Proposal template
(Technical annex)

Research and Innovation actions

Future and Emerging Technologies: Call FETOPEN

Please follow the structure of this template when preparing your proposal. It has been designed to ensure that the important aspects of your planned work are presented in a way that will enable the experts to make an effective assessment against the evaluation criteria. Sections 1, 2 and 3 each correspond to an evaluation criterion.

⚠ **Page limit:**

The part B (cover page and sections 1, 2 and 3) is strictly limited to 16 A4 pages and shall consist of:

- **A single A4 title page with acronym, title and abstract of the proposal.**
- **Maximum 15 A4 pages consisting of an S&T section (section 1), an Impact section (section 2) and an Implementation section (section 3).**

All tables in these sections must be included within this limit. The minimum font size allowed is 11 points. The page size is A4, and all margins (top, bottom, left, right) should be at least 15 mm (not including any footers or headers).

⚠ **A proposal that does not comply with these page limits will be declared ineligible.**

Important remarks:
- *This strict page limitation does not apply to the other additional sections that contain information related to the description of the participating organisations and to the ethics self-assessment.*
- *The list of the participants' main scientific publications relevant to the proposal is to be included in section 4. Any other list of scientific publications relevant to the proposal must be included in sections 1-3, that is within the strict page limit.*

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Title of Proposal:

Innovative Single Stage Cyclotron for High Power Applications

Acronym: CYCLotrons for Accelerator-Driven Systems

CYCLADS

Abstract: More than 30000 accelerators contribute today in the world to different areas like radiation treatment, diagnosis, scientific discovery, industrial processes. However the accelerators of tomorrow, as they might be designed and manufactured by the European industry using the combination of new technologies in different domains, should bring this important S&T sector further ahead, shaping the future of Europe with new applications that cover interdisciplinary areas like carbon free production of energy, or even cleaner nuclear power. The CYCLADS project aims to generate a transformative impact to EU economy and society joining advances in accelerator expertise and innovative ideas on nuclear science and technology and superconductive materials to design a novel high power cyclotron able to source accelerator-driven systems which could spur nuclear isotopes production, nuclear materials development and advanced nuclear materials management. With regard the latter application, i.e. transmutation of nuclear materials posing longer-term radiological risks, CYCLADS seeks to change the technical-economic equation for accelerator-driven systems for so-called waste transmutation by bringing innovative and performing solutions alleviating most of the cost-drivers identified in ~~LINAC-based~~ other ADS-designs. Higher power accelerators are anyhow a necessity to address the waste transmutation option ~~where cyclotrons can make the difference in rendering this more economical than LINAC-designs have been proposing during the last decade~~ and single-staged cyclotron based ADS's may be useful as effective transuranic (TRU) transmuters in the light of ~~though~~ the technical-economic performance of this options ~~has mostly been jeopardized by the accelerator part and specific facets of the sub-critical reactor design.~~ After more than two decades R&D, especially in Europe, and building upon the best-updated technological insights in cyclotron and an experience-based look on sub-critical reactor designs, CYCLADS seeks to provide a more pragmatic and realistic ADS-option. A very important benefit of CYCLADS being the transposition of the CYCLADS's cyclotron design into very important applications as nuclear isotopes production and nuclear materials R&D as performing irradiation device.

~~The international R&D activity on TRU-transmuters has pointed to Accelerator Driven Systems (ADS) as the most effective mean for the intensive burning of the long-lived component of the nuclear waste.~~ Unfortunately, mainly because of the accelerator design considered to coupling with the sub-critical core, the past studies led to ADSs of complicate design and bulky layout, and hence predictably expensive and eventually not viable. The use of a cyclotron required so far the installation of several modules in series, with the result that cyclotron-driven ADSs appear both complicate and non-reliable; on the other hand, the Linac, the alternative accelerator deemed to be the more suitable for a high-power ADS, is expensive and requires large and bulky infrastructures. The state-of-the-art of the high-power ADS implies also the use of a heavy liquid metal, either Lead-Bismuth Eutectic (LBE) or pure lead, as both the beam spallation target and the reactor coolant. Also, the sub-critical systems of current design remain unsatisfactory.

The present proposal is intended to be a breakthrough in the ADS design, making it in principle adoptable by the market, by means of innovative solutions relevant to the three ADS components: the accelerator, the subcritical system and the target. The innovative components analyzed are i) a compact, single-stage superconducting cyclotron (SCRC) that can be easily accommodated within the same containment system of the reactor, ii) a very compact innovative subcritical system and iii) a short target.

In order to meet its objective, the CYCLADS project will gather a multidisciplinary group of EU leading experts in the key technological areas ensuring the full value chain is enclosed in a multifaceted analysis of the problem of radioactive waste disposal offering to decision makers not only technological innovation and advances, but also answers to questions such as: *What's the final pay-off of these technology developments? When could a market be envisaged and what are the key drivers influencing this market potential? What's the cost-risk-optimised level of activity and funding for innovative technologies in uncertain market context?*

The CYCLADS design of an innovative machine producing high power neutron beam, can later be translated to other S&T domains, like neutrino physics, nuclear isotopes production and nuclear R&D, Accelerator Driven Systems for clean energy production, water and gas pollution cleaning facility, therefore multiplying the societal and economic value. The high and medium high-technology manufacturing sector, where this area of development could be addressed, is worth more than 12 M employees in 2013 European landscape.

According to Eurostat data, values for 2008, before the crisis were at least 1 million more, indicating potentiality for growth.

List of participants

Participant No	Participant Organization Name	Country
1 (Coordinator)	European Organization for Nuclear Research - CERN	International European Interest Organization
2	AIMA	France
3	ASG	Italy
4	ENEA	Italy
5	Hydromine Nuclear	Luxemburg
6	iThEC	Switzerland
7	Nuclear-21	Belgium
8	PSI	Switzerland

Section 1: S&T Excellence

1.1 Targeted breakthrough, Long term vision and Objectives

One of the key challenges facing the nuclear fuel cycle is reducing the radiotoxicity and lifetime of spent nuclear fuel. EU (as well as the rest of the world) needs to address the issue of safe storing and disposal of radioactive waste. Partitioning or sorting of nuclear waste isotopes and accelerator-based transmutation combined with geological disposal can lead to a more acceptable societal solution to the problem of managing spent nuclear fuel. In fact, in about 60 years of nuclear power plants activity, Europe has been growing a large stock of radioactive waste that poses issues of safety, proliferation, environmental challenge and societal sense of security [from the IAEA Data Waste Counter, today in the world there are 29,620,000 m3 of radioactive waste, 1/3 of which in Europe]. In addition, as it is more apparent in the USA, the unduly long delay in providing tangible management solutions to this nuclear waste imposes financial risks to operators and governments which may render the nuclear energy less competitive and thus might remove a significant non-GHG emitting energy source for the future. The phasing out of the nuclear option, already progressing in many European countries, as a source of energy production, will neither resolve the waste problem, because a safe, definitive, accepted and viable solution is still to come for the nuclear reactor park having been operating since more than 50 years. On the other hand, if nuclear energy is ever to be accepted in Europe both at political, economic and societal level, this can only happen if the issue of the waste finds a technical and socio-political acceptable solution. As can be seen in Figure 1.1, the accumulation of radioactive waste produced by nuclear plants, is going to increase by more than a factor 2 in the next decades, in spite of the reducing numbers of prospected plants, therefore increasing also the dimension of the problem.

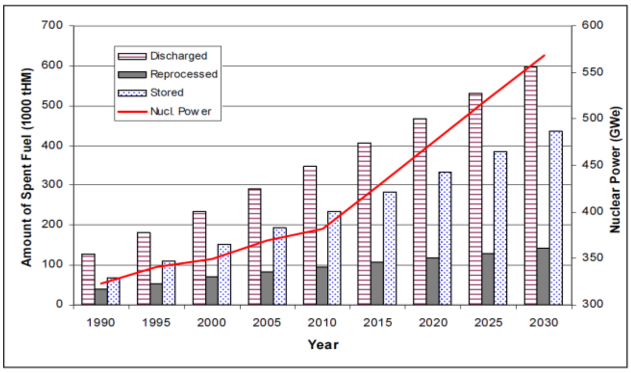


Figure 1.1 Spent nuclear fuel from nuclear plant worldwide. Data from IAEA-TECDOC-1613, April 2009

<u>The objective of the CYCLADS project is, by the combined and interdisciplinary action of superconductivity, innovative accelerator technologies, new materials, environmental and nuclear</u>

sciences, to present a concrete technical and more affordable solution for a major societal challenge helping Europe to attain leadership in the domain of radioactive waste management.

Starting from the current technology status and market outlook, we want to define the requirements for a high-power, compact, cost effective and easy to operate, cyclotron for transmutation of nuclear waste. The objective is to deliver a conceptual design that is in principle adoptable by the commercial companies. We plan to demonstrate the main conceptual aspect of our design with prototypes and Proof of Concept (PoC) demonstrators aimed to bridge the gap to industrialization. We plan to get a full understanding of the cost factors that so far have hindered the adoption of this technology and which may render the waste transmutation option more affordable than previous LINAC-designs.

The above-stated CYCLADS objective entails a **long-term vision,** however the project also provides a medium and short term perspective, because the developments from our activities are expected to foster cross fertilization in many different areas, one example are accelerators playing a role in environmental conservation through their use in processing water and flue gas, or paving the way for the next generation of neutrino experiments. Indeed, we aim to develop a design that can be also adapted to the requirements of neutrino and muon beams for fundamental research. In fact, high power cyclotrons, such as the world record facility PSI-HIPA[1], are being reconsidered as drivers for high precision measurements with capabilities to discover physics beyond the standard model: a high power cyclotron concept, could lead to important advances also into the future generation of accelerator projects for the next decade neutrino physics. [2]

The accelerator complexes proposed so far as drivers for energy amplifiers or waste transmutation plants, generally consist of large dimension machines (linear machines), or are assembled by the combination of two or even three cyclotrons, acting as injector(s) and boosters. This approach, because of the complex operation, reliability concerns, and overall dimension and costs of the plant, is not appealing. This is one of the main reasons why the original idea of ADS was never adopted. It has become now clear that cyclotrons for waste transmutation have to guarantee a high level of reliability, ease of operation and high conversion efficiency from electrical to beam power. In addition to that, R&D on ADS can only be accomplished with the help of accurate and state of the art MonteCarlo simulations, and an end-to-end package providing a complete solution to the problem of the design and optimisation is still missing. Moreover, most of the existing codes are not designed to take full advantage of the capabilities of modern processors and accelerators such as (GP)CPUs and Intel® Xeon Phi. The development of a complete simulation and optimisation system describing in details the functioning of an ADS system, including the thermal and isotopic composition of the materials involved and the fuel cycle, is now possible thanks to the combined capabilities of the new generation of high-performance computing architectures and to the excellence of the partners involved in this project in the field of MonteCarlo radiation transport simulation. CERN experience in the development of detector simulation software will be crucial to tackle the design features that CYCLADS aims to address. The use of innovative high temperature ductile superconductor, like MgB2, will make operation simpler and cheaper, and design more compact, avoiding large cryogenic complications. The manufacturing experience of the industrial partners of the Consortium will produce a realistic and credible design that will take into account from the start the feasibility issue of the most difficult components. The design objectives of compactness and simplification of the cyclotron will be complemented by the proposed

[1] 1.4 MW protons on target at 590 MeV.

[2] Advances in High Energy Physics, Volume 2014 (2014), Article ID 347097, 22 pages; http://dx.doi.org/10.1155/2014/347097 Review Article, Cyclotrons as Drivers for Precision Neutrino Measurements: A. Adelmann,1 J. Alonso,2 W. A. Barletta,2 J. M. Conrad,2 M. H. Shaevitz,3 J. Spitz,2 M. Toups,2 and L. A. Winslow4;

compactness of the sub-critical system. This is mainly obtained taking advantage of the LFR-As-200 design recently proposed by Hydromine which allows the compaction of the reactor assembly of a Lead-cooled Fast Reactor (LFR), up to achieving a volume of the primary system per unit power of less than 1 m^3/MWe, a value about 4 times lower than that of the SPX1 Sodium-cooled Fast Reactor (SFR), and also several times less of that of the international LFR projects disclosed so far to the international community. The proposed fuel assembly of the project includes additional improvements, which present strong benefits, namely the vented fuel pins and the improved core thermal reactivity feedbacks. The fuel pins, vented towards an ex-vessel decay storage, are relieved from any inner overpressure, which otherwise could be critical in a fuel loaded with Minor Actinides (MAs) due to the increased generation of fission gas, thereby allowing a substantial increase of the fuel lifetime. The improved thermal reactivity feedbacks of the core, enhancing the intrinsic response of the system against any possible accidental transients, allow to increase the k_{eff} while operating the reactor in safe conditions; this in turn permits to reduce the proton beam power per unit power of the reactor. The recent progress in lead technology (fuel rod coated with alumina) will be used, and we will propose a coolant, which is safe and economic.

The project has a number of concrete objectives that will be achieved over 3 years:
1. present the conceptual design of a high power innovative cyclotron able to tackle the challenge of radioactive waste reduction 2. introduce in the design innovative concepts, like HTS and multiple injection source, in order to increase the reliability of the machine, reduce its cost and dimension and increase its simplicity of operation, 3. study the coupling and interfaces of the cyclotron with the spallation target and with an innovative, compact subcritical system to deliver a credible concept for a viable ADS transmuting radioactive waste 4. develop a complete integrated code system, able to evaluate spallation, particle transport process effectively and accurately 5. present a life-cycle analysis of the machine operation to demonstrate the economic viability of the proposed process and its safety for all foreseen applications (waste transmutation, heat/electricity generation, radioisotope production, etc…) 6. manufacture industrial proof-of-concepts able to demonstrate, on a meaningful scale, the technical viability of the proposed solutions

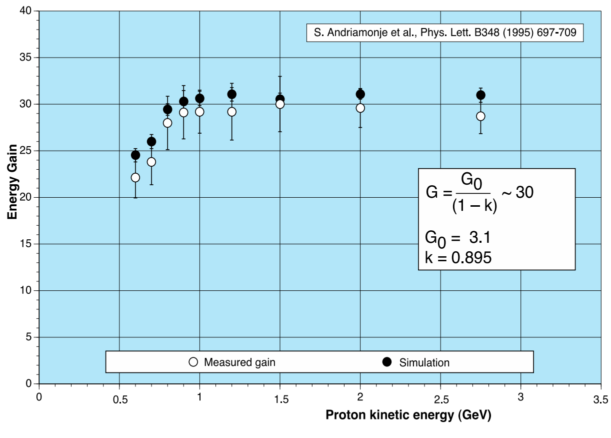


Figure 1.2 FEAT experiment data

FEAT experiment at CERN has demonstrated that to achieve a proper transmutation efficiency, it is necessary to produce a beam of several MW. At this power, one aspect to address carefully is the beam losses at the accelerator site. For this problem a novel approach of analysis, based also on recent investigation made in ETH and PSI and that foresees both modelling and experimental verification will be employed. This innovative model will allow the investigation to focus on the dynamics of the halo particles and estimate the halo extent, introducing for the first time in this analytical description, non-linearity effects. In this new[3] "reduced order model" we can have good statistics, much more than in the traditional particle core model and this will improve significantly the modelling capabilities w.r.t multi objective optimization. Due to the computationally inexpensive nature of this model, large-scale multi objective optimisation is feasible, with real number of halo particles and hence we obtain the required statistics to estimate controlled and uncontrolled beam losses.
A careful and comprehensive uncertainty quantification (UQ) of the beam dynamics model (sensitivity analysis, forward uncertainty propagation and quantifying of parametric uncertainties), will contribute to the robustness and validity of the full Start-to-End (S2E) models, with the goal of halo characterisation and mitigation. The thermal stresses on the reactor components coming from unwanted trips of the beam is one of the technical challenges we aim to address by increasing the beam reliability. Both the experience of PSI that is running the largest world cyclotron with a beam availability close to 98% than the proposed multi-injection line will be key aspects into making it a valuable design.

Another innovative aspect of our project is the magnetic configuration of the cyclotron we propose. This patented "reverse-bend" configuration is critical to allow for the first time a Single Stage accelerator system for the ADS. Indeed the current reversal in the central area allows to accelerate particles at low energy, with higher currents and therefore with strong focusing, strongly mitigating one of the typical problems of conventional accelerator of this type.

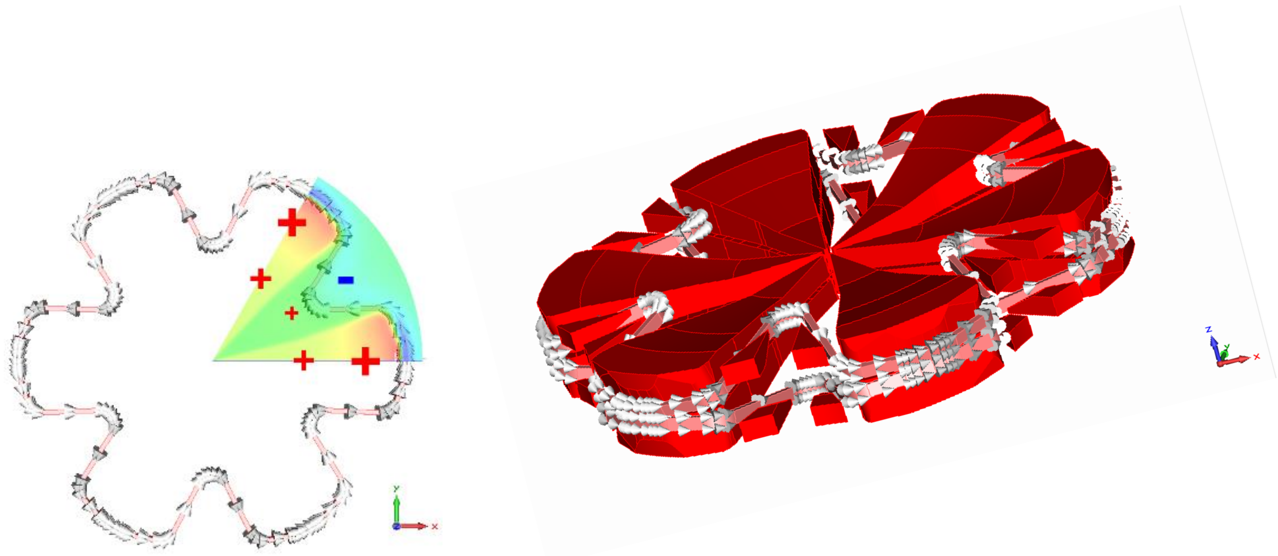


Figure 1.3 AIMA magnetic configuration "reverse-bend" current

[3] PSI research in reduced order models and multi-objective optimization was awarded with the PRACE (Partnership for Advanced Computing in Europe) award in 2012 (http://www.prace-ri.eu/the-prace-award-winners-2012/)

1.2 Relation to the work programme

The CYCLADS project in the frame of the H2020 FET-Open-01-2016-2017 RIA work programme called “FET-open Research project”, will confront the specific challenge of:

The successful exploration of new foundations for radically new future technologies requires supporting a large set of early stage, high risk visionary science and technology projects to investigate new ideas. Here agile, risk-friendly and highly interdisciplinary research approaches are needed with collaborations that are open to all sciences and disciplines and that dissolve the traditional boundaries between them. The renewal of ideas is complemented by the renewal of actors taking these new ideas forward. Therefore, this topic encourages the driving role of new high-potential actors in research and innovation, such as excellent young, both female and male, researchers and high-tech SMEs that may become the scientific and industrial leaders of the future.

CYCLADS, based on the interdisciplinary composition of the Consortium, which includes leaders in field of cyclotron operations and design, accelerator science, nuclear physics and engineering, and European leading industries in superconductivity and new materials domain, will aim to introduce and demonstrate game-changing concepts for the nuclear and accelerator industry. The integrated operation of the proposed single stage cyclotron will provide an effective solution for the transmutation of the radioactive waste, for clean, carbon free, energy production, and for HEP physics. **In fact CYCLADS has the vision to present a more affordable ADS-option as specific value-adding component in advanced nuclear energy systems which increasingly require using advanced fuels, specifically transuranic fuels as well as more fertile fuels as thorium, that benefit from the use of particle beams. Both these approaches could lead to an increase in power generation through greenhouse gas emission-free nuclear energy and could provide a long-term strategy for the energy supply in Europe, opening a completely new line of market for the cyclotrons business, with expected large impact on new jobs creation in Europe.**

In addition to radioactive waste transmutation and clean energy production, the cyclotron could cross-fertilize areas as diverse as neutrino physics. Accelerator-based neutrino sources are central to the future physics research programme in Europe, where technical advances are required to deliver the “headline” long- and short-baseline experiments and the programmes required to minimise systematic uncertainties. The exciting neutrino-physics programme of the next decades will depend on advances in accelerator capability and on how CERN will continue to play leading and seminal roles in the programme.

1.3 Novelty, level of ambition and foundational character

CYCLADS ambition is to demonstrate a viable and economical contribution to the solution of management of the exponential increase of the planet stock of nuclear radioactive waste. According to IAEA analysis referenced in fig 1.1 the quantity of radioactive waste is expected to grow exponentially in the next 60 years, even in the case where all nuclear plants on the planet were phased out now. The info-graphics below shows the today and medium-term projected Nuclear Energy Systems, indicating how much Europe is involved into the challenge.

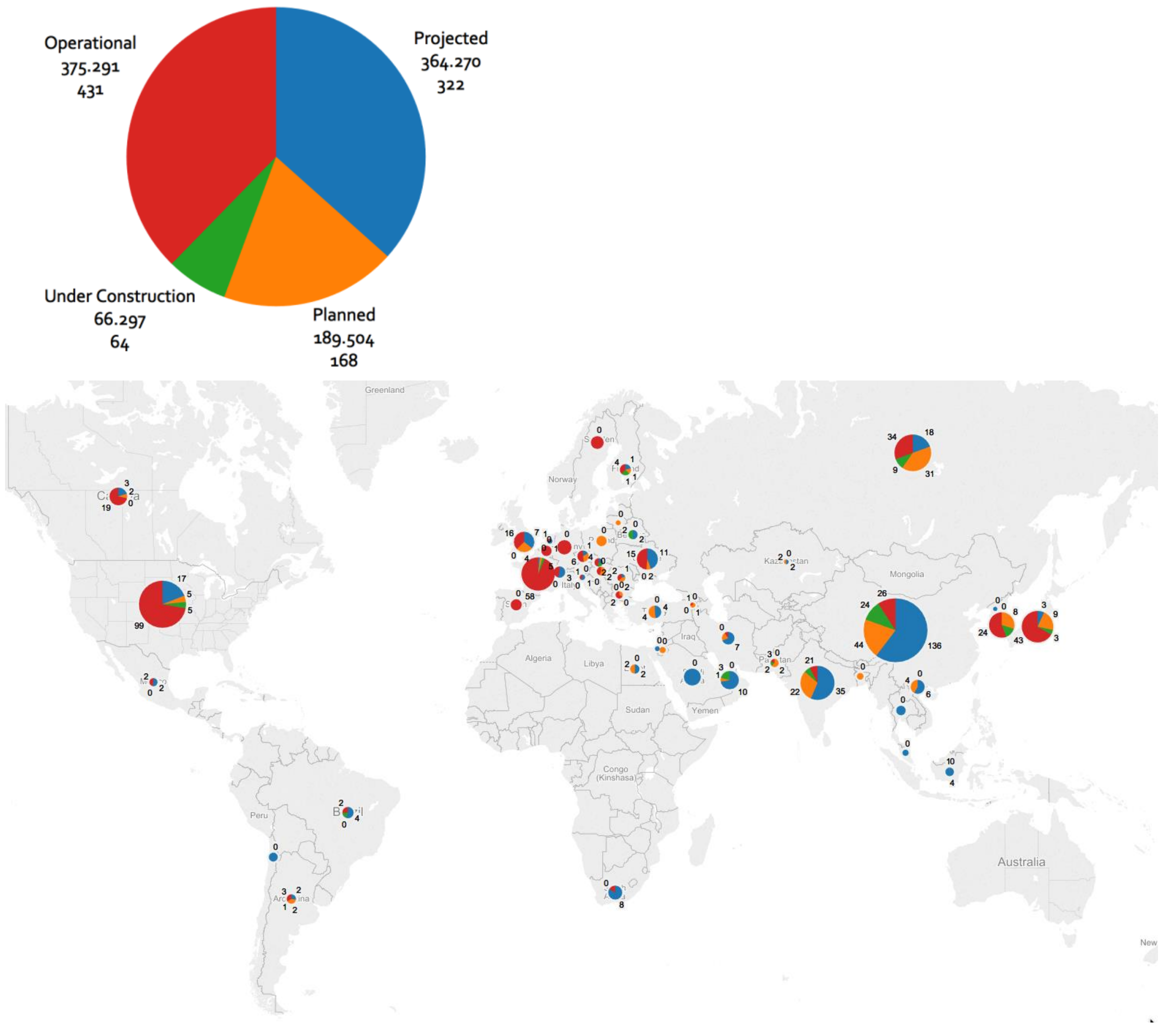


Figure 2.1 Nuclear energy System distribution

Realistically, there is no single valid solution. At the moment, geological disposal is the only end-point option that is being actively pursued for nuclear waste storage. However, the extremely long period during which nuclear wastes must be isolated casts doubt on our ability to guarantee a safe system of disposal. None of our political or social institutions have been stable over a period of 1,000 years, therefore there is no way to ensure that a stable monitoring system can remain in place as long as necessary. Moreover, the geologic disposal of radioactive waste requires a series of complicate analyses to entrust the site for use: mechanisms of groundwater flow into and radionuclide transport out of the repository must be identified and possibly followed for decades; the geologic behavior of the repository area and of material response must be predicted over time spans of hundreds of thousands of years. Last but not least, ethically, we do not have the right to burden future generations with the potential risks posed by nuclear wastes unless we've provided the options to minimise them at best and keep options open for future improved management.

We are convinced that partitioning (separating the waste), reprocessing and transmuting is the acceptable solution, both morally acceptable and economically sustainable, on a human time scale. We expect a larger community gathering around the idea of providing a viable contribution to solve a planet problem, both by the supporters of nuclear industry and by those who are persistently opposing it. ~~The ambition of the project is well based on the know-how of CERN and PSI in particle interaction with matter, and on the seminal work on this topic by Nobel Prize scientist (*ref to Rubbia work on this*.....), of research activities carried out in CERN and outside~~

~~*(ref….)* on the capability of laboratories like PSI that operated since many years the largest cyclotron in the world, and as well on the innovative contribution of industries that are leader in their respective technical field in Europe and in the world.~~As nuclear energy is an essential part in any realistics path towards sustainable energy provision to the world, increasing innovation is required in nuclear energy to match this objective. CYCLADS, based on the collective knowledge of world-renown experts within its consortium, seeks to address this objective of providing a more performing and more affordable option towards such sustainable nuclear energy use worldwide.

Paving the way to a new line of industrial applications, the CYCLADS project will be also **foundational,** because the design of the innovative cyclotron will help the development of the next generation of detector simulation code replacing GEANT4 code and as well establish new possibilities for commercial and diverse exploitations, such as the mentioned clean energy production (via Thorium fuel cycle) or neutrino physics. The **novelty** aspect is represented by the use of advanced computing architecture optimized for the simulation of spallation and particle transport processes, the comparative simplicity of the machine we propose, its compactness, reliability and economics. As for the safety aspects, the proposed ADS will include passively actuated and passively operated decay heat removal systems, which means that Fukushima type accidents cannot occur.

The unprecedented linear dimension of the new concept cyclotron, thanks also to the combination of HTS, multiple injection sources and compact subcritical system, makes it easily deployable in proximity of existing reprocessing or re-fabrication plants, opening to the concept of shared, regional fuel management complexes, providing a comprehensive service to the present nuclear plants, while reducing the risks connected with transportation and storage of the fule. The reduction in size of the subcritical system is achieved through a process of simplification, that in addition to the absence of intermediate circuits, a feature common to any other LFR project, has allowed to eliminate several components typical of SFR and LFR, namely (i) the in-vessel refueling machine, (ii) the above core structure, (iii) the diagrid, (iv) the strongback, (v) the shielding elements, (vi) in-lead bearings of the pumps, (vii) the "LIPOSO" or equivalent tubular hydraulic connection between pumps and core and (viii) the "Deversoir" or equivalent system to maintain the reactor vessel at homogeneous temperature of the cold collector. The advantages of the innovative MgB2 approach can be various: possibility to use a cryo-free cooling concept, higher thermal and superconductive stability than NbTi based conductor, perspective cost reduction of conductor and cost reduction also of the machine operation, with increase in its simplicity.

1.4 Research methods

The cyclotron, the spallation target and the subcritical system are the principal elements of the system we are investigating. We will design the spallation target and develop the simulation code describing in details the functioning of an ADS system, including the thermal and isotopic composition of the materials involved and the fuel cycle. These components will be optimized together with the reactor core design taking into account the accelerator specifications. We believe that the most important part of our design is the cyclotron component, able to produce a particle beam of the necessary intensity and power. However, the target and the subcritical system are included into our conceptual design because we need to demonstrate the full and credible integration into a complete system with all the necessary components. The reactor core will be investigated up to the technical and safety interfaces. Even if our principal focus will be the accelerator and the integration of the machine, this does not mean that we are going to use "conventional" concepts for the target or subcritical system: innovative concepts will be developed here as well. For example, our proposed innovative nuclear core is presenting a reduction in dimension (and hence in cost) of a factor of 5, or even 10, compared with equivalent systems, thanks to the introduction of innovative components and eliminations of several others no more needed, while increasing the overall safety. In this sense the proposed design intends to be breakthrough even with respect to the past European Project IP-EUROTRANS, relatively to the accelerator, to the subcritical system and also to the fuel cycle.

The proposal will be implemented via a collaborative effort between the companies (1) AIMA, which is a French company leader in EU for the design of cyclotrons and has a long record of realization of cyclotrons for medical and industrial applications, (2) ASG, Italian company which is leader in the EU market of superconductive magnets for different applications like fusion, accelerators, medical and research, (3) CERN which is the site of the largest accelerator in the world, (4) the Hydromine Nuclear Energy company, based in Luxemburg, whose professionals have long record in nuclear engineering and research and hold many patents of specific interest for this project (5) iThEC a not for profit organization based in Geneva and active for the promotion of Th application in nuclear energy (6) Nuclear-21 a consultancy based in Belgium with strong tie with nuclear industry and (7) PSI that is a world leader in cyclotron technology, (8) ENEA that is one of the leading companies in the development of the lead technology for application to nuclear systems.

1.5 Sex and Gender consideration

We aim to reach a minimum balance of 70% - 30% of men/women in the project, and we will strive to increase the women contribution of the female scientists, mainly through the PhD and post-doc that will be hired for the tasks development.

1.6 Interdisciplinary nature

CYCLADS has a deep interdisciplinary nature bridging different domains of advanced science and technology: superconducting magnet technology, nuclear engineering, physic simulation and software modeling, accelerator based exploration, neutronic and material science, high energy physics and particle physics are all together in a synergistic mixture that provides reciprocal benefits and compounds the possibilities of exploitation.

For example, one of the CYCLADS **ambitions** is to design a machine that could be used as well for neutrino physics: preliminary analysis made in CERN indicate that …add here contribution from Ceccucci…

In addition to high-flux neutrino physics and muon or meson beams, the production of abundant, clean and safe energy, and the production of radioisotopes for medicine are all sectors of research that can strongly benefit from the project and its cross fertilization. Neutron and gamma generators are widely used for a broad range of applications of strategic importance in national security (e. g., active interrogation techniques for detection of nuclear material, nuclear non-proliferation and safeguards), industry (e. g. well logging and materials metrology) and in emerging medical applications (e. g., Boron Neutron Capture Therapy). A sustained and focused R&D effort is urgently needed to develop the scientific and technological underpinnings of advanced neutron and gamma generators with game changing capabilities that enable their wide spread field use in highly strategic areas of national security, industry and materials science.

We expect that CYCLADS, demonstrating a commercially viable high intensity neutron source, will be able to address as well the worldwide demands in the several domains indicated above.

Section 2: Impact

2.1 Expected impacts

To remain competitive, the European effort in the domain of high-power beams must be increased and broadened, at a time when United States of America, India and China have dedicated programs to develop the high intensity accelerators of tomorrow (*ref here ……)*

For this, Europe should make use of its unique infrastructure and know-how represented by particle physics laboratories such as CERN and PSI and, at the same time, exploit the synergy with the industrial partners to develop alternative accelerator technologies, aiming at a broad spectrum of industrial and research applications.

In Europe, at present, the main developments are based on LINAC type accelerators with the European neutron Spallation Source (ESS) in Lund, Sweden, and with the MYRRHA Accelerator-Driven System (ADS) project in Mol, Belgium.

However, the cyclotron we propose with a beam energy ranging from 600 to 800 MeV and a beam power from 3 to 5 MW, different from the linear machines, because of its compactness and innovative design based, among other things, on superconducting magnets, offers the possibility of a cost effective solution for high-power protons beams and provides benefits in terms of energy efficiency, reliability, robustness and impact on the environment.

CERN has developed strong expertise in Accelerator Driven Systems (ADS) through the work of Nobel Prize Laureate and former director general of CERN, Carlo Rubbia. Twenty years ago, CERN filed a patent on innovative transmutation methods. Superconducting technologies are a key toward a highly energy-efficient next generation cyclotron.

"kick starting an emerging innovation eco-system of high potential actors around a solid baseline of feasibility and potential for a new technological option, ready for early take-up".

It is equally important to note that ADS should open the way to the use of Thorium fuel instead of uranium fuel, whose impact on the society would be impossible to minimize. This will make nuclear energy essentially sustainable on the human time scale and socially acceptable, since Thorium is many times more abundant and efficient than Uranium, thanks to the fact that it is practically proliferation immune and the waste produced during its burning are highly minimized. The minimization of waste production and the waste management simplification of the Thorium fuel cycle are raising growing interest in the scientific community worldwide, because the waste issue is perceived as one of the major road blocks toward a systematic deployment of nuclear energy. iThEC, one of the partners in this proposal, has the goal of promoting R&D for the exploitation of Thorium in the energy sector. ADS are subcritical, which means that Chernobyl type of accidents cannot occur. ADS based on a subcritical system with passively operated and passively actuated DHR eliminate risks of events like Fukuijma. ~~Furthermore, with Thorium fuel, ADS are highly resistant to nuclear weapon proliferation.~~ They also offer the possibility of modulating the electric power production, which would facilitate the complementary deployment of intrinsically varying renewable energy sources, such as solar and wind.

Considering the large economic and safety implication for a system like the one we aim to introduce, we cannot expect start-ups companies to take up its design for immediate industrialization. Instead, we believe that the impelling necessity to address the planetary

requirements for clean energy and waste management shall drive the political will of European countries to consider taking up the technical offer that we are preparing for further important developments. In this sense, we aim to complete our technical design with a **Technical-economic and socio-political assessment of the merits and risks for advanced nuclear separation and transmutation (S&T) technologies, allowing EU to set a road map to deploy valid solutions for the interests of the planet.** We aim to increase public engagement on the subject by a wide action of dissemination: all the partners are already working, separately, on promoting events and workshops on this specific technical matter. In the late years there has been a growing interest into the topic and an ideal drive on this subject is witnessed by the number and quality of workshops and specialized conferences *(ref….)*. CERN will host in the next months, in the frame of the EUCARD-2 project and with EPS support (ref here) just another workshop on ADS and their possible application., with participation of politicians and scientist.…
Include table with expected impact

Expected impact	Contribution of CYCLADS
Enlarge the portfolio of viable solutions to the radioactive waste management	CYCLADS will demonstrate the viability of the ADS to burn MAs
Extend the deployment of a CO2 free and safe energy source	The conceptual design complemented by proof of concepts and demonstrators will provide evidence of the technical and economic benefits of our project.
Active involvement of new and high potential R&I players.	The project will lead to new collaborations between important actors in nuclear physics, HEP physics, and the nuclear industry.
Offer to HEP community a tool for investigating physics beyond standard model	CYCLADS will boost new direction in HEP contributing to the new generation of neutrino and meson physics experiments

2.2 Measures to maximise impact

a) Dissemination and exploitation of results

The WP1 leader will develop a detailed communication and dissemination plan showing how data generated by the project are collected, used and manipulated during the project life-cycle and beyond. The main target audience will be the scientists working on ADS worldwide. But not limited to these, we want to involve also industries of the nuclear, energy and environmental sectors, neutrino physicists, and decision makers on energy matters. The aim of the communication plan is to present to a wide audience a realistic pathway to radioactive waste management and to engage from the very early stage of design both the industrial and the academic sectors in order to meet the unprecedented level of technological and political challenge.

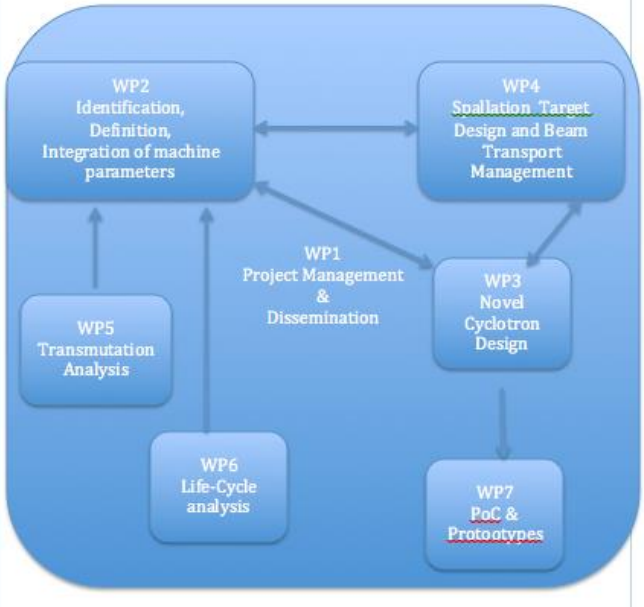
b) Communication activities

The communication activities will be facilitated by a collaborative workspace for project members and a public website with dedicated links that will help sharing and enhancing knowledge of technical information between academia, industry and general public. This will also help increase general awareness of the waste management challenge and demonstrate the benefit of the project collaboration to the policy makers. Policy makers will be informed about costs and benefits of the solution, scientists will have a base for exchanging of technical information, the general public will be exposed to data on which basing their informed judgement.

In addition to the usual participation to conferences, presenting progress of the project activities, and publishing related papers, the collaboration will organize annual meetings and as well 3 (?) workshops and events of the type “academia meets industry” to gather as many experts and policy makers around the same table of discussion, proposal making, technical information sharing.

Section 3: Implementation

The project is structured in 7 Work packages, whose inter-relationship is illustrated in Fig.2



WP1 is managed by CERN, in charge of the management tasks for the projects. CERN will act as host lab for the activity of coordination and will make use of the expertise and know-how in managing EU funded projects in its dedicated office with competences in the administrative sector. CERN will be integrating all the activities of the consortium, individuating and defining interfaces and ensuring consistency of the work according to the plan and financial follow-up.
PSI is leading WP2, developing full Start to End (S2E) models of the cyclotron designs, with the goal of halo characterisation and mitigation. Additional research on novel space charge models for high power cyclotrons, including ROM (reduced order models) will for the first time enable multi-objective optimisation in the process of halo mitigation.
Eventually PSI will perform calibration and benchmarking of the models with existing data from the PSI proton cyclotron facility and/or data from dedicated beam experiments of the PSI-HIPA facility. This also includes the understanding of high power beam diagnostics needs and their relation to the beam dynamics model.

AIMA will lead WP3 and in collaboration with ASG and the others partners, will contribute to the magnetic, mechanical and cryogenic design of the Cyclotron, in order to define the characteristics of the magnet, the issues to be developed and the technologic challenges to resolve. Based on its long experiences, ASG will give a contribution on feasibility of this project investigating on design and manufacturing aspects and in so doing validating the model analysis and the assumption of cost and operations.

HNE, within WP4, will devote to the full integration of the Single Stage Cyclotron (SCRC) with the target and the innovative subcritical system.

iThEC is leading WP5 and will take care of the Nuclear Assessment studies, contributing to the optimization of the machine parameters by developing an advanced simulation code to describe, among other things, spallation and fuel cycle evolution.

WP6, led by Nuclear-21 will present a thorough market analysis for advanced nuclear technologies addressing radioactive material management, sketch the development and deployment scenario matched to the market prospects, and will assess the Technical-economic and socio-political benefits for advanced nuclear separation and transmutation (S&T) technologies.

WP7 (ASG, AIMA) will be dedicated to the Proof of Concepts and prototypes. Indeed we realize that the project shall need to be complemented by manufacturing evidences and demonstrators, if we aim to offer an appealing design for industries. Therefore, any problematic aspects relative to magnet design and/or to the multiple injection lines, will be especially investigated by means of PoC and prototypes. For example, the use of MgB_2 based conductor will be demonstrated in all the typical aspects related to conductor performances.

3.1 Project work plan

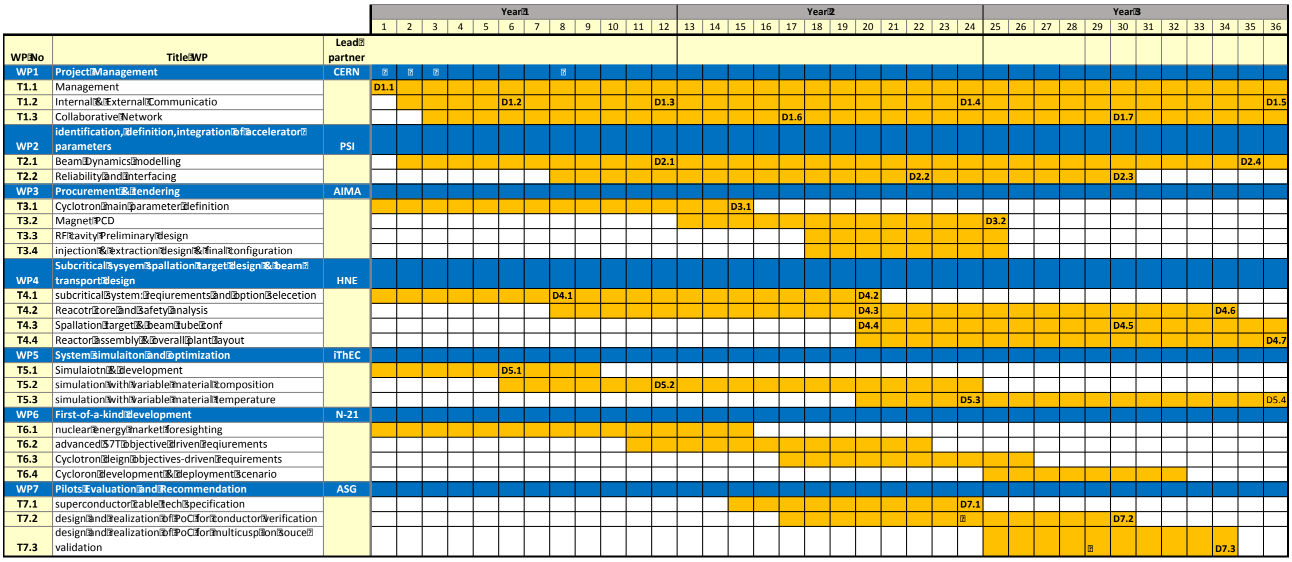


Table 3.1a: Work package description

Work package number	1	**Lead Beneficiary**					
Work package title	Management, dissemination, integration						
Participant number	1						
Short name of participant	**CERN**						
Person/months per participant:	72						
Start and end month	M1-M36						

Objectives :

- Implement the Work Plan with efficient organization and management of the project, with on-time and on-cost delivery of the scope
- Develop the synergies with the partners and links with EC
- Manage IPR, reporting, dissemination in and out of the Consortium.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

Task 1.1. Management

- Effectively manage and steer the whole project
- Monitor and report on the overall scientific and technical progress
- Contractually and financially follow-up project and report the use of resources
- Manage the administrative and IPR aspects of the research carried out
- Coordination of legal issues and project risk management

Task 1.2. Internal & external communication, dissemination, scientific publications

- Coordinate and Monitor the publication efforts of the project community
- Maintaining contact with EC
- Plan and implement project communication strategy
- Communicate the publication status to project leaders
- Prepare the periodic and final reports
- Organise meetings with beneficiaries and external collaborators, as well as industry

Task 1.3. Collaborative Network on advanced ADS systems

- Organise workshops (target, reliability, ….) open to the whole community and dedicated mini-workshops on specific topics, establish a communication web-based tool for facilitating exchange of information and documentation on the project.
- Identify mechanisms ensuring sustainable collaborative R&D on ADS systems.

Deliverables: D1.1 Consortium Agreement, D1.2 Data Management Plan, D1.3 Progress report (Mx, My), D1.4 Final report to EC, D1.5 workshops organization (Mx, My, Mz)

Work package number	2	**PSI (iThEC ?)**					
Work package title	Identification, definition and integration of machine parameters						
Participant number	8	2	3	1	5		
Short name of participant	PSI	AIMA	ASG	CERN	HNE		
Person/months per participant:	96						
Start and end month	M1-M36						

Objectives:

- Non-linear beam dynamics design and large scale optimization for halo characterization and mitigation
- Definition and analysis of key beam parameters for the high power accelerator
- Definition and analysis of the reliability requirements for the super conduction ring cyclotron
- Validation of the models with calibration and benchmarking activities

Description of work. Together with all other participants, to establish a set of functional specifications for the SSRC including the required beam dynamics (BD), beam losses, emittances and reliability. The latter has to be done in close collaboration with other WPs. A full S2E model will be developed, including the transport line to the target.

Task 2.1 Beam Dynamics Modelling

- Characterization of halo particle formation using the high-fidelity, open-source beam dynamics code OPAL (Object Oriented Parallel Accelerator Library)
- Halo mitigation through optimisation of initial conditions and collimator placing
- Large scale system optimization with the Reduced Orbit Model (ROM)

• Sensitivity analysis of the BD model and identification of crucial design parameters • Includes the injection and extraction system in the S2E model. • Model validation with the high fidelity OPAL model and PSI-HIPA data **Task 2.2 Reliability and interfacing** • Minimum reliability requirements for a demonstrator • Reliability requirements for a production machine • Interface parameters between accelerator and target • Define functional cyclotron parameters **Deliverable** D2.1 S2E beam dynamics model & golden table (w.r.t. beam dynamics) of the facility D2.2 Estimation of halo that contributes to controlled and uncontrolled losses D2.3 Uncertainty quantification of beam dynamics model D2.4 Validation of the used model using data from the PSI-HIPA facility

Work package number	3	**AIMA**				
Work package title	Novel Superconducting Ring Cyclotron SCRC					
Participant number	2	3	1			
Short name of participant	AIMA	ASG	CERN			
Person/months per participant:	72	39	4			
Start and end month	M1-M36					

Objectives: Define, design and optimize the components and sub-components of the Single Stage Ring Cyclotron (SSRC)

Description of work. Under AIMA leadership this WP will define the general concepts of the Cyclotron, up to a final Conceptual Design. The contribution of ASG is scheduled in the 5 phases of the activities, to validate concept and technologies, fully validating the feasibility, and to optimize construction costs, based on its past experiences

Task 3.1: Cyclotron main parameters definition

Task 3.2: Magnet preliminary Conceptual design in collaboration with ASG: this task is made of 5 Phases with validation with ASG at the end of each Phase.
The conceptual magnet design , that is up to ASG , will be composed by the following phases that can be an iterative process with AIMA

- Feasible Magnetic design
- Conductor conceptual design
- Mechanical conceptual design
- Cryogenic conceptual design
- Conceptual Magnet protection design

Task 3.3: RF cavity preliminary design made of 2 phases. Phase 2 includes a participation of CERN specialist

Task 3.4: Injection design

Task 3.5: Extraction design and final configuration

Deliverables: D3.1 (Cyclotron main parameters definition), D3.2 (Conceptual Magnet Design)

Work package number	4	**HNE**	
Work package title	Subcritical system spallation target design & beam transport design		

Participant number	5	1	6	8	4		
Short name of participant	HNE	CERN	iThEC	PSI	ENEA		
Person/months per participant(* here I have preliminarily used a cost/month of 5000 Euro):	88	10	20	20	38		
Start and end month	M1-M36						

Objectives:

- Definition and verification of system configuration and overall Plant Layout
- Spallation Target and reactor core definition
- Functional coupling of the cyclotron with target and reactor core

Description of work. The activity will provide verification of a consistent system configuration, including the Containment System and the Overall Plant Layout. The reactor core targeting transmutation will be defined as well as a Reactor Assembly Configuration complying with all the interfaces among Cyclotron, Target, Core and main components of the primary system.

Functional coupling of the Cyclotron with the Target and Reactor Core via spallation process will be considered including power transfer from the core and target via SG and DHR systems. Given the great compactness of the cyclotron, its installation inside the reactor containment system will be addressed.

Task 4.1- Subcritical system technology: general requirements and options selection (HNE, PSI, iThEC, ENEA, CERN)

- Definition of requirements of the subcritical system and associated spallation target
- Licencing analysis of the whole concept.
- Identification of the interfaces for the mechanical design of the Fuel Assembly

Task 4.2 - Reactor core and safety analysis (ENEA, iThEC, HNE, CERN)

- Definition of the design objectives and constraints resulting also from the required interfaces (including the level of sub-criticality)
- Definition of an uranium-free core for the lead-cooled ADS
- Reference core configuration baseline and safety analysis

Task 4.3 Spallation target and Beam tube configuration (HNE, PSI, , iThEC, ENEA)

- Definition of technical options for the target system and for the spallation loop components (HNE)
- Definition of the shape of the proton beam and beam tube (PSI)
- Definition of the isolation window(s)and bending magnet on the beam line between the cyclotron and the target (PSI) and their impact on component handling and the refuelling system (HNE).

Task 4. 4Reactor Assembly Configuration and overall Plant Layout (HNE, PSI)

- Definition of the main components of the subcritical system
- Overall ADS configuration including functional and mechanical interfaces among cyclotron, beam pipe, target and subcritical system.

General arrangement drawings including cyclotron. beam pipe, target and subcritical system

Work package number	6	**iThEC**					
Work package title	System simulation and overall optimization						
Participant number	6	3					
Short name of participant	iThEC	CERN					

Person/months per participant:	54	12					
Start and end month	M1-M36						

Objectives:

- Development of an integrated software for MonteCarlo simulation of spallation and particle transport for ADS system, in the range between hundreds of MeV to 10 GeV.
- Using the developed code, simulate the geometry of beam, spallation target and subcritical core, optimizing proton beam energy vs beam intensity
- Optimization of other machine parameters like power, time structure, losses into the environment footprint on spallation target
- Feedback on overall performance of the machine and cost analysis

Description of work. This WP will develop a complete simulation and optimisation system describing in details the functioning of an ADS system, including the thermal and isotopic composition of the materials involved and the fuel cycle. This will be done by combining the capabilities of the new generation of high-performance computing architectures to the know-how of the partners involved in this WP in the field of MonteCarlo radiation transport simulation. The code, processing available nuclear data, will create a set of data libraries in a format suitable to be used as input to the simulation process, and to describe the nuclear spallation process in the region between hundreds of MeV and 10 GeV, the generated particle transport and interaction with the matter. The code will also allow adjusting dynamically the material composition, cross-section Doppler broadening, geometry and to calculate classical scoring such as energy deposit, material damage, heath generation. Eventually, mix full and fast simulation techniques per region or particle and evaluating material composition evolution during transport for nuclear cycle studies.

Task 5.1 – Simulation tool development

- Development, tuning and validation of the hadronic interaction packages describing the spallation region to make sure that the particle production, and in particular the neutron yield is described correctly;

Task 5.2 – Simulation analysis with variable material composition

- Introduction of macroscopic time-steps in the simulation framework to allow simulating evolution of a device and its burnup over months or years with variable conditions and variable material composition
- Development of the possibility to include variable material composition during the same simulation, driven by full Bateman equations and particle flux calculations;

Task 5.3 – Simulation analysis with variable material temperature

- Development of the possibility to include variable material temperature during the same simulation, including recalculation on-the-flight of the Doppler broadened neutron cross-sections and other temperature-dependent features;

Deliverables: D5.1 Spallation-optimized, (M6) D5.2 Time dependent simulation to study burnup over long period (M12), D5.3 Simulation package for the study and optimization of the CYCLADS system (M24), D5.4 Final report on the simulation activities,

Work package number	6	**Nuclear-21**					
Work package title	Technology and Market Outlook						
Participant number	7	1					
Short name of participant	Nuclear-21	CERN					
Person/months per participant:	36	2					
Start and end month	M1-36						

Objectives

- Present a thorough market analysis for advanced nuclear technologies addressing nuclear material management;

- Technical-economic and socio-political assessment of the merits and risks for advanced nuclear separation and transmutation (S&T) technologies;
- Sketch the development and deployment scenario matched to the market prospects

Description of work. Advanced nuclear technologies, such as high-power cyclotrons intended to address nuclear material management objectives, face uncertain technology and market prospects given absence of sufficiently long-term energy and technology development vision in most countries. It is therefore important for energy and technology development stakeholders to have a clear decision-supporting framework allowing to address critical questions on (a) What's the final pay-off of these technology developments? (b) When could a market be envisaged and what are the key drivers influencing this market potential? (c) What's the cost-risk-optimised level of activity and funding for innovative technologies in uncertain market context?

Task 6.1 Nuclear Energy Market Foresighting

- Assessment of advanced separation and transmutation technologies addressing the effective management of used fuel and separated materials for a sustainable future
- Definition and projection of nuclear energy market developments covering this century

Task 6.2 Advanced S&T Objectives-driven requirements

- Analysis of the role, timing and deployment conditions for advanced S&T in scenario families
- Overall benefit/cost/risk life cycle analysis of advanced S&T

Task 6.3 HPCyc-design Objectives-driven requirements

- SCRC-specifications addressing advanced S&T-objectives
- Technical-economic assessment of SCRC and associated fuel cycle operations

Task 6.4 HPCyc development & deployment scenario

- Development and deployment roadmap matching market prospects according the scenario families
- Risk/Cost-mitigating and key influencing factors impacting development roadmap for SCRC
-

Deliverables: D6.1

Work package number	7	**ASG**					
Work package title	PoC & Prototypes						
Participant number	3	2	1				
Short name of participant	ASG	AIMA	CERN				
Person/months per participant:	30	22.6					
Start and end month	M1-M36						

Objectives: detail definition, specification of the superconductors magnet parameters, on the ground of magnetic, mechanical and cryogenics requirements defined in WP2 and WP3, and validation of the manufacturing technologies associated. The ion source performances for the selected ion to be accelerated will be investigated with injection prototypes on the AIMA test stand

Description of work. In this WP, the main problematic aspects relative to magnet design raised from the previous WP3 will be investigate by means of PoC and prototypes. In order to investigate the possibility to use a MgB2 based conductor all the typical aspects related to conductor performance will be objects of this WP. The main activities in the WP will be : Development of the Mgb2 conductor with specified critical current, (contribution od Columbus sister company of ASG), Measurements of critical current in working condition, Study of radiation effect on critical current (with contribution of CERN and PSI) Characterization of chosen conductor Manufacturing of scaled conductor (keeping the density critical current of chosen conductor) Realization of a PoC using scaled conductor in order to investigate minimum bending radius, cooling concepts, quench protection system, maximum operating critical current.

Task 7.1

- Definition of Conductor technical Specification - ASG/Columbus
- Characterization of Conductor Parameters - ASG/Columbus
- Manufacturing of chosen / scaled conductor - Columbus

Task 7.2

- Design of the PoC , it will be constituted by a scaled s.c. coil (Mock up) in order to investigate the conductor parameters in working condition - ASG

- Mock up Manufacturing - ASG
- Mock up Measurements and testing ASG

Task 7.3

- Realization of PoC tests of the multicusp ion source (accelerated ion has been selected in the WP3) performances on the AIMA test stand.

Deliverables: D7.1 (ASG Contribute) ,D7.2 (ASG Contribute) D7.3 (AIMA Contribute)

Table 3.1b: List of work packages

Work package No	Work Package Title	Lead Participant Short Name	Start Month	End month
1	Coordination and Management, Dissemination, integration	CERN	1	36
2	Identification, definition and integration of machine parameters	iThEC (PSI?)		
3	Novel Cyclotron Design	AIMA		
4	Subcritical system, Spallation Target & Beam transport design	HNE		
5	Simulation and Optimization	iThEC		
6	Technology and Market outlook	Nuclear-21	1	36
7	PoC, prototypes	ASG		

Table 3.1c: List of Deliverables[4]

Work package No	Deliverable name	Wp No	Short Name	Type	Dissem. COlevel	Delivery date
D1.1	Consortium Agreement	1	CERN	OTHER	CO	M1
D1.2	Dissemination Plan		CERN			M6
D1.3	Progress report 1		CERN			M12
D1.4	Progress report 2		CERN			M24
D1.5	Progress report 3		CERN			M36
D1.6	Workshop 1		CERN			M17
D1.7	Workshop 2		CERN			M30
D2.1	S2E beam dynamics model & golden table (w.r.t. beam dynamics) of the facility	2	PSI			
D2.2	Estimation of halo that contributes to controlled and uncontrolled losses	2	PSI			

[4] If your action taking part in the Pilot on Open Research Data, you must include a data management plan as a distinct deliverable within the first 6 months of the project. This deliverable will evolve during the lifetime of the project in order to present the status of the project's reflections on data management. A template for such a plan is available on the Participant Portal (Guide on Data Management).

D2.3	Uncertainty quantification of beam dynamics model	2	PSI			
D2.4	Validation of the used model using data from the PSI-HIPA facility	2	PSI			
D3.1	Cyclotron main parameters definition	3	AIMA			M15
D3.2	Conceptual Magnet Desing)	3	ASG			M25
D4.1	Subcritical system general requirements and main options selection.	4	HNE	R	CO	M8
D4.2	Definition of the main components of the target unit: Report and Drawings.	4	HNE	R	CO	M20
D4.3	Definition of the beam tube and bending magnet configuration.	4	PSI	R	CO	M20
D4.4	Preliminary core design.	4	ENEA	R	CO	M20
D4.5	Functional sizing of the main components of the subcritical system: Report and Drawings.	4	HNE	R	CO	M30
D4.6	Core transient behaviour under typical DBC and DEC.	4	ENEA	R	CO	M32
D4.7	Final Report of the ADS configuration including all main components.	4	HNE	R	PU	M36
D5.1	“Spallation-optimized” hadronic interaction package and related documentation and validation report;	5	iThEC		R	M6
D5.2	Time dependent simulation allowing to study burnup over long period and related documentation;	5	iThEC		R	M12
D5.3	Simulation package for the study and optimization of the CYCLADS system	5	iThEC		R	M30
D5.4	Final report on the simulation activities, including simulation of the core physics with temperature effects, neutron multiplication factor (k and k_{source}), energy gain as a function of the beam energy, etc. and choice of the beam parameters as a function of the overall simulation of the system (energy, intensity, shape, time structure if any)	5	iThEC		R	M36
D6.1	Nuclear Energy Market Foresighting defining the CYCLADS nuclear materials transmutation market	6	Nuclear-21.Net	R	R	M18

D6.2	Technical-Economic Objectives for CYCLADS as nuclear materials transmuter	6	Nuclear-21.Net	R	R	M24
D6.3	HPCyc Development & Deployment Outlook	6	Nuclear-21.Net	R	R	M36
D7.1			ASG			M24
D7.2			ASG			M36
D7.3			AIMA			M27

3.2 Management and risk assessment

CERN, based on its 60 years' experience on the field of particle beams, will lead the project. AIMA, a leading company in EU for the design of cyclotrons, and ASG a EU leader for the manufacturing of magnets, are the industries pillars that will carry out the innovative but concrete design of the machine. Nuclear expertise and simulation will be taken care by a iThEC, a not-for profit organization based in Geneva with researcher consultancies globally based. PSI will bring the valuable expertise in operating the largest cyclotron in the world. Nuclear-21, with expertise covering the whole decisional process from early consideration to develop nuclear science & technology applications up to the investment and business development process and HNE and ENEA, with their long record of solid technical expertise in nuclear technology, core and system design and safety analysis, complement the Consortium. This consortium, with record of innovation achievements in the respective field of competence, will deploy novel ideas, never adopted before for a similar system, to produce a design of a reliable machine. The decision making structure is consistent with the size and complexity of the project, and based on a clear share of tasks and responsibilities. The structure will be clearly spelled out in the Grant Agreement (GA) to be signed with the EC, and before, agreed among the partners in a Consortium Agreement (CA) where all the aspects of IPR will be defined and properly treated. At the same time CERN has strong links and technical connections with all and each of the partners and important technical works and investigations that will also be used in our project have been conducted in CERN since the last decade of last century. CERN shall coordinate the activities and provide expertise, consultancy and know-how in the field of magnet design, beam optics, high-power target design and simulations of particle interaction with matter.

The ultimate decision making body is the Steering Committee, STC, that is regulated by majority vote mechanism, and that is composed by Project Coordinator (PC), and 1 representative of each parties. STC will approve/decide on time (schedule), cost and financial decision, and shall approve the reporting to the EC, the amendments and reviews to the contractual relation with EC. The Project Coordinator (PC) will act as advisor to the chair of STC (appointed among members, at STC first meeting), and will prepare the meetings and agendas. Project Coordinator of CYCLADS will be Dr. Marcello Losasso, by CERN. He will be responsible for the overall organization, planning, and control of the project, the use of resources in accordance to the EC directions, the on-time delivery of the project deliverables, the reporting to the EC, and exploitation and dissemination of results. PC will be assisted by the EU office in CERN, which has extensive administrative and financial experiences in managing EU projects (at today more than xxx projects have been managed by CERN). The Project Management Team (WP leaders + PC) that will be in charge of the daily management of the project and of the technical problem solving, meeting not less than once per month.

Table 3.2a: List of Milestones

MS short name	Milestone name	Wp No	date	Verification
M5.1	Delivery of D5.01	5	6	R
M5.2	Complete simulation of the first version of the setup to be simulated with Geant4.	5	12	R
M5.3	Delivery of D5.02	5	18	R
M5.4	Benchmarking of the simulation with previous experiments (TARC, FEAT, n_TOF) and optimization of the target neutron yield.	5	24	R
M5.5	Delivery of D5.03 and design of the core to optimize transmutation rate and energy production;	5	30	R
M5.6	Delivery of D5.04 and choice of optimized accelerator parameters;	5	36	R
MS4.1	Preliminary definition of the ADS configuration and preliminary input data for the design of components and system of the ADS.	WP4	M8	D4.1 uploaded on the project website; subcriticality level and thermal cycle approved by PMT.
MS4.2	Core, main components of the target unit, beam tube and bending magnet defined.	WP4	M20	D4.2, D4.3, D4.4, uploaded on the project website.
MS4.3	Main results of typical DBC and DEC transient available.	WP4 (ENEA)	M32	D4.6, uploaded on the project website
MS4.4	Definition of the overall ADS configuration.	WP4	M36	Included in Final Project Report
MS5	Definition of the Decay Heat Removal System as input for reactor block design, containment system and general plant layout.	WP4	M2	
MS6	Definition of the Reactor Block Configuration for feasibility confirmation and input for general plant layout.	WP4	M30	
MS7	Definition of the Refuelling and component handling System for feasibility confirmation and input for general plant layout.	WP4	M30	
MS8	Definition of the overall ADS configuration.	WP4	M36	

MS9		WP		
MS10	Magnet parameter definition	WP3	M6	
MS11	Definition of magnet sector angle	WP3	M15	
MS12	Definition of injection and central region	WP3	M21	M21
MS13	Definition of extraction	WP3	M25	M25
MS14	End of Cyclotron Conceptual Design	WP3	M33	M33
MS15	Conceptual Magnet Design complete of Magnetic Superconducting, Mechanical, Cryogenic and Protection aspects.	WP3	M12	M12
MS16	Definition of Conductor Design and its characterization (Critical Current , Critical Temperature etc)	WP7	M24	M24
MS17	Mock –up Design	WP7	M28	M28
MS18	Mock –up Manufacturing	WP7	M32	M32
MS19	Mock –up Test	WP7	M36	M36
MS20	Nuclear Energy market scenario analysis with identification of CYCLADS-market outlook	WP6	M18	M24
M21	CYCLADS Technical-economic performance objectives	WP6	M24	M30
M22	HPCyc development and deployment Roadmap	WP6	M30	M36

Table 3.2b: Risks register

Risk No	Description of risk	Impact	probability	Mitigation proposed
R1		medium	high	New partners will be invited to join
R2				
R3				
R4				
R5				
R6				
R7				
R8				
R9				
R10				
R11				

3.3 Consortium Agreement, IPR.

3.4 Resources and budget

The overall financial plan of CYCLADS is summarized in table xx

WP No	Title WP	Lead partner	1 CERN	2 AIMA	3 ASG	4 ENEA	5 HNE	6 iThEC	7 Nuclear-21	8 PSI	TOTAL
WP1	**Project Management**	**CERN**									
T1.1	Management		30.0								30.0
T1.2	Internal & External Communication		16.0								16.0
T1.3	Collaborative Network		30.0								30.0
WP2	**identification, definition, integration of accelerator parameters**	**PSI**									
T2.1	Beam Dynamics modelling									40.0	40.0
T2.2	Reliability and interfacing									56.0	56.0
WP3	**Procurement & tendering**	**AIMA**									**0.0**
T3.1	Cyclotron manin parameter definition			7.2	6.0						13.2
T3.2	Magnet PCD			28.8	29.0						57.8
T3.3	RF cavity Preliminary design		2.0	13.5	4.0						19.5
T3.4	injection & extraction design and final configuration		2.0	22.5	2.0						26.5
WP4	**Subcritical sysyem spallation target design & beam transport design**	**HNE**									
T4.1	Subcritical system: requirements and option selecetion		2.0			9.5	22.0	5.0		5.0	43.5
T4.2	Reacotr core and safety analysis		2.0			9.5	22.0	5.0		5.0	43.5
T4.3	Spallation target & beam tube conf		3.0			9.5	22.0	5.0		5.0	44.5
T4.4	Reactor assembly & overall plant layout		3.0			9.5	22.0	5.0		5.0	44.5
WP5	**System simulaiton and optimization**	**iThEC**									
T5.1	Simulaiotn & development		4.0					18.0			22.0
T5.2	simulation with variable material composition		4.0					18.0			22.0
T5.3	simulation with variable material temperature		4.0					18.0			22.0
WP6	**First-of-a-kind development**	**N-21**									
T6.1	nuclear energy market foresighting		9.0								9.0
T6.2	advanced S7T objective driven requirements		9.0								9.0
T6.3	Cyclotron deign objectives-driven requirements		9.0								9.0
T6.4	Cycloron development & deployment scenario		9.0								9.0
WP7	**Pilots Evaluation and Recommendation**	**ASG**									
T7.1	superconductor cable tech specification				10.0						10.0
T7.2	design and realization of PoC for conductor verification				17.5						17.5
T7.3	design and realization of PoC for multicusp ion souce validation			20.7							20.7
TOTAL			**138.0**	**92.7**	**68.5**	**38.0**	**88.0**	**74.0**	**0.0**	**116.0**	**615.2**

Table 3.4a: Summary of staff effort

The project duration is 36 M and the budget requested to achieve its objectives is €3.9 M.

The breakdown cost explanation is:

Direct personnel costs (€x.x) have been calculated using average gross monthly salary costs for each partner.

The Other direct costs (total of €X) amount to:

- Travel costs (total of: €x): calculated at €500 for travel + €200 subsistence costs per meeting (in case of overnight stay) per person per partner (exception 2 people for the coordinator). Additional meetings will be held electronically. Where possible, meetings have been combined to reduce cost.
  - Kick-off meeting
  - 5 General Consortia meetings (and WP meeting the same day)
  - 1 Interim project meeting
  - 2 dissemination events and workshops
- Networking meetings and events will be carried out by WP1 leader.

- Equipment (total: €xx). Equipment acquired for activities directly relevant to the project execution are budgeted.
- Other Goods & Services incl. CFS (total: €xx.xx): €10.000 has been allocated to the coordinator in WP1 for developing and maintaining the project website and hosting meetings. CERN CFS costs are €3.500.
- Subcontracting (total: €xx) ,,,,,

- The table clearly shows each partner's share in the costs of delivering the scope.
- The CYCLADS budget does not contain further (additional) funding from either national or other Community programmes.
- All partners will also mobilise their own funds in delivering the coordination and networking activity deliverables of this project.
- There are no Third Parties involved in the delivery of this project. (are there ?? Columbus?)

Table 3.4b: 'Other direct cost' items (travel, equipment, other goods and services, large research infrastructure)

To safe space I propose to have one TOTAL table like the one below, with accompanying description. In our table than we have to agree on the shares.

TOTAL for all Participants	Cost (€)	Justification
Travel	XX	5 Consortium meeting, dissemination events, conference
Equipment	YY	Consumables, Storage for simulation data (25TB), IT equipment (3 workstations);
Other goods and services	ZZZ	- Production and distribution of dissemination materials (10000): development and servicing of the project website: organization of 3 workshops, licences, materials for PoC, CPU cycles for S2E models (based on PSI Injector 2 estimate + GPU) Publication cost (3*3 = 9 paper a 1.500 €)
Total		