IFAST ACCELERATORS FOR SOCIETAL APPLICATIONS

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Abstract

IFAST is the latest in a series of EU projects undertaking R&D for particle accelerators and coordinated by CERN. The IFAST Accelerators for Societal Applications task is investigating a range of novel applications of particle accelerators from the medical, environmental and imaging fields, with the aim of identifying those with the most potential. It will then develop a strategy for delivering these applications. In addition, it is studying barriers which are discouraging the uptake of accelerators in industry and elsewhere and attempting to identify ways of overcoming these.

1. INTRODUCTION

The Innovation Fostering in Accelerator Science and Technology (IFAST) EU Horizon 2020 innovation action [1] is the latest in a series of EU funded projects undertaking particle accelerator R&D and coordinated by CERN. The main focus of these projects has been on R&D for accelerators used for research, with the aim of improving performance in many areas. However, starting in Framework Programme 7 with the EuCARD2 project [2], there has been an increasing emphasis on the societal applications in the energy, environmental and medical areas. This is continuing and expanding with IFAST, due to the particular focus on innovation in this programme.

The work package structure of IFAST is shown in Table 1. As required by the EU call, the work is separated into three activities:

(a) Strategies: study groups to define "roadmaps" for specific technologies.
(b) Prototypes: prototyping with industry at higher TRL.
(c) Developments: development, often with industry, at lower TRL.

Each WP usually has at least one of each activity, with the work being done by tasks within the WP.

The relevant WP for the paper is WP12. This has three tasks, as follows:

- Task 12.1: A Strategy for Implementing Novel Societal Applications of Accelerators
- Task 12.2: Design of advanced electron accelerator plant for biohazards treatment
- Task 12.3: Design of Internal RF Ion Source for Cyclotrons

These are a strategy, a development and a prototype, respectively. The paper describes the first of these, Task 12.1. As this is a strategy, the aims of the Task had to meet the appropriate EU requirements. As a result, these are:

- To study some new and important societal applications of accelerators with the aim of developing roadmaps for their innovation:
    - Novel forms of radiotherapy for cancer treatment.
    - Reduction in environmental pollution.
    - New imaging techniques.
    - Improved methods for radioisotope production.
- To develop a strategy to deliver these roadmaps.
- To study the barriers which discourage the use of accelerators in industry.

To achieve these aims, the work of the Task is split into the 6 sub-tasks shown in Table 2.

TABLE 1. THE WORK PACKAGES IN THE IFAST PROJECT

WP number	Description
1	Management, coordination and dissemination
2	Training, communication and outreach for accelerator science and technology
3	Industry engagement
4	Managing innovation, new materials
5	Strategies and milestones for accelerator research and technology
6	Novel particle accelerators concepts and technologies
7	High brightness accelerators for light sources
8	Innovative superconducting magnets
9	Innovative superconducting cavities
10	Advanced accelerator technologies
11	Sustainable concepts and technologies
12	Societal applications
13	Technology infrastructure
14	Ethics requirements

IFAST started on 1st May 2021 and will run for four years. The paper will briefly describe the work done by each sub-task in the first year of activities and the plans for the rest of the project.

TABLE 2. THE SUB-TASKS OF THE PROJECT

Sub-task number	Description	Coordinated by
12.1.1	Management and communication	Rob Edgecock (University of Huddersfield, UK), Andrea Sagatova (Slovak University of Technology, Slovakia)
12.1.2	Novel forms of radiotherapy	Angeles Faus-Golfe (CNRS, France)
12.1.3	Environmental applications of electron beams	Toms Torims (Riga Technical University, Latvia), Andrzej Chmielewski (INCT, Poland)
12.1.4	Accelerator imaging	Graeme Burt (Lancaster University, UK)
12.1.5	Accelerator production of radioisotopes for imaging and therapy	Concepcion Oliver and Diego Obradors (CIEMAT, Spain)
12.1.6	Barriers to accelerator adoption by industry	Andrzej Chmielewski (INCT, Poland) and Andrea Sagatova (Slovak University of Technology, Slovakia)

2. SUB-TASK AIMS AND ACTIVITIES

The main focus of the Task in the first year has been to assess the state of the art in each application area, select those with the most potential and study the main issues facing those applications. This has been done by building on the work of earlier projects in EuCARD2 [2] and ARIES [3], the book “The Applications of Particle Accelerators in Europe” [4] produced by EuCARD2 and discussions with colleagues working on these topics around the world. The following subsections will describe briefly the work done and the conclusions drawn so far.

2.1. Novel forms of radiotherapy

The aims of this sub-task are to study new forms of radiotherapy for cancer treatment that are currently under development, for example FLASH [5] and mini-beams [6], and to investigate novel beams and accelerators able to achieve the optimal requirements for these treatments. FLASH is a technique in which the dose is delivered very quickly. Standard radiotherapy delivers about 2 Gy/min. In FLASH, the dose is delivered very much faster, at least 40 Gy/s, but usually much faster. In trials, this has been shown to be very effective against tumours, while reducing the damage to healthy cells, and hence the side effects of the treatment. With mini-beams, only a part of the tumour is treated, in a grid-like manner. This has also been shown to be effective against the tumour, while sparing healthy cells.

The main issue is that these techniques, in particular ultra-fast FLASH, are difficult to deliver with the current technology used for radiotherapy, linear electron accelerators up to 20 MeV. These tend to be based on rather old technology and although that makes them well-proven and reliable, they cannot easily be adapted to these new therapies. While other projects are developing low energy linear accelerators better able to meet the requirements, the focus of this sub-task is Very High Energy Electron radiotherapy (VHEE), using electron beams of up to about 200 MeV. As well as being able to deliver the dose more accurately in the transverse direction, and hence being better suited to mini-beams, this therapy also has a better dose-depth profile than standard radiotherapy with x-rays or electrons or proton therapy. This has a sharp peak, the position and structure of which depends on the beam energy and the focussing employed [7]. The main problem with VHEE is that this therapy requires higher energy electrons than standard radiotherapy, but the accelerators able to deliver these must still be sufficiently compact and not too expensive. The sub-task is studying ways of doing this, with the aim of developing a strategy for delivering this therapy.

2.2. Environmental applications of electron beams

This sub-task is studying the use of electron beams for removing a wide range of pollutants from air, water and sewage sludge before they enter the environment. The technique works by using electron beams up to 10 MeV to create many radicals in water. These then react with the pollutants. In the case of biological organisms, the radicals damage the DNA or RNA, leading to cell death. With chemicals, they have various reactions usually resulting in the breakup of long molecules [8]. IFAST is studying a number of topics, building on work that started in ARIES and other projects. In particular, it is studying, the removal of contaminants from sewage sludge, from the exhaust gases of marine diesel engines and from the ballast water of ships.

For sewage sludge, it is collaborating with Task 12.2. It is already known that electron beams are very effective against the pathogenic contaminants in sludge [8], with doses of around 10 kGy being able to reduce nearly all possible pathogenic contaminants by at least six orders of magnitude. There are also measurements that suggest if electron beam treatment is used before anaerobic digestion (AD), there are significant increases in biogas production and the sludge is made more digestible, so the same digestor can treatment more sludge [9]. The requirement now is to incorporate an electron beam into a production sewage sludge treatment plant and demonstrate that these results can be achieved in practice. This is what these two Tasks are aiming to do. In addition, this sub-task is also investigating the removal of “modern” contaminants such as microplastics from the sludge and dealing with the issue of AD being a source of anti-microbial resistance (AMR) growth [10].

The use of electron beams has shown much potential for the removal of acid rain causing gases, SO_2 and NO_x, and volatile organic chemicals from the exhaust gases of marine diesel engines [11]. The technique was demonstrated with a real marine diesel engine in ARIES (see Fig 1) and studies are continuing in IFAST. This work includes the development of a toroidal electron accelerator which will surround the exhaust and direct the electron beam inwards through the gas, studies of novel, ultra-thin window materials able to withstand the exhaust gases and the development of a strategy to test the method on an operating ship.

Studies are also being made of the treatment of the ballast water from ships to remove organisms and other pollutants before the water is discharged into the sea. In certain regions, such discharges are not allowed without treating the water.

2.3. Accelerator imaging

This sub-task is exploring innovation in the use of particle beams for imaging, in particular in the security and medical areas. It has made an assessment of which imaging techniques have the most potential and is now examining what the main future requirements are for these. It has selected the following and identified what further studies are required:

- X-ray cargo scanning and non-destructive testing.
    - What are the advances that will shape that market in the next few years?
    - Are there any disruptive technologies?
    - Are there challenges without solutions?
    - Will compact muon sources ever become economic enough to find an application?
- Ion beam analysis for cultural heritage for which new compact radio frequency quadrupole (RFQ) based ion sources have been developed [12].
    - Can these devices be made mobile?
    - What applications is this technology most appropriate for, especially if mobile?
    - Can the technology be improved or made more cost-effective?
- Medical imaging.
    - Proton radiography has a lot of potential but requires 350 MeV protons. How can this be achieved in the most cost-effective manner?
    - Plasma technology offers compact coherent X-ray sources with higher resolution than current X-ray scanners. What is needed to break this technology through to the market?
    - Prompt gamma range verification technology also has much potential in radiotherapy, but how can this be made available in hospitals?

The next step will be to create a strategy for finding answers to the questions raised.

Figure 1: Test of treating the exhaust gases from the diesel engine in a marine tug in Riga harbour using a mobile accelerator from the Fraunhofer FEP Laboratory in Dresden, Germany (courtesy, HERTIS Collaboration)

2.4. Accelerator production of radioisotopes for imaging and therapy.

The sub-task is examining the production of medical imaging, therapeutic and theranostic radioisotopes and assessing improvements that may be required in the near future. It has determined that the following are needed:

- The development of innovative routes of production for therapeutic and diagnostic radionuclides.
- The development of optimized irradiation targets, that are interchangeable to allow use within the whole supply network.
- That there is an urgent need to achieve convergence on the radiation dosimetry and safety aspects of radioisotope use.

- That there is a need to ensure an adequate supply of radioisotopes, with reduction of costs along the whole supply chain.
- The demand for alpha-emitting radionuclides for therapy and theranostics significantly exceeds the supply, so new production routes need to be identified.

The sub-task is now developing a strategy for how these future needs might be met, as well as undertaking a study of how the radioisotope market might evolve in the future.

2.5. Barriers to accelerator adoption by industry.

This sub-task is studying the barriers which are discouraging some companies from benefitting from accelerator technologies. It will also use experience from companies that have successfully introduced them to address these concerns. So far, it has looked at technological, financial and knowledge barriers and identified a number. The accelerators used tend to be based on rather old technology. Although these work well, they can limit the performance that can be achieved. It is possible that technologies developed for research can help, but these must be made reliable and available at reasonable cost before they can be used in machines for industrial and societal applications. Another related concern is an absence of in-house specialized and auxiliary facilities and equipment for accelerator service and maintenance. This can in part be dealt with by the development of remote customer-support technologies. These can be used to monitor the accelerators, identify when servicing is required and aid staff in industry to do maintenance and some repairs. A third barrier identified is the absence of in-house accelerator experts and staff for accelerator operation, service and maintenance. This can be addressed by the introduction of dedicated educational schemes and study programs bringing together accelerator experts, IT engineers and users. Examples of such programs now exist, including the ARIES Massive Online Open Course (MOOC) [13].

The next step for this sub-task is to examine the legislative and security barriers discouraging the adoption of accelerators, before moving onto application specific barriers.

3. CONCLUSIONS

The IFAST Societal Applications Task is studying novel applications of particle accelerators in the medical, environmental and imaging areas. It has been active for one year and in that time has identified applications to focus on and a range of issues that need to be dealt with. The next step will be to develop strategies to overcome these issues and create roadmaps for the delivery of the new applications.

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