Long Range Plan 2016

WG6 - Applications and societal benefits

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Conveners: Marco Durante, Alain Letourneau

Town meeting 11-13 January 2017

Plan

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   - 1.1 Next generation fission reactors
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Introduction

- Nuclear physics technology is ubiquitous in our lives
- Many of today's most important advancements in medicine, materials, energy, security, climatology etc. emanate from applications of nuclear physics.
- Economic impact is significant: DOE estimates 500 G$ from particle beam accelerators; EPS estimated a total turnover from physics activity in Europe of 3760 G€ in 2010.
- Answers to some of the most important questions facing our planet will come from interdisciplinary efforts in medicine, energy, climate, and marketplace innovations, all involving nuclear physics
- Applications to energy, medicine, materials, space, security and environment are the fields with the largest expansion potential in nuclear physics

1. Energy applications

Key questions

- *How can advance nuclear systems help to the sustainability and acceptability of nuclear energy generation?*
- *How can safety of current nuclear reactors be improved?*
- *How can nuclear power source be provided for space applications?*

Key issues

- *Accurate nuclear data and predictive modeling of nuclear reactions (induced by neutron and charged particle and decay)*
- *Design and construction of high-power and reliable accelerators and targets.*
- *Stability of components in extreme environments (radiation and chemically reactives)*
- *Synergies with other fields (radioisotope production, silicon doping, fuel and material testing, fundamental research)*

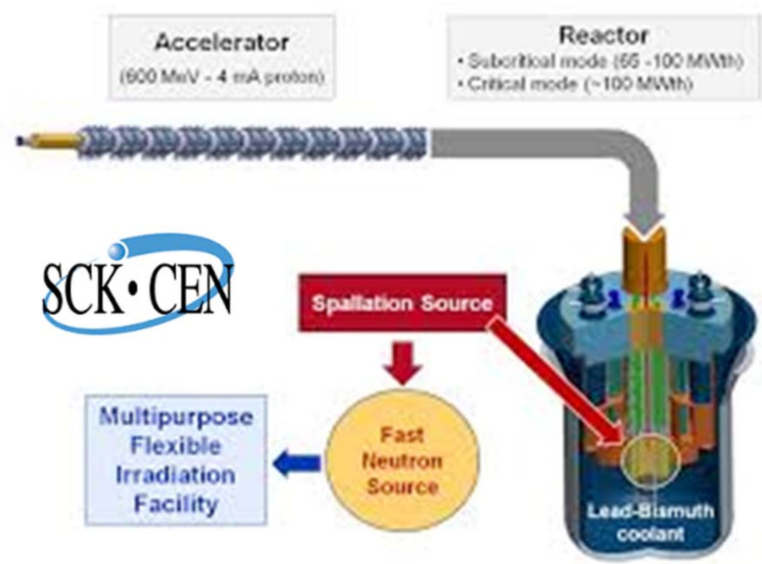
1. Energy applications

1.1 Next-generation fission reactors

- In the wake of the Fukushima accident it has become of high priority in Europe to improve safety standards of existing nuclear reactors, as well as of fuel fabrication and waste management installations.
- Accurate nuclear data and models are needed for the assessment of the performance of nuclear systems in normal and accidental conditions

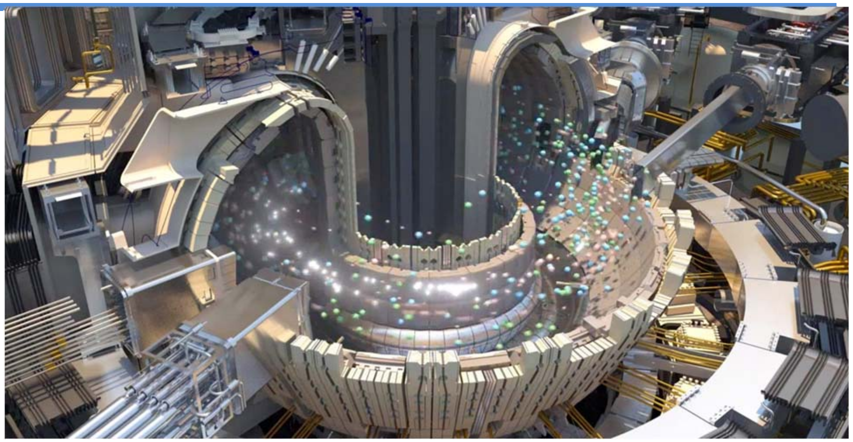
1.2 ADS

- ADS for nuclear waste transmuation has still many challenges: nuclear data, models of spallation reactions, structral materials, high-intensity accelerators, resilient spallation targets
- MYRRHA will be a fast spectrum reactor able to operate in sub-critical (ADS) and critical mode with a spallation target in liquid Li-Bi



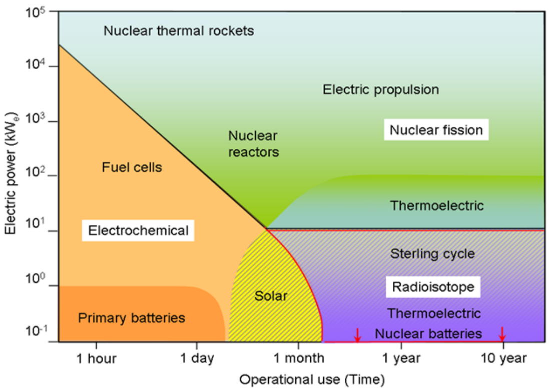
1.Energy applications

1.3 Fusion reactors



- ITER (Cadarache, France) is the greatest challenge for fusion technology
- The very high fluxes of high-energy neutrons are a major problem for the structural reactor material
- IFMIF can play a key role as a test facility with 14 MeV n

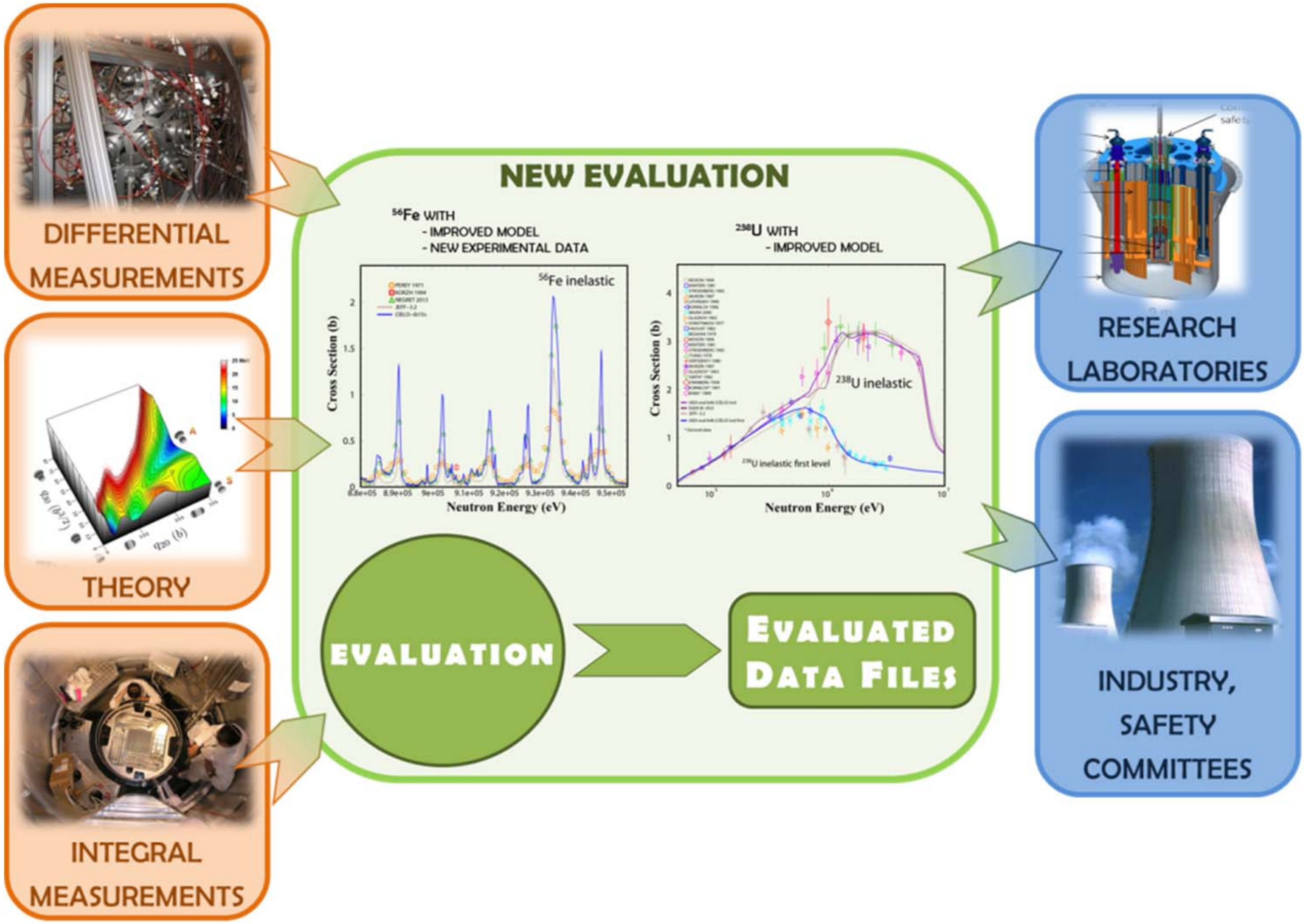
1.4 Nuclear power sources for space applications



- In Europe the major emphasis is on developing new fuel and production technology to replace ^{238}Pu. Current efforts concentrate on ^{241}Am, extracted from civilian waste stocks.

- A need for miniaturized nuclear power sources has also recently arisen, largely fueled by the growing interest in small satellites and technical developments in nano-technology. Active semiconductors can be used to convert the radioactive emissions generated by embedded alpha and beta sources

Nuclear Data

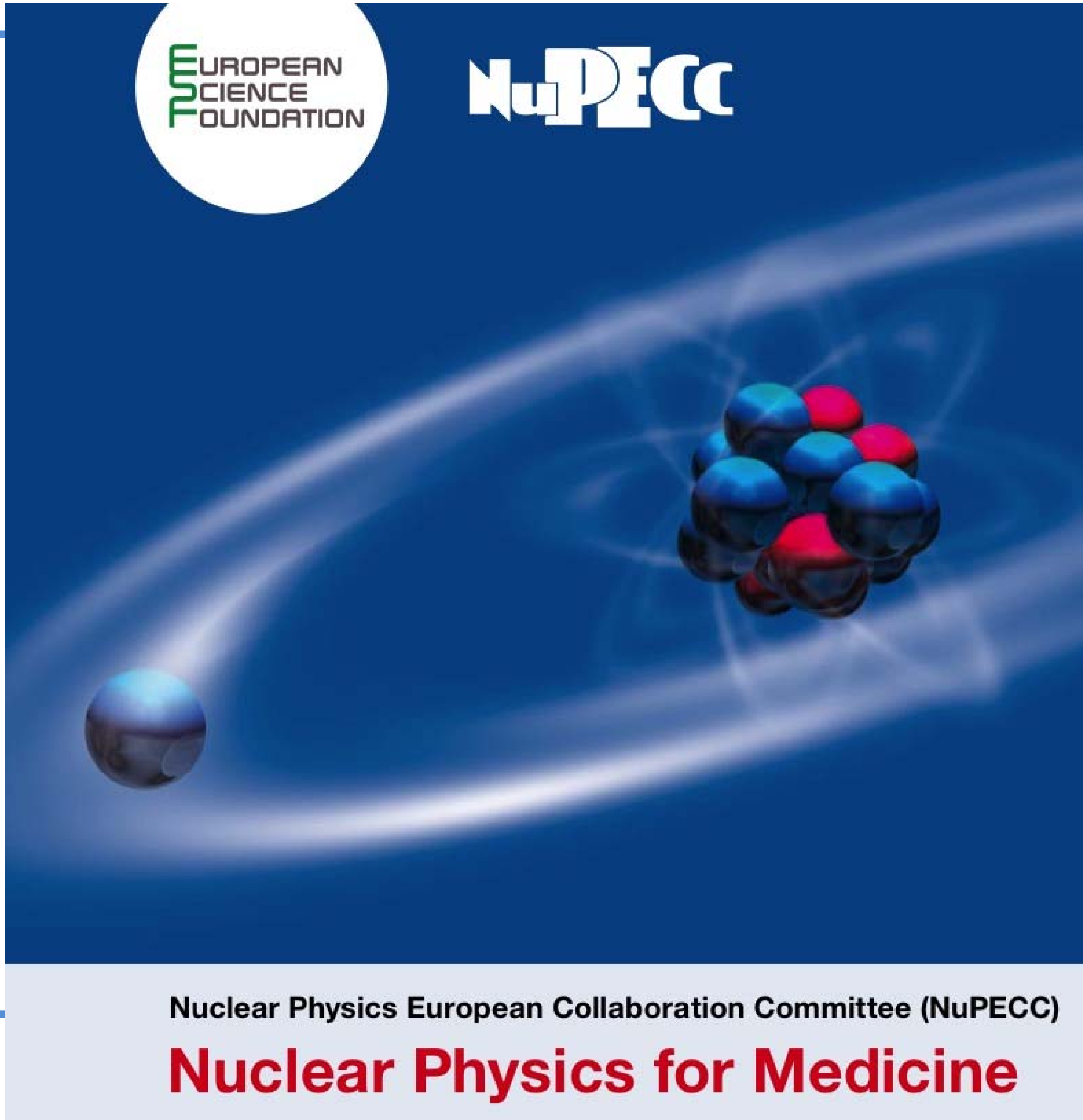


1. Energy applications

Recommendations

- *Support efforts in nuclear data measurements, evaluation and modeling.*
- *Continue developments for high power and high stability particle accelerators.*
- *Exploit synergies with other fields (detectors, accelerators,…).*
- *Support specific projects as MYRRHA and IFMIF/ELAMAT in Europe.*

2. Health applications



www.nupecc.org

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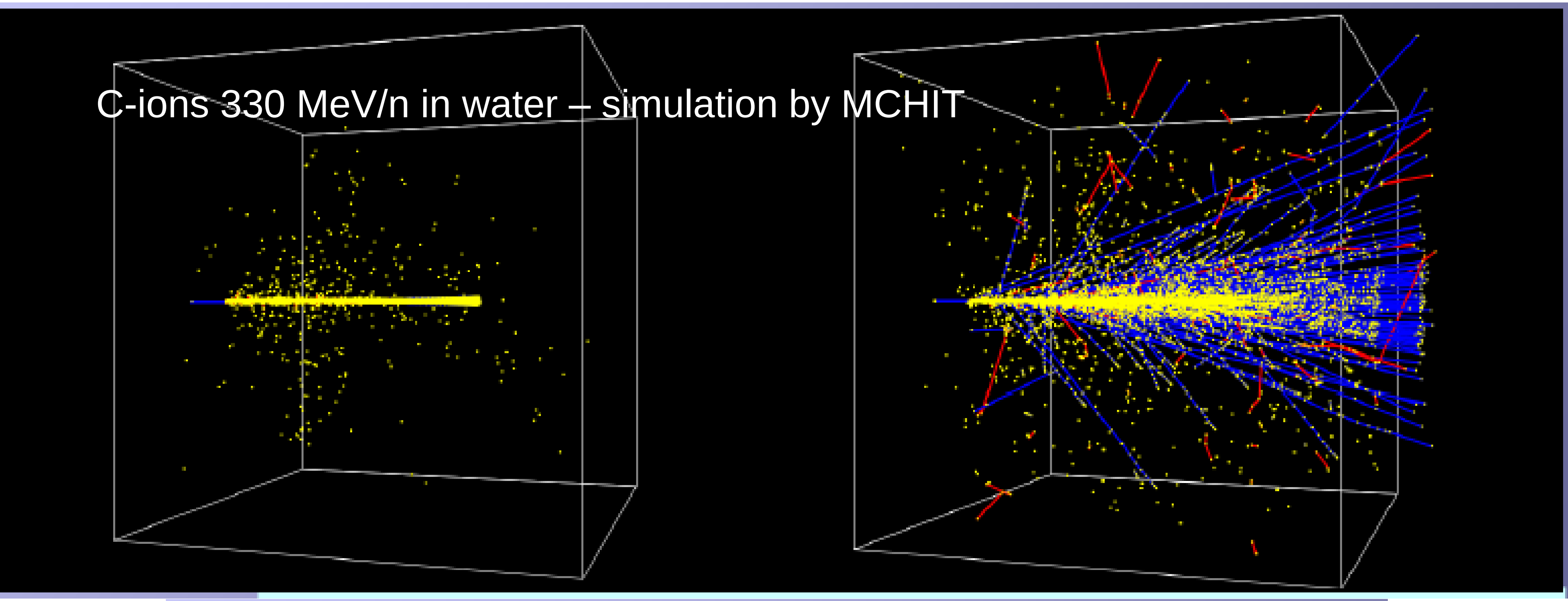
2. Health applications

2.1 Particle therapy



Electromagnetic interactions only

EM interactions + hadronic elastic scattering and fragmentation reactions

Courtesy of FIAS Frankfurt Institute for Advanced Studies

2. Health applications

TCART, UT Southwestern Medical School, Dallas, TX

Carbon ion therapy

- Japan: 5 (+2)
- China: 2
- Europe: 3 (+1)

VIEWPOINT

Heavy Ions in Cancer Therapy

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Hak Choy, MD

Radiation therapy is one of the oldest modalities for cancer treatment and is currently prescribed to more than 50% of all patients. It is based on delivering high doses of ionizing radiation to well-localized tumor targets in the body. The goal is to kill all the tumor cells with acceptable toxic effects to the surrounding normal tissue, which is unavoidably exposed. Indeed, radiotherapy success is limited by the toxicity in the normal tissue.

X-rays (photons) are used in most patients treated with conventional radiotherapy. As x-rays are delivered from an external source, they deposit most of their energy upstream of the tumor in healthy tissue. This energy deposition also occurs beyond the tumor, affecting additional healthy tissue. Special beams delivered from many directions and intensity modulation are used

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a stop in the tumor
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This unique feature
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JAMA Oncology Published online August 18, 2016

International Symposium on Ion Therapy, Milan, Italy, November 3-4

2. Health applications

Radioimmunotherapy: a new frontier

Weill Cornell Medicine

Courtesy of Silvia Formenti

Does Heavy Ion Therapy Work Through the Immune System?

Marco Durante, PhD,* David J. Brenner, PhD,† and Silvia C. Formenti, MD‡

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RT

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2. Health applications

SCIENTIFIC REPORTS

OPEN

Feasibility Study on Cardiac Arrhythmia Ablation Using High-Energy Heavy Ion Beams

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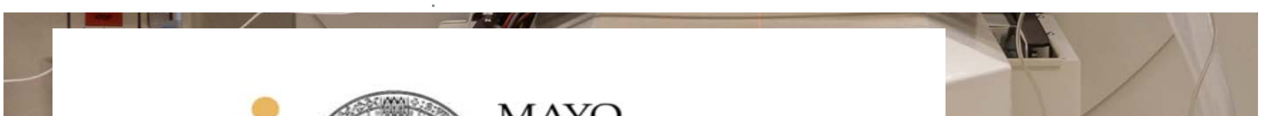
Published: 20 December 2016

H. Immo Lehmann[1,*], Christian Graeff[2,*], Palma Simoniello[2], Anna Constantinescu[2], Mitsuru Takami[1], Patrick Lugenbiel[3], Daniel Richter[2,4], Anna Eichhorn[2], Matthias Prall[2], Robert Kaderka[2], Fine Fiedler[5], Stephan Helmbrecht[5], Claudia Fournier[2], Nadine Erbeldinger[2], Ann-Kathrin Rahm[3], Rasmus Rivinius[3], Dierk Thomas[3], Hugo A. Katus[3], Susan B. Johnson[2], Kay D. Parker[2], Jürgen Debus[6], Samuel J. Asirvatham[1], Christoph Bert[2,4], Marco Durante[2,7] & Douglas L. Packer[1]

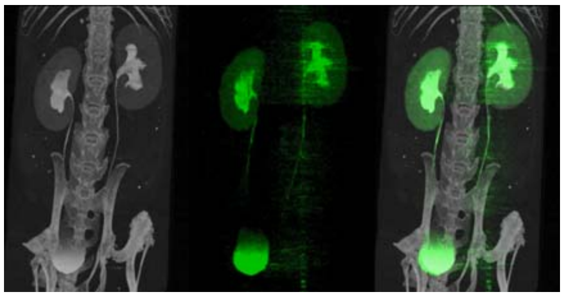


GSI

MAYO CLINIC

2. Health applications

2.2 Imaging



- Spectral CT, including K-edge imaging, based on hybrid pixel detectors
- 3-photon cameras (gamma-PET)
- IGRT for particle radiosurgery using CBCT, online PET, particle radiography, prompt γ or charged particle emission

2.3 Radioisotopes

- Therapy (radioimmunotherapy)
- Theranostics (with nanoparticles)
- Production: need increasing, R&D required
- Purity: Physical separation (replicing chemical) based on mass separators like ISOLDE

2.4 Radioprotection

MELODI

2. Health applications

Key questions

- *How cancer treatment efficiency can be improved, reducing the dose to the patient?*
- *How diagnostic methods can be improved?*
- *What are the risks of low-dose radiations?*

Key issues

- *To develop new methods to better target the treatment on the tumor cell.*
- *To improve the quality of imaging technologies decreasing the dose to the patient.*
- *To develop radiobiology studies.*

Recommendations

- *Develop Monte-Carlo approaches which combine and validate contemporary imaging, dosimetry and diagnostic processes.*
- *Development of new tools and techniques to improve the quality and computational speeds leading to more accurate and faster dosimetric calculations in real time, thereby optimising patient treatment planning and throughput.*
- *Promote the development of accelerators and targetry towards intense beams and consider in the design or upgrades of existing facilities the production of innovative radiopharmaceuticals. Develop related mass separation techniques to obtain high purity radio-isotopes.*
- *Promote the study of radionuclide production using suitable and focussed types of nuclear reactions in order to enlarge the choice of available radionuclides*
- *Take advantage of alternative radionuclide properties to develop new “theranostic" concepts in imaging and therapy*

3. Environmement and Space

Key questions
- *What is the part and what is the impact of anthropogenic activities on climate change and modification of our environment?*
- *What is the radiation content of near-Earth environment and its impact on human activities?*

Key issues
- *To develop efficient technologies (ion-beam analysis, radiation detection, radiotracers,…) for elemental and radionuclide analysis and to monitor environment changes.*
- *To reconstruct the past atmospheric concentration of mineral dust to correlate its variations with climatic change.*
- *To study and identify aerosol sources on a global and local scale and their effects on climate and environment*
- *Investigate the origin of cosmic radiations and their impact on near-Earth environment*

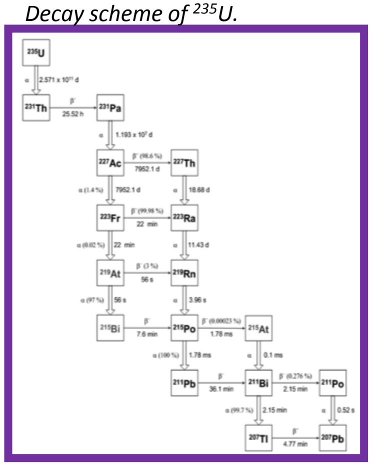
3. Environmement and Space

3.1 Climate and Earth science

- An increasing concern about the problems related to the high levels of Particulate matter which affects human health and climate change.
- PIXE is particularly well adapted for elemental analysis of aerosols. In Europe, several low energy accelerators are operating but only two are particularly devoted to the analysis of aerosol samples, the PIXE Laboratory in Lund and the LABEC Tandem Laboratory in Florence.

3.2 Environmental radioactivity

Decay scheme of ^{235}U.



- Gamma-ray spectrometric measurements and nuclear data are essential for environmental radioactivity measurements and verification of International Comprehensive Treaty Ban Organisation commitments

3. Environment and space

3.3 Space radiations

The New York Times — Space & Cosmos

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

ENVIRONMENT SPACE & COSMOS

Data Point to Radiation Risk for Travelers to Mars

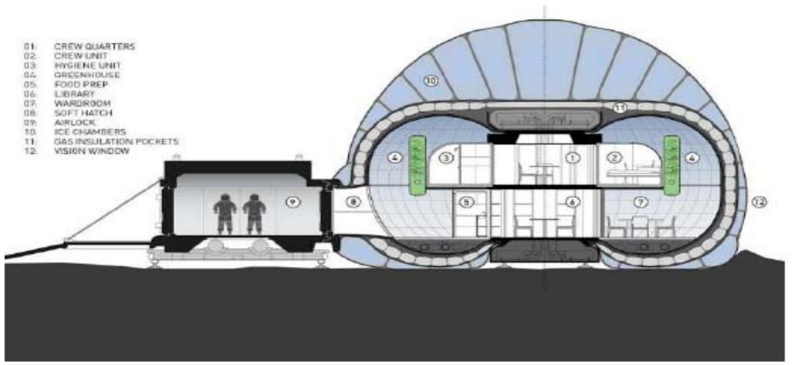
Dose=1.8 mSv/dayx!

NASA might build an ice house on Mars

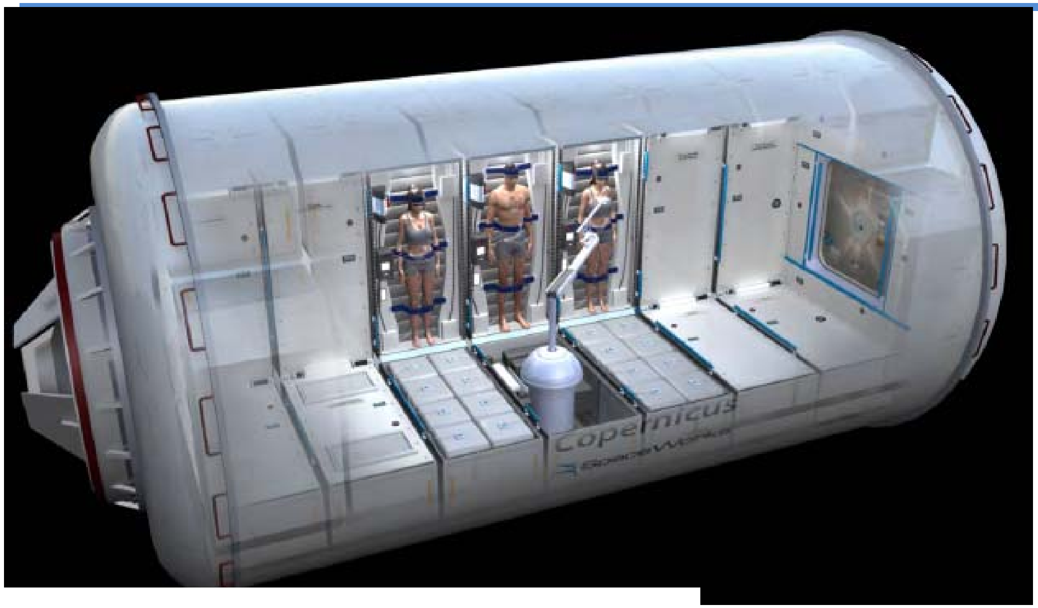
December 30, 2016 by Nancy Atkinson, Universe Today

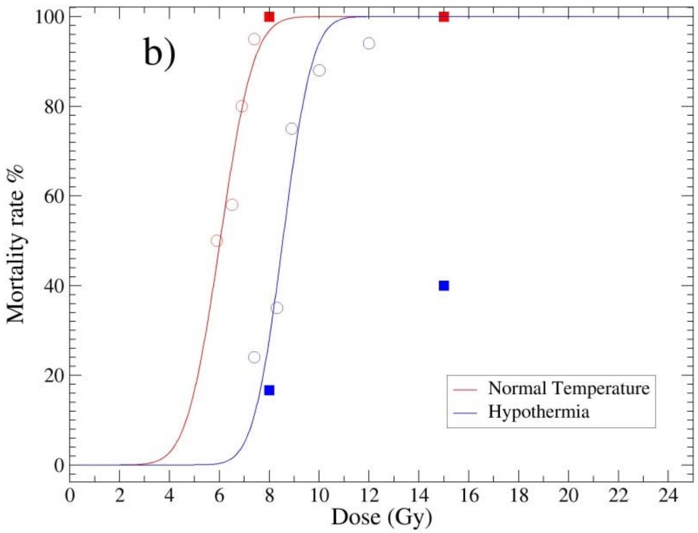
FAIR

Facility for Antiproton and Ion Research in Europe GmbH

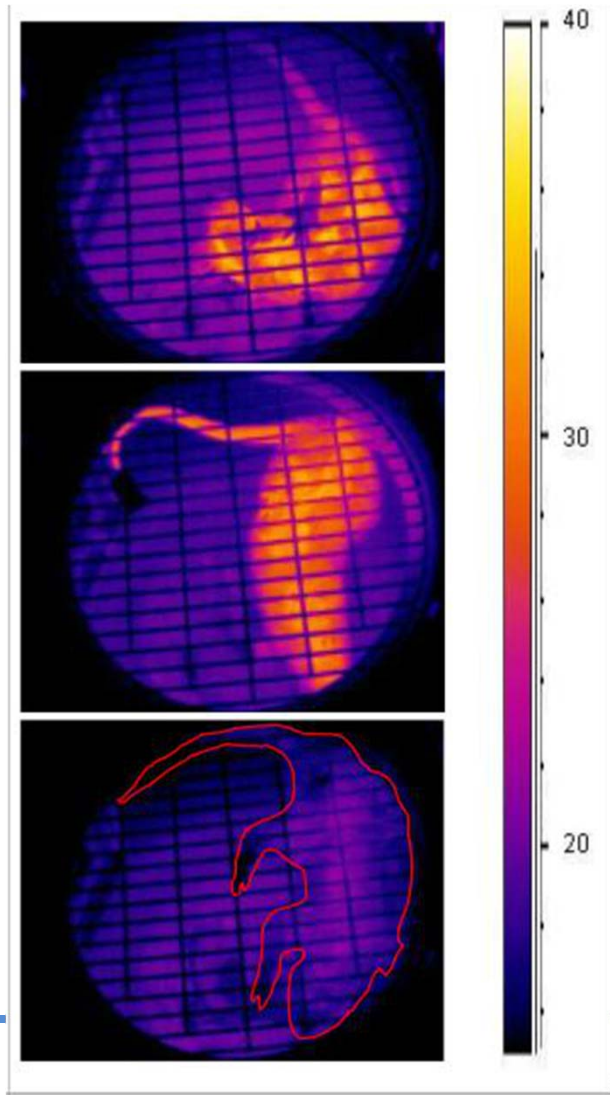


3. Environment and space





Cerri et al., Life Sci. Space Res. 2016



3. Environmement and Space

Recommendations

- Nuclear techniques provide only part of the desired information with regard to the chemical composition. PIXE researchers should not limit themselves to PIXE and IBA analyses, but try to diversify their activities by performing also other chemical and/or physical and optical measurements and to establish collaborations with other groups (chemists, geologists, physicists….).
- It is important to participate to all the phases of cross-disciplinary projects regarding urban air quality, climate research, ecology, meteorology and epidemiology.
- The European nuclear physics community must upgrade its expertise in the measurement and characterisation of radioactive sources across the wider environment. This includes a recommendation for up to date measurements on key nuclear decay data such as half-lives and gamma-ray emission probabilities values for a the most important environmental radioactive sources.

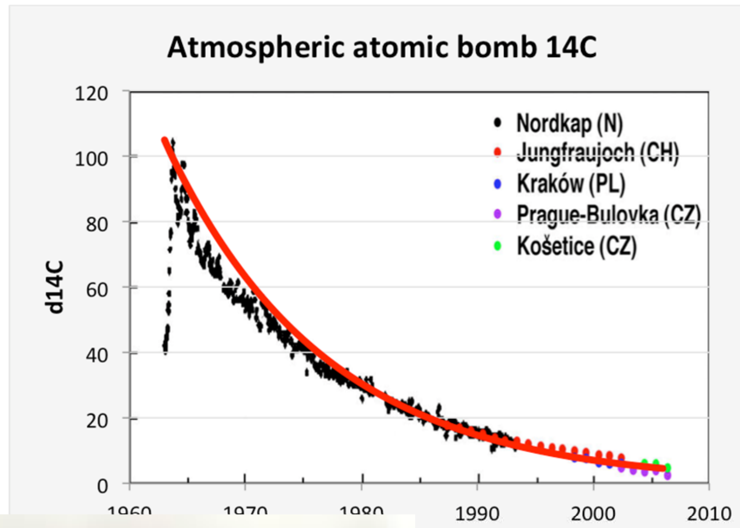
4. Societal applications

Key questions
Which technical developments to strengthen the position of nuclear techniques compared to other methods?

Key issues
Safe boundaries of nuclear techniques to minimise the side-effects of the applied radiation
Develop and use instrumentations with more modalities
Access to analytical facilities
Better communicate with end-users?

4. Societal applications

Carbon dating and the bomb spike



Occipital neurons are as old as an individual, while nonneuronal cells change (Spalding et al., Cell 2005)

Ivory aging to fight poaching in Africa, (Uno et al., PNAS 2013)

Authentication of Cosa Nostra's "papello" to blackmail government

4. Societal applications

Recommendations

- *Using the maximum number of simultaneous modalities to gain the maximum information during the irradiation*
- *Upgrading detection systems for higher efficiency and safer irradiations*
- *More synergy with other physical and chemical techniques*
- *Better communication with stakeholders*
- *Participation in and support of E-RIHS, the dedicated European Research Infrastructure for Heritage Science*

- *Need to develop detectors with directional detection and with simultaneous gamma-ray and particle identification.*
- *High priority should be given to the standardization of list-mode data with Time and Geo-localisation.*
- *Lightweight detectors and manipulators should be developed for remote-controlled radiation measurements.*
- *To foster the emergence of innovative, qualified, efficient and competitive security solutions, through the networking of European experimental capabilities.*

5. Cross-disciplinary impact

Key Questions

- *What are the local and long-range chemical and magnetic structures of materials?*
- *What are the dynamical properties of materials and how do ultrafast processes take place in materials?*
- *How do atoms and materials behave under extreme conditions?*
- *How can materials be modified by nuclear tools?*

Key Issues

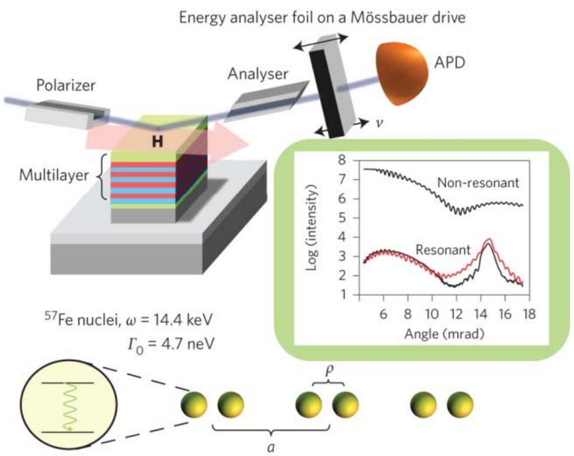
- *Increasing sensitivity, increasing depth and lateral resolution of analytical techniques*
- *Extending the temperature, pressure and magnetic field range accessible for nuclear methods*
- *Controlled modification and nanostructuring of materials*

5. Cross-disciplinary impact

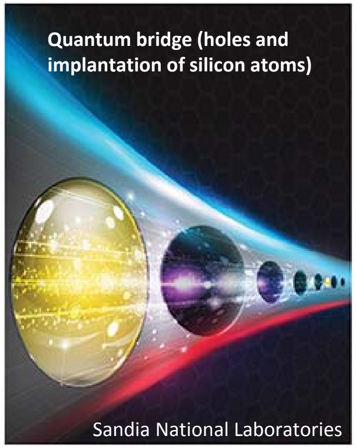
5.1 Materials sciences

- Material characterization by:
  - Ion beam analysis
  - Neutron scattering analysis (ESS, ILL, Orphée)
  - Nuclear Resonant cattering (ESRF, Soleil,..)
  - Muon-spin rotation and positron annihilation

Nuclear Resonant Scattering



J. Haber et al., Nature Photonics, 2016

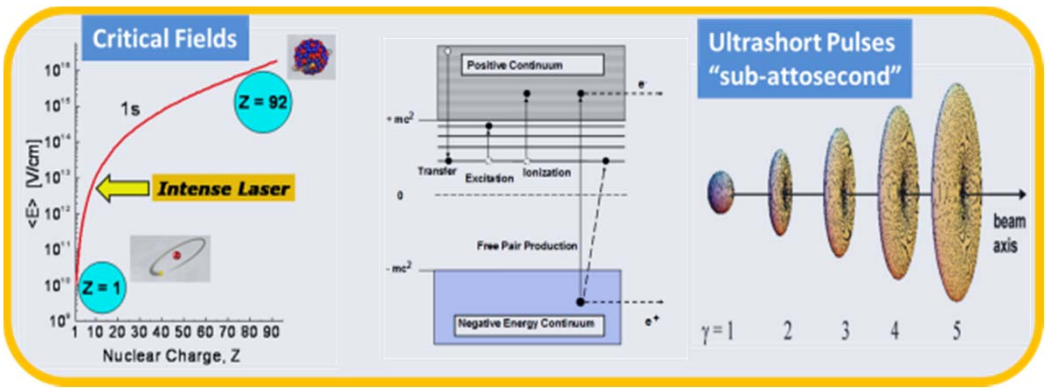


A. Sipahigil et al., Science, 2016

- Material modification (semi-conductor doping) by ion or neutron implantation with two orientations:
  - in extreme conditions of doses or environment (fusion reactors, planetary sciences)
  - controlled single ion implantation for spintronic and q-bit

5. Cross-disciplinary impact

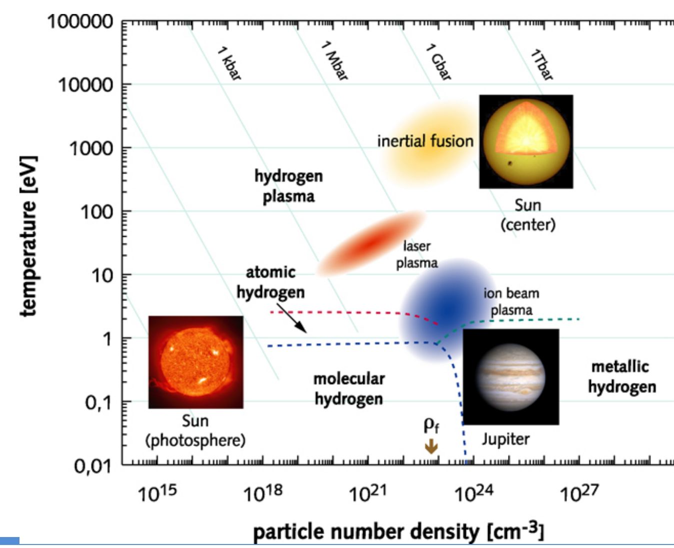
5.2 Atomic and Plasma physics



- Study of atomic matter subject to extreme electromagnetic fields

→ QED tests in non-perturbative bound-states

- Study of matter in extreme conditions of temperature and pressure



5. Cross-disciplinary impact

- With the availability of new installations (ESS, FAIR, SPIRAL2, CILEX) providing intense cold neutrons, ion beams and laser pulses, outstanding and worldwilde unique experiments will be possible to explore the structure of materials and atomic properties in extreme conditions

Recommendations

It is our vital interest to find schemes that link operators of applied nuclear facilities to potential user groups in materials sciences and related areas.

6. Summary and recommendations

Important progresses and new orientations since the last Long Range Plan in 2010

- In the nuclear energy domain, the safety of existing and future installations is became the main concern in the wake of the Fukushima accident. The main consequences are a need for accurate and predictive simulation codes based on reliable nuclear data (cross sections, decay data).

- In the medical domain, the new theranostic approach leads to the development of adapted techniques for cancer treatment, in particular to the development of specific radio-isotopes, and more efficient imaging techniques. Thanks to the developments of high light-yield and fast scintillators coupled with high-performance computing Monte-Carlo codes the efficiency of diagnostics are improved and the dose to the patient can be reduced. Such developments should also permit to improve the detection techniques for nuclear security and counter terrorism.

- In the environmental domain, the global warming and urban pollution are become of main concern for our societies. Efficient low-energy accelerator-based techniques are used to trace aerosols and study their role and impact in these problematics.

- With the availability of high-intensity accelerators and new installations (Ganil, ESS, FAIR, HIE-Isolde) new studies in material, atomic and plasma physics will be possible, exploring matter in extreme conditions. Some of these installations will also be used to study and develop the production of new radioisotopes for medical use.

6. Summary and recommendations

Recommendations

- *Maintain an adequate level of competences and expertises in the field of Applied Nuclear Physics in Europe through training and education of young researchers.*

- *Strengthen the communication between Nuclear Physics community and end-users (stakeholders).*

- *Applied Nuclear Physics communities should be encouraged to build open-access networks offering their services (i.e., research infrastructure, knowledge and data) to potential users. Such networks as distributed and/or virtual research infrastructures should be integrated in the emerging European Open Science Cloud.*

- *Pursue the developments of novel accelerators and sensors for medical applications.*

- *Maintain a high level of expertise and support nuclear data activities (measurement, compilation, evaluation and dissemination) to meet the requirements of a continuously developing European research and applied sciences landscape through targeted training and mentorship schemes*

NuPECC

WG6

- 1st meeting: ECT* Trento,Italy, 11.3.2016
- 2nd meeting: University of Lisbon, Portugal, 18.7.2016