuclides transfers in realistic natural systems;

  reinforcement in chemical modelling required.

General and specific recommendations

Facilities

- The maintaining (performance and human resources) of the **irradiation platforms** and **characterization instruments specific to IN2P3** which are essential to the theme;

- Support for IN2P3 teams' access to the new **international experimental facilities** (NFS@GANIL,…);

- **Studying the possibility of a joint research infrastructure (RI)** between IN2P3 and INC for the **handling and study of radioactive material.**

General and specific recommendations

Structuring/Networking

- The maintaining and support of tools structuring the theme at the national level: **GDR SciNEE** (Sciences Nucléaires pour l'Energie et l'Environnement);
- IN2P3 support for the **NEEDS programme** (Nuclear, Energy, Environment, Waste and Society) or, in the long term, for another structure that provides both project financing and mobilization of partners;
- Support for IN2P3's participation in national interdisciplinary tools CNRS **“Zone Atelier » (ZA Territoires Uranifères) and “Observatoire Hommes Milieux » (Fessenheim) and OSUNA**
- Support at European level to guide future PAAs, in particular **EURATOM** (lobbying);
- Support to the IN2P3 **Becquerel IN2P3 network** and the **EMIR&A research federation and infrastructure**;
- Strong interaction between IN2P3 and **university partners**, notably for a common HR strategy linked to the importance of training through research issues in this field.

General and specific recommendations

Science Society interaction

- The maintaining of a strong link with nuclear energy players;
- Ensuring an institutional presence of IN2P3 in the various steering structures for research on nuclear energy, CNE, CSFN, I2EN, ANCRE;
- Support to academic expertise actions (CLI, Scientific Councils, ASN permanent group, ...);
- Strong national issue in high level training & education in nuclear energy : link between research and education has to be maintained to keep high level of skills
- Support for a communication action on nuclear energy towards citizens.

3. Conclusions and recommendations (digest)

Science Drivers: involvement in societal issues

- **SD11.1**: Exploring the potential of nuclear energy for the future and its impact on resources, wastes and costs

- **SD11.2**: Understanding the behavior of current and future nuclear materials in extreme conditions, contributing to nuclear waste ma safety and developing innovative methods for fuel reprocessing.

- **SD11.3**: Studying the behavior, fate and impact of radionuclides in the natural environment

Avis du Groupe de travail « Transition énergétique et transition globale » du Conseil scientifique du CNRS (15/10/21)

« …Les travaux amont du CNRS en instrumentation, et le programme pluridisciplinaire « NEEDS » apparaissent exemplaires et devraient être renforcés ; *une politique volontariste du CNRS en grands moyens expérimentaux, ou en participation à des infrastructures de recherche à l'échelle européenne, devrait être envisagée.****(…) Le CNRS a la légitimité scientifique et institutionnelle pour être pilote d'une relance de la recherche amont sur les enjeux majeurs liés à l'énergie nucléaire et au cycle du combustible dans la transition globale. »***

Recommendations

Strategic orientations (unranked)

- Maintaining IN2P3's leadership in the field of nuclear data
- Capitalizing the IN2P3 long-term effort in reactor modeling
- Developing multi-scale modeling (nuclear materials and molecules, radiochemistry,…)

Facilities: Maintaining (performance and human resources) of the irradiation platforms and characterization instruments specific to IN2P3, and support for access to international experimental facilities

Supporting networking/structuring: GDR, NEEDS, ZATU, OHM, OSUNA, Bq, EMIR&A, EURATOM…

Science Society interaction

- Maintaining of a strong link with nuclear energy players, presence in steering structures for research on nuclear energy (CNE, CSFN, I2EN, ANCRE), support to academic expertise actions (CLI, Scientific Councils, ASN permanent group, ...), involvement in high level education
- Support for a communication action on nuclear energy towards citizens