INNOVATIVE APPROACH TO THE SAFETY AND LICENSING OF SMALL MODULAR REACTORS

Acronym: **ADSMR: Accelerator-Driven SMR**

List of participants

Participant No.	Participant organisation name	Short name	Country
1 (Coordinator)	European Organization for Nuclear Research	CERN	IEIO [1]
2	Centro de Investigaciones Energeticas, Medioambientales y Tecyhnologicas	CIEMAT	Spain
3	Centrum Výzkumu Řež SRO	CVR	Czech Republic
4	NINE Nuclear and Industrial Engineering SRL	NINE	Italy
5	Agenzia Nazionale per le Nuove Tecnologie, l' Energia e lo Sviluppo Economico Sostenibile	ENEA	Italy
6	Universita degli Studi di Genova	UNIGE	Italy
7	Paul Scherrer Institut	PSI	Switzerland
8	Hydromine Nuclear Energy S.a.r.l	HNE	Luxembourg
9	Istituto Nazionale di Fisica Nucleare	INFN	Italy
10	Kungliga Tekniska Högskolan	KTH	Sweden
11	Universitaet Stuttgart	USTUTT	Germany
12	International Thorium Energy Committee	iThEC	Switzerland

[1] International European Interest Organisation (IEIO)

1. Excellence

1.1 Objectives

In the general stagnation context of nuclear energy in Europe and in the Western world, Small Modular Reactors (SMR) have nonetheless gained a rising interest, as shown by the broad diversity of designs with very distinct characteristics, and the large number of countries involved (**Table 1**). Indeed, considering carbon emission concerns and fossil fuels availability in the medium term, nuclear energy is considered as one of the realistic portfolio solutions to the growing energy demand [2]. In this scenario, SMR may provide the possibility of deploying nuclear plants easier to install and less prone to severe accidents. The World Nuclear Association (WNA) foresees a large potential market for SMR, with many systems in operation by 2030. Hundreds of such systems could be deployed in China, according to WNA experts. However, as of today, the development and deployment of SMR is at a very early stage. The Korean 100 MWe SMART SMR is the only reactor to have received design approval from a regulatory body and only at the beginning of 2019, that Canada submitted a license application for its first SMR [3].

The SMR definition used by IAEA is: "SMRs are newer generation reactors designed to generate electric power up to 300 MW, whose components and systems can be shop fabricated and then transported as modules to the sites for installation as demand arises." [4] This broad definition may be complemented by that of Micro Modular Reactor (MMR), limited to about 50 MWe. Since the late 1970s, MMR units have been deployed in remote areas of Siberia to produce affordable electricity in locations difficult to access.

A large-scale commercial deployment of SMR is directly conditioned by the economics of the technology, its safety and consequently by the licensing process which is an important driver of the cost.

The high potential of SMR rests on a number of potential factors:

- Their small size combined with economy of series production lowers a main hurdle in the deployment of nuclear energy systems, namely, the high investment cost;
- Because of their small size and modularity, SMR could be built in a central factory setting and installed module per module, improving the level of construction quality and efficiency;
- Their small size and enhanced safety features make them suitable for countries in need of distributed energy sources and with less experience in nuclear power;
- Size, construction efficiency and safety advantages can lead to easier licensing compared to larger reactor plants;
- SMR are proliferation resistant, as the fuel inventory is smaller than in conventional power plants and there is little or no access to the fuel;
- SMRs could be an interesting alternative for new electricity generation capacity in many countries, in particular where there is the need to replace some of the retiring coal plants.

However, to benefit from all the advances of nuclear technology, current regulations which are mainly tailored to light water reactors need to be adapted to these new technologies and in addition, the licensing process should be staged to provide applicants with a clear roadmap to facilitate the process, as pointed out by NIA[5]. In particular, as SMR have several innovative features in terms of fuel, cooling, control and safety, they are largely unstudied from a regulatory perspective. Special attention must therefore be dedicated to the Licensing Process (LP), that was historically developed for larger Nuclear Power Plants (NPP).

[2] International Energy Agency, Key World Energy Statistics 2018

[3] http://world-nuclear-news.org/Articles/First-Canadian-SMR-licence-application-submitted

[4] Advances in Small Modular Reactor Technology Developments, A Supplement to: IAEA Advanced Reactors Information System (ARIS) 2016 Edition, IAEA

[5] Enabling Nuclear Innovation, Strategies for Advanced Reactor Licensing, A Report by the Nuclear Innovation Alliance, Ashley E. Finan, et al., April 2016

The main SMR technologies developed so far are based on:

- Water-cooled reactor technology, both land-based and marine-based;
- High temperature gas-cooled reactors;
- Fast neutron spectrum, sodium- or other liquid metal-cooled reactors;
- Molten salt reactors.

SMRs in general, have not yet been licensed (except for the SMART 100 MWe SMR developed by KAERI, which received the first-ever Standard Design Approval (SDA) from Korean regulatory body, in 2012). Most designs have not yet been widely analysed by regulators. The Status of Deployment of SMR design around the world is shown in Table 1.

Table 1: *Status of Deployment of SMR Designs and Technologies* (Source: Advances in Small Modular Reactor Technology Developments, A Supplement to IAEA Advanced Reactors Information System (ARIS) 2018 Edition, IAEA)

Design	Output MW(e)	Type	Designers	Country	Status
PART 1: WATER COOLED SMALL MODULAR REACTORS (LAND BASED)					
CAREM	30	PWR	CNEA	Argentina	Under construction
ACP100	100	PWR	CNNC	China	Basic Design
CAP200	150/200	PWR	CGNPC	China	Conceptual Design
DHR400	(District Heating)	LWR(pool type)	CNNC	China	Basic Design
IRIS	335	PWR	IRIS Consortium	Multiple Countries	Conceptual Design
DMS	300	BWR	Hitachi GE	Japan	Basic Design
IMR	350	PWR	MHI	Japan	Conceptual Design
SMART	100	PWR	KAERI	Republic of Korea	Certified Design
ELENA	68 kW(e)	PWR	National Research Centre "Kurchatov Institute"	Russian Federation	Conceptual Design
KARAT-45/100	45/100	BWR	NIKIET	Russian Federation	Conceptual Design
RITM-200	50 × 2	PWR	OKBM Afrikantov	Russian Federation	Under Development
RUTA-70	70 MW(t)	PWR	NIKIET	Russian Federation	Conceptual Design
UNITHERM	6.6	PWR	NIKIET	Russian Federation	Conceptual Design
VK-300	250	BWR	NIKIET	Russian Federation	Detailed Design
UK-SMR	443	PWR	Rolls-Royce and Partners	United Kingdom	Mature Concept
mPower	195 × 2	PWR	BWX Technologies	United States of America	Under Development
NuScale	50 × 12	PWR	NuScale Power	United States of America	Under Development
SMR-160	160	PWR	Holtec International	United States of America	Preliminary Design
W-SMR	225	PWR	Westinghouse	United States of America	Conceptual Design
PART 2: WATER COOLED SMALL MODULAR REACTORS (MARINE BASED)					
ACPR50S	60	PWR	CGNPC	China	Preliminary Design
ABV-6E	6-9	Floating PWR	OKBM Afrikantov	Russian Federation	Final design
KLT-40S	70	Floating PWR	OKBM Afrikantov	Russian Federation	Under construction
RITM-200M	50 × 2	Floating PWR	OKBM Afrikantov	Russian Federation	Under Development
SHELF	6.4	Immersed NPP	NIKIET	Russian Federation	Detailed Design
VBER-300	325	Floating NPP	OKBM Afrikantov	Russian Federation	Licensing Stage
PART 3: HIGH TEMPERATURE GAS COOLED SMALL MODULAR REACTORS					
HTR-PM	210	HTGR	INET, Tsinghua University	China	Under Construction

GTHTR300	300	HTGR	JAEA	Japan	Basic Design
GT-MHR	285	HTGR	OKBM Afrikantov	Russian Federation	Preliminary Design
MHR-T	205.5x4	HTGR	OKBM Afrikantov	Russian Federation	Conceptual Design
MHR-100	25 – 87	HTGR	OKBM Afrikantov	Russian Federation	Conceptual Design
A-HTR-100	50	HTGR	Eskom Holdings SOC Ltd.	South Africa	Conceptual Design
HTMR-100	35	HTGR	Steenkampskraal Thorium Limited	South Africa	Conceptual Design
PBMR-400	165	HTGR	PBMR SOC Ltd	South Africa	Preliminary Design
SC-HTGR	272	HTGR	AREVA	United States of America	Conceptual Design
Xe-100	35	HTGR	X-energy LLC	United States of America	Conceptual Design
PART 4: FAST NEUTRON SPECTRUM SMALL MODULAR REACTORS					
4S	10	LMFR	Toshiba Corporation	Japan	Detailed Design
LFR-AS-200	200	LMFR	Hydromine Nuclear Energy	Luxembourg	Preliminary Design
LFR-TL-X	5~20	LMFR	Hydromine Nuclear Energy	Luxembourg	Conceptual Design
BREST-OD-300	300	LMFR	NIKIET	Russian Federation	Detailed Design
SVBR-100	100	LMFR	JSC AKME Engineering	Russian Federation	Detailed Design
SEALER	3	Small Lead Cooled	LeadCold	Sweden	Conceptual Design
EM^2	265	GMFR	General Atomics	United States of America	Conceptual Design
SUPERSTAR	120	LMFR	Argonne National Laboratory	United States of America	Conceptual Design
WLFR	450	LFR	Westinghouse	United States of America	Conceptual Design
PART 5: MOLTEN SALT SMALL MODULAR REACTORS					
IMSR	190	MSR	Terrestrial Energy	Canada	Basic Design
CMSR	100-115	MSR	Seaborg Technologies	Denmark	Conceptual Design
CA Waste Burner	20	MSR	Copenhagen Atomics	Denmark	Conceptual Design
ThorCon	250	MSR	Martingale	International Consortium	Basic Design
FUJI	200	MSR	International Thorium Molten-Salt Forum: ITMSF	Japan	Experimental Phase
Stable Salt Reactor	37.5×8	MSR	Moltex Energy	United Kingdom	Conceptual Design
Stable Salt Reactor	300~900	MSR	Moltex Energy	United Kingdom	Pre-Conceptual Design
LFTR	250	MSR	Flibe Energy	United States of America	Conceptual Design
Mk1 PB-FHR	100	MSR	University of California, Berkeley	United States of America	Pre-Conceptual Design
MCSFR	50	MSR	Elysium Industries	USA and Canada	Conceptual Design
PART 6: OTHER SMALL MODULAR REACTORS					
eVinci	0.2~15	Small Heat Pipe	Westinghouse	United States of America	Under Development

All these technologies still have major issues to be resolved in order to make them convincingly safe:

- PWR SMR have to work at high pressure and with high enrichment of the fuel to compensate for the high neutron leakage;
- High-temperature gas-cooled SMR operates at high helium pressure, a coolant that is difficult to contain; its fuel is expensive and difficult to reprocess.

- Fast neutron spectrum, sodium-cooled SMR has a coolant that is not compatible both with air and with water, hence sodium leakage must be made impossible, or must be treated with extreme caution.

- Fast neutron spectrum, lead-bismuth- or pure lead-cooled SMR have mainly corrosion issues at high temperature, as well as polonium issue;

- Molten salt SMR require online extraction of the hot fuel with challenging chemistry online, have to deal with neutron irradiation outside the core, and there are corrosion issues.

In addition, all these technologies have unresolved waste management issues. Dealing with its long-term radiotoxicity is a key challenge. In about 60 years of nuclear power plants activity, Europe has been accumulating a large stock of radioactive waste that may pose issues of safety, security, proliferation, environmental challenge and societal concern. According to IAEA Data Waste Counter [6], today over 400,000 tons of spent fuel have been discharged all over the world, out of which about one third in Europe. The problem will only increase in magnitude in the coming years, despite the decreasing number of nuclear plants in Europe. In the rest of the world, nuclear power is expanding, in particular in China and India. The most worrisome long-lived component of the waste, the TRU, now exceeds 3,000 tons world-wide (Fig. 1).

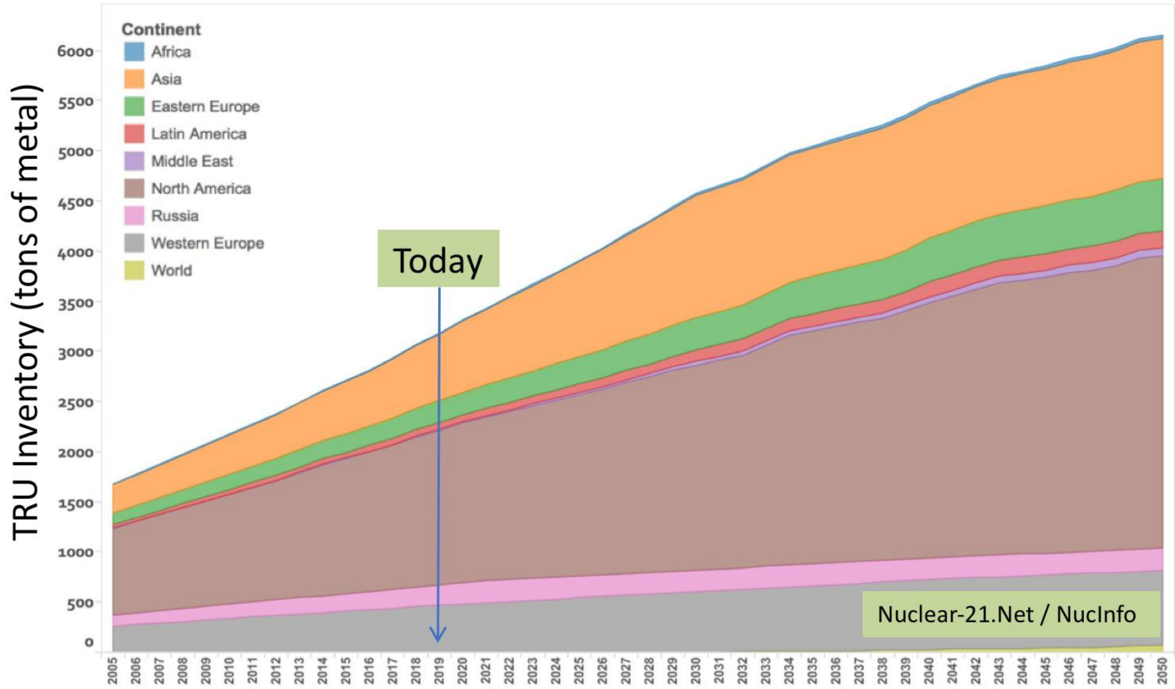

Figure 1: TRU represent the dominant part of the long-lived nuclear waste. This figure shows the evolution of the world inventory of TRU with extrapolation to 2050, assuming that only currently approved new power plants will be deployed. (Source: Nuclear-21.Net / NucInfo)

As is more apparent in the USA, the unduly long delay in providing definite management solutions to nuclear waste imposes financial risks to operators and governments, which renders nuclear energy less competitive and thus removes a significant CO_2-free emitting energy source for the future. Geological disposal is today's technological paradigm, as the only actively pursued option for spent fuel or High Level Waste (HLW) management. However, this option raises strong concerns in the public opinion on the ability to guarantee a safe and secured system for the extremely long period of time during which nuclear waste must be isolated (200,000 years or longer). Our political or social institutions have not even been stable over a period of only 1,000 years; therefore, it is not obvious how to ensure stable monitoring and safeguarding for the required long term. Moreover, geological disposal of radioactive waste requires careful analysis projecting the site geo-chemo-physical evolution into the future for millennia. In addition, several voices questioned whether it is ethically acceptable to burden future generations with the potential

[6] https://newmdb.iaea.org

risks posed by nuclear waste.

We believe that the future of nuclear energy depends on the capability of the forthcoming systems to cope with the concurrent issues of safety, proliferation, waste production reprocessing and management, cost. Acceptability by the public is a requirement considered as a mandatory review step in the usual LPs and political decision is the normal initiation phase of all LP. A system layout that is not able to address convincingly all of the above-mentioned issues will not pass these barriers.

On the other hand, SMR, with their distributed deployment nature introduce a new situation both in terms of waste management, as more spent fuel transport might be necessary, and in terms of resistance to proliferation, as the number of sites increases.

For all these reasons, we believe that further innovation is required in the design of SMR in order to meet the most stringent requirements of safety, proliferation, waste management, and sustainability all together.

So far, most or all of SMR research was concentrated on critical SMR systems. However, the significant progress in accelerator technology in the past 20 years, makes it possible today to consider Accelerator-Driven SMR (ADSMR) (Fig. 2). The presence of an external neutron source provided by a proton accelerator allows an innovative approach to safety and waste management, which should lead to a much-simplified licensing process.

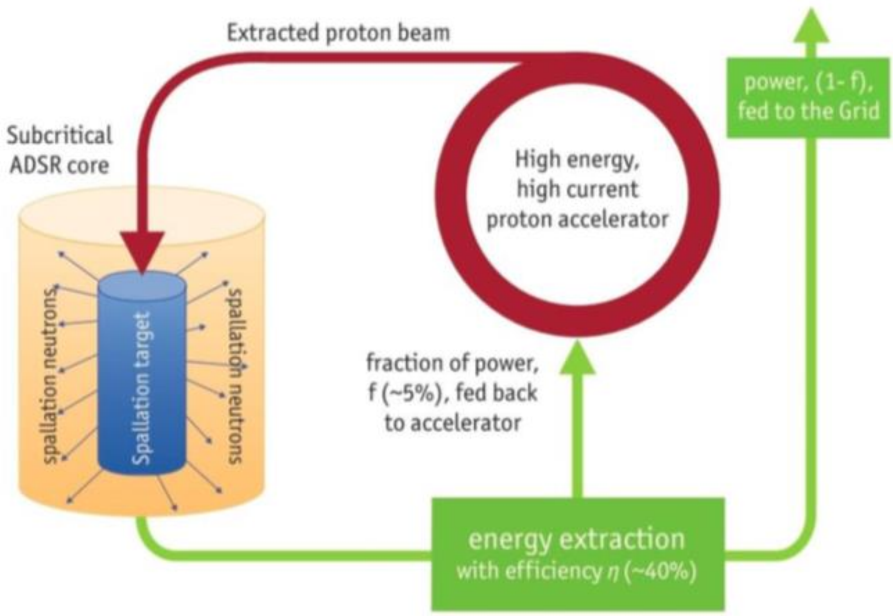

Figure 2: Schematic representation of the concept of Accelerator-Driven SMR (ADSMR)

The ADS concept is not new, as it originates from the late 1940s with Lawrence in the USA and the beginning of the 1950s with Lewis in Canada. However, the progress today in accelerator technology as well as in spallation target technology, makes the concept much more realistic.

Already in the 1990s at CERN, Nobel Prize Laureate Carlo Rubbia proposed the concept of Energy Amplifier (EA)[7], an Accelerator-Driven System (ADS) with a proton beam impinging on a spallation target enclosed within a subcritical core. Today, the ADS state-of-the-art project is MYRRHA [8]. However, there is also an ambitious ADS project in China, the Accelerator-Driven Advanced Energy System (ADANES) [9]. Furthermore, in the past 20 years, Europe carried out a systematic R&D program on transmutation and partitioning across several EU Framework

[7] An Energy Amplifier for cleaner and inexhaustible nuclear energy production driven by a particle beam accelerator. CERN/AT/9347 (ET)

[8] https://myrrha.be

[9] http://www.world-nuclear-news.org/NN-Chinese-collaboration-for-accelerator-driven-systems-1103164.html

Programmes for Research and Technological Development, EUROTRANS [10]. EUROTRANS included a broad programme of R&D on pure lead and lead-bismuth technologies, in particular, on corrosion, which limits the output temperature, hence the energy efficiency of electricity production. A status of world efforts on ADS may be found in [11].

Today, all the elements of an ADS have been built and tested at a scale appropriate for significant power, but only separately:

- Proton accelerators have exceeded 1 MW of beam power, both for linacs (SNS in the USA) and for cyclotrons, cyclotrons (PSI Cyclotron), which because of their compactness, high reliability and high electric efficiency are the preferred option for ADSMR (PSI Cyclotron);
- Spallation target: MEGAPIE, a Pb-Bi eutectic spallation target of 1 MW was operated successfully at PSI for several months. A 5 MW proton beam is under construction at Lund, in Sweden, to drive the future European Neutron Spallation Source;
- Heavy-metal-cooled reactor cores: for instance, Russia, which developed about 80 years of experience in the operation of lead-bismuth submarine reactors, obtained recently an export license from IAEA for its SVBR-75/100, a Lead-Bismuth critical core SMR that could be readily adapted to an ADSMR.

The proposed ADSMR is a novel and innovative concept that corresponds to a paradigm shift when the concepts of SMR and of ADS are combined. The main added advantages include:

- Sub-critical operation of the core;
- Possibility to work with a lower enrichment of the fuel;
- Higher flexibility in the choice of fuel;
- Simpler and more reliable control system through the accelerator, allowing load modulation, to follow demand;
- Enhanced safety features;
- Possibility of mitigating the issue of spent fuel management through the use of thorium fuel;
- Possibility to envisage economic competitiveness for power production units smaller than 300 MWe, because of the simpler passive safety characteristics of the system.

The main objective of the ADSMR proposal is ***to analyse the Licensing Process (LP)*** applied to a specific, innovative concept, the Accelerator-Driven Small Modular Reactor (ADSMR).

As the LP is layout-specific and inherently linked to the specific project characteristics and to the targeted applications, we present a specific, innovative and safe ADSMR concept, with a view to define a generic ADSMR design, in order to advance towards standardized plant projects for authorization of construction and operation. The targeted applications of the concept we propose include, but are not limited to, ***energy production, hydrogen production, and nuclear waste transmutation.***

We want to demonstrate that harmonization of engineering aspects, manufacturing and accompanying certifications can ***standardize the LP***, thereby, facilitating the licensing of ADSMR, which, together with its economies of scale, could make it more attractive for industry. The final aim of this study would be to facilitate efficient progression of regulatory activities for licensing general types of SMRs.

[10] https://www.oecd-nea.org/pt/iempt9/Nimes_Presentations/KNEBEL.pdf

[11] https://indico.cern.ch/event/564485/contributions/

We want to define criteria that allow for ADSMR "generic site" prescriptions, and "generic engineering project", in order ***to fully exploit the modularity concept*** applicable to critical SMR projects, identifying what factors would facilitate international licensing of SMR.

We want to define the framework of authorizations for construction, operation, decommissioning for a generic ADSMR. To do this, we need to define the ***magnitude of risks*** embedded in the specific ADSMR, with the aim of applying a ***graded approach***. We will put the basis for a licencing application considering both the licensee and the licensor viewpoints.

We want to study deployments scenarios, including the ***management of spent fuel*** and compare their competiveness as a function of the energy scale.

Education, training, communication and dissemination are additional objectives: We expect that the level of innovation combined with the importance of energy issues for the future of our civilization should strongly motivate a new generation of young researchers in the field of nuclear energy. We need to ensure competence building and transfer of knowledge on ADS and SMR. This will be done through:

a) Training of young researchers within the project through simulation and/or targeted experiments carried out to validate new concepts and elements of the system, as well as the overall system behaviour, schools and workshops on specific topics

b) Documentation, communication and dissemination of the results, addressing the directly concerned community involved in the nuclear waste disposal safety case and a broader scientific community.

Therefore, our vision, in a time horizon at the middle of this century, is that ADSMR can allow a new development of nuclear industry, by providing distributed energy supplies with load following capacity that would be a complement to fluctuating wind and solar energy systems as its power output can be readily modulated through variation of the accelerator beam intensity, with a view of progressively replacing the retiring fossil-fuel power plants and to extend to other applications such as water desalinization, hydrogen production, etc. To help quantify the potentiality of the market, we note that Nuclear Energy Insider estimates that in the USA alone, replacing coal power plants (that will have to be shut down sooner or later), offers a market opportunity of 30 B$.[12]

Once the concept engineering features (modularity, reactor / safety system integration, sub-grade installation, etc.) will have demonstrated technical and economic feasibility, the principle will be more easily scaled to ***multi-unit installations*** allowing for a cost-efficient deployment of SMR able in addition to cope with a vision that surpasses the current paradigm of "burying the waste", by the use of a new technology that provides a workable contribution to solving a crucial worldwide problem, and that at the same time helps increasing the social acceptability of nuclear power plants. More in detail, our project consists of:

1) a new SMR design, making use of ADS technology advances;

2) the development of tools for the assessment of improvement in safety, waste reduction, and cost;

3) a new licensing strategy including a set of safety specifications and requirements, in line with the EU directives and IAEA recommendations;

4) a study of deployment scenarios, fuel cycle and economic aspects, including waste management.

[12] http://www.nuclearenergyinsider.com/smr/pdf/USSMRUtilityMarket5.pdf

In order to develop the ADSMR project, we have structured the scope into 11 Work Packages, one dedicated to the management and coordination of the activities (WP1) and the other 10 summarily described here below:

WP2: Concept of Accelerator system for ADSMR (INFN)

This WP will present a conceptual design of the compact, superconductive cyclotron able to drive the ADS SMR. The features of the circular accelerator, in a single stage, will enhance and complete the concept of modularity and safety of the analysed SMR. Availability is the critical parameter for industrial applications and high availability demands for high reliability and good maintainability of the accelerator system. Existing studies on LINAC4, LHC, FCC availability show the effort that is needed to get valid and well-grounded availability numbers of accelerators. Depending on the existence of data / similar running accelerators, the reliability management can be based on existing data or demands for testing and extensive modelling, which includes Machine Protection Systems needed to achieve high safety of the system. This requires expertise in modelling functional dependencies to be able to include failure chains within the reliability and availability model

a. Concept design of the accelerator system
b. Requirements, performances, features
c. Beam losses and reliability
d. Optimization to enhance the system reliability and licensing feasibility
e. How the Accelerator design contributes to safety/licensing

WP3: General system layout (HNE)

This WP will present the concept of the ADS cluster and its role in the general application target of electricity/energy production system (concept of a cluster of ADS for waste transmutation). An estimation of the number and size of ADS for HLW transmutation at EU scale will be presented. The main component design of a reactor will be worked out, in order to activate the potential grouping of resources (cores, accelerator current, accelerator beams, fuel reprocessing etc.). A study of the distribution of demand (input of transmutation fuel), of resources, of consequences for modularity, as well as the transferability of results to electricity production will be presented. The ADS cluster is a complex system itself which needs careful reliability study of all components (done in WP2). Unreliable options will be excluded in early stages of the reliability management process of the ADS cluster. High maintainability must be guaranteed by design, to be able to have the system run again in little time.

a. Reactor, reactor coolant and connected system design.
b. Conceptual design of the primary circuit of the reactor
c. Interface with the accelerator
d. Decay heat removal and the schematic diagram of the BOP
e. Principles of operation with the schema of the principle of the regulations.

WP4: Core performance and safety assessment (ENEA)

This WP will take care of the simulations and neutronic analysis, which include the fuel cycle, reactivity parameters and optimisation and the spallation target design. Extensive use of most updated nuclear data libraries will be made. The thermo-hydraulic of the primary circuit will be simulated and validated. The concept of monitoring system for subcritical operation will be designed, with the associated control requirements and drafting of control procedures for normal operation and some DBA. Impact of this on the licencing process, and the potential flexibility for progressive licencing will be part of the scope of the WP. For safety management, a qualitative modelling of all functions of the system is necessary. This could be possible with standard methods such as FMEA, but also by integrating more advanced methods like STAMP/CAST/STPA into a safety model.

a. Characteristics of the proposed ADSMR layout (neutronic, Th, accelerator, …) and neutronic calculations: Fuel definition and Core optimization, Reactivity and safety parameters evaluation and optimisation in different conditions (BOL, EOL, some DBA)

b. Spallation target calculations (optimization of size and position, Requirements of beam intensity, heat and damage deposited, Spallation target wastes),
c. Uncertainties and safety margins for the previous calculations with examples showing safety advantages
d. Assessment of the nuclear data induced uncertainties and impact of uncertainties on the licencing procedures.
e. Thermal hydraulic calculations: Validation of the heat balance calculations for the primary circuit, with some transient calculations.
f. Design of the ADS monitoring and control system.

WP5: Spallation target (CVR)

This WP will develop the spallation target design linking the technical scope of the accelerator (WP2) and of reactor (WP3). The concept of the spallation target will include reliability and safety aspects, with technical choices able to ensure the system requirements also in terms of maintainability and inspectability.

a. Concept and technical choices
b. Potential performance characteristics
c. Safety issues from the Spallation target and potential advantage of the proposed layout
d. How the Accelerator design contributes to safety/licenciability
e. Examples that show safety advantages
f. Examples that show the way to handle new accident initiators in ADS

WP6: Fuel cycle evaluation (CIEMAT)

This WP will develop the fuel cycle and the fuel management, including back-end. Evaluation of uncertainties and the impact on safety will be also included in the (quantitative and) qualitative parts of the reliability management process.

a. Spent fuel composition and Waste production (including spallation target and fuel)
b. Fuel cycle models including ADSMR
c. Mass balance and dimensioning of fuel cycle facilities,
d. Evaluation of uncertainties,
e. Economic assessment
f. How the ADSMR layout impact on the fuel cycle safety
g. Fuel cycle implications on licencing

WP7: ADSMR Safety Analysis (NINE)

Within this WP safety analysis issues will be faced starting from the basic point of developing a list of Postulated Initiating Events (PIE) that should be categorized and analysed in view of a licensing application. The PIE list will be developed taking into consideration the ADSMR design features and following similarities and differences from LWR technology. Selected (3 to 5) safety cases will be addressed drafting the content of the related Safety Analysis Report subsections in order to provide with guidance to potential licensees.

This WP will include a task on central reliability management, connecting all efforts on reliability, availability and safety to make sure that all components and subsystems have the reliability budget that needs to be complied with. Interdependencies will be modelled to be able to include failure chains on system level and to be able to plan maintenance and inspectability of the full system.

a. Overview of the ADSMR safety
b. Examples of ADS safety calculations
c. Safety analysis conclusions for the licencing of ADSMR
d. Global reliability evaluation and optimization of concept options

WP8: Licensing Process (NINE)

This WP will provide answers to the ADSMR licensing process. In this view (and following International Standard approach) safety principles will be defined and the ADSMR safety requirements will be established to respond to the fundamental safety objectives of the proposed reactor design. Such basic work is required being the ADSMR a novel technology not regulated yet. The development of the Licensing Process within the present proposal will benefit of some established regulations related to SMR and to the Accelerator. However the interactions between the two main constituents of the ADSMR require specific investigation notably in terms of requirements. The final goal of the WP8 is to draft a licensing framework under which an ADSMR application can fit.

a. Draft safety file exercise
b. Conclusions of ADSMR strengths for licencing
c. Weakness of ADSMR for licencing: safety weakness, specific uncertainties, components needing further demonstration or Experimental validation
d. Revision of the licencing route

WP9: Training, Dissemination and Outreach (KTH)

The WP will develop a common understanding of all basic aspects of reliability to make sure, that all WPs are aligned on the specified requirements, sharing a failure database, failure analysis, understanding of availability, maintenance issues. This will be achieved also with a specific reliability training for all the project participants.

a. Training activities
b. Dissemination plan and actions
c. Outreach

WP10: Present SMRs classification and motivation for ADSMR (UNIGE)

Starting from the present SMRs scenario, this WP will classify the designs according to their technical and licensing features, as well identify the motivation for developing the specific ADSMR design, the benefit of compactness and modularity, in terms of reliability and safety. This WP will argument in detail the previous points and will design a layout for the ADSMR and its clusters that allows to validate and evaluate the licencing model and the advantages of the ADSMR from the Safety and licencing perspectives. Existing SMRs will be classified as well for their reliability features and the impact of small adaptions to the full system reliability. It will be assessed the following points:

a. Closing the fuel cycle: an opportunity to provide an alternative solution to direct geological disposal by including the transmutation of Minor Actinides
b. Clusters of ADS of limited power around the reprocessing plants as a valid tool to close the fuel cycle
c. Benefit from making modular the ADS design, redundancy of clusters to improve reliability: ADS qualification as SMR
d. Analysis of present scenario of SMRs, classification into main categories of design and relative licensing processes. Proposal of a licencing model/route for these ADS SMR showing specific advantages from the Safety and licencing perspective
e. ADS dedicated to electricity production using Th fuel and other available ADS concepts

1.2 Relation to the work programme

This proposal relates to the work program topic NFRP-05 which concerns the methodologies for performing safety evaluations and safety improvements fostering safety standards of SMR. We propose an innovative SMR, which combines both critical SMR and ADS technologies, and we will show that ADSMR offers new safety features which represent a significant advance towards certification. For this, we define a safe generic small modular ADS (ADSMR) as a case study and make a systematic analysis of all safety related issues, taking both standard nuclear reactors and critical SMR for comparison.

Safety by design

For SMR, the safety-by-design can be enhanced by the subcriticality of the system, in addition to the use of proper passive safety systems activated by force of nature (gravity, conduction, convection, etc.) that represents the second level of safety. In ADS, the spallation technique is the efficient way to produce high neutron flux by externally supplying neutrons into the reactor. In this way, including the low inventory of radioactive materials with respect to larger NPP, as well as the capability of the accelerator to very rapidly shut the beam down, thereby interrupting the nuclear chain reaction, the ADSMR can set a benchmark in the nuclear safety standard. The safety-by-design, reducing the probability of accidents and mitigating the consequences, produces a system which is simpler, safer, cost effective and, in principle, easier to-be-licensed. The long operating experience (OPEX) accumulated singularly on the main components of the ADSMR reduces uncertainties and mitigates risks. In fact, accelerator technologies are deployed since almost a century, with operating data available in terms of safety, availability and reliability. Even if it is not obvious that a smaller reactor means a shorter technical assessment (the time to complete the review is influenced by the time needed to confirm that the proposed safety and control measures meet regulatory requirements), for the subcritical reactor the demonstration of safety in support to the application for authorization is expected to be easier (e.g. because of the physical response to abnormal conditions).

Conditions for achievement

Requirements for SMRs may be site-specific and also legislation dependent, and therefore the regulatory and legal requirements in different countries can jeopardize one of the main features of SMR: exportability. Moreover, the precise legal authority and role of the regulatory body is not the same in all countries. But even if requirements cannot be harmonized between different countries due to legal structure differences, acceptance of common methodologies can facilitate the use of one regulator's conclusions to inform another's technical assessment work, which would reflect into time and cost savings. This would include for example the use of common mechanical design codes, personnel and process qualifications, materials and analysis requirements, and a quality assessment (QA) system that includes design change management. Standardization is a key factor for SMR, because factory production is one of the distinctive features of this type of systems, differentiating it from the existing nuclear supply chain. Indeed, the SMR business model has been assimilated to the production of nuclear engines for ships. The ADSMR project should be highly standardized, which implies that the possible vendor must find an appropriate balance between standardization and customization demands. In addition, any rework should be avoided because it disturbs the assembly process. Finally, all components/parts/kits required for ongoing work should be available at due time because any delays will affect the production of the entire plant and not only one unit. An important challenge for the factory assembly of SMRs is nuclear regulation. While all of the safety features of SMRs could be addressed generally within the existing regulatory framework, there are issues that must be resolved. In particular, current regulatory practices might not be fully compatible with a factory assembly model, especially if the assembly process is automated. Regulators must adapt their methods of work to test the units to the greatest extent possible at the assembly stage and reduce the potential for rework. For the successful deployment of SMRs, a new approach to licensing should be developed to allow factory-based manufacturing and serial deployment. It might require strong co-ordination not only between regulators but also between manufacturers. On the other hand, full factory assembly of SMR units will allow large savings in manufacturing costs.

Market and other economic aspects

Many factors are influencing the SMR market. According to NEA [13], among the several factors influencing the SMR market, the nuclear regulatory barriers and the public attitude towards nuclear power need to be included. In the case of ADS, we should add to the challenges the sceptical attitude towards this specific industrial application of accelerator technology, which is sometimes in our opinion wrongly perceived as a research instrument, more than industrial, domain-cantered activity. We believe that ADSMR can deal with all these challenges at the same time, by targeting basic safety objectives able to support future SMR licensing processes, and demonstrating that today's accelerator technologies can be as well applied also with the industrial required standard of the nuclear sector. This will be achieved in particular by complementing the choice of the accelerator layout with a careful component and system reliability analysis. Moreover, the close interaction witin the Consortium among designers, typical manufacturers of specific components (magnets for example, or spallation target) and regulators will allow examining

[13] https://www.oecd-nea.org/ndd/pubs/2016/7213-smrs.pdf

various approaches and possibilities, providing more realistic results.

1.3 Concept and methodology

(a) Concept

The conceptual and traditional scheme of an ADS is shown in fig. 2 (from [14]). The ADSMR concept stems from the combination of particle beam accelerator technology and compact nuclear reactor technology. The benefits of this combination multiply the advantages of the single SMR in terms of safety, cost and environmental impact. Because the LP has been individuated as a barrier to the deployment of SMRs in general, and therefore of ADSMR, our goal is to analyse the LP specifically for the ADSMR system in order to advance the concept to a realistic approach.

Baseline design

The accelerator: We believe that a cyclotron is a better choice than a linac to power an ADSMR. Several innovative cyclotron concepts exist. The Institute Paul Scherrer in Switzerland operates a cyclotron that exceeded 1 MW of beam power. An 800 MeV high-power cyclotron was proposed, among others by some members of ADSMR consortium, for the Daeδalus experiment, searching for CP violation in the neutrino sector[15]. In order to be successfully adopted as proper driver for the SMR, the circular accelerator should have high beam power to grid power efficiency, a high reliability and availability factors; it should be cost effective and have compact dimensions compatible with the concept of SMR. These requirements call for a special design features: single stage for compactness, multiple injection line for reliability, choice of well-demonstrated technology (NbTi superconductor).

The subcritical core: One of the main strategic choices is the choice of coolant and moderator, between pure lead and lead/bismuth eutectic. Pure lead is obviously desirable for industrial applications of ADS, due to the limited availability of Bi, and to the safety aspects related to the Po production in the use of LBE. However a pure-lead core has not yet been built until now. The two main contributors to lead-cooled core technology so far are ROSATOM in Russia and our partner HNE in UK. Materials exist already that can resist corrosion up to lead temperatures of about 500 ˚C [16]. As well as in Milano university and at Oakridge National Laboratory, new alumina-forming austenitic stainless steel alloys have been developed for a temperature range from 700 to 800 ˚C that will, obviously be of interest for the future, as temperature increases the efficiency of conversion of heat into electricity.

Today, it would be safer to opt for a Lead-Bismuth Eutectic (LBE) core. There is experience in Russia over 80 years of operation of LBE reactors for submarines, an example is the SVBR 75/100, which is shown in Fig. 3.

HNE develops lead-cooled critical cores. For a subcritical core, they propose an innovative safe and simple fuel loading strategy. For our project we will analyse the pros and cons of the two technologies and we will decide on the ground of the criteria of safety, LP and future applications.

[14] R. Cywinski, A. Herrera-Martínez, G. Hodgson, et al., “Towards an Alternative Nuclear Future,” The Thorium Energy Amplifier Association (ThorEA), 2009

[15] J.M Conrad and M. H. Shaevitz, PRL 104, 141802 (2010).

[16] Corrosion Studies of Low-Alloyed FeCrAl Steels in Liquid Lead at 750 °C; Dömstedt, P., Lundberg, M. & Szakalos, P. Oxid Met (2019) 91: 511. https://doi.org/10.1007/s11085-019-09896-z

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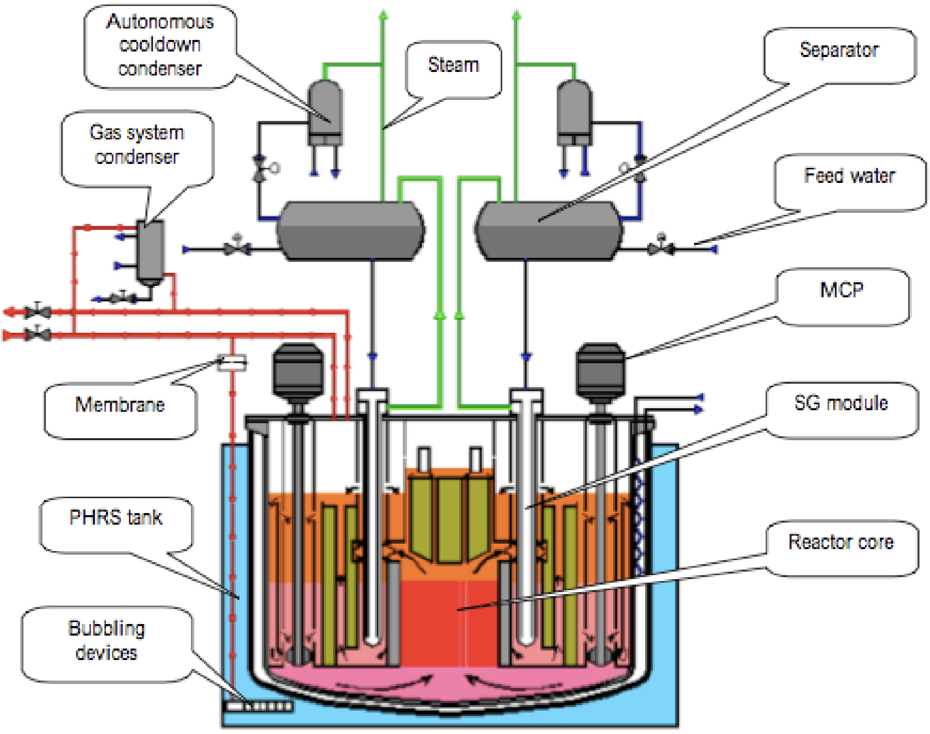


Figure 3: Schematics of a Russian SVBR 75/100, with a lead/bismuth core, showing all basic systems of the reactor installation. At a thermal power of 280 MW the SBBR produces 101.5 MW of electrical power.

The spallation target: For the spallation target, we will make use of the experience of the MEGAPIE project, a 1 MW target that was operated successfully at PSI, and that was designed and manufactured with important contribution by some of our partners (PSI and CVR). The MEGAPIE design would have to be integrated into the subcritical core. The technical interface between accelerator and reactor includes window and target and this part of the project will require strict coordination among the partners.

Scale of the ADS-SMR to be considered

An economical critical SMR needs a power at the order of 300 MWe, however, the advantages of ADS in terms of safety might make a smaller system worth considering. In addition, if we want to avoid extrapolating existing elements of an ADS too far and also be representative of MYRRHA at the same time, then we should stay within a reasonable factor from these existing elements. In order to keep the accelerator within readily achievable performance it would be safe to aim for an ADSMR of 100 MWe. At least initially, which would correspond to an order of 300 MW of thermal power. Fixing an electric power goal defines essentially most of the system, within a range of parameters to be used for optimization.

The ADS parameters that are to be optimized in order to reach the required thermal power, are the operational temperature (T_{op}), the level of sub-criticality (k), the target efficiency represented by the gain factor G_0, the beam energy (E_{beam}), and the beam current (I_{beam}).

The SVBR-75/100 works at a primary coolant temperature of 482˚C at the core outlet and 320 ˚C at the core inlet, which results in an electric conversion efficiency of 36%. Using the same thermal efficiency implies that the thermal power to be produced for an electric power of 100 MWe is 278 MW.

In order to ensure sub-criticality at all times, the k value should not exceed 0.975[17], which is therefore the highest value that should be considered. Figure 4 shows, under the above conditions, the beam intensity required as a function

[17] This is for the case of thorium based fuel.

of beam energy in order to produce 100 MWe. Figure 5 shows the beam power under the same conditions. For instance, with a 600 MeV beam, the beam intensity required is 6.7 mA, corresponding to a beam powers of 4 MW.

Therefore, the task of the cyclotron designer, will be to optimize for beam losses and reliability, along the curve of figures 1 and 2, perhaps also in terms of cost.

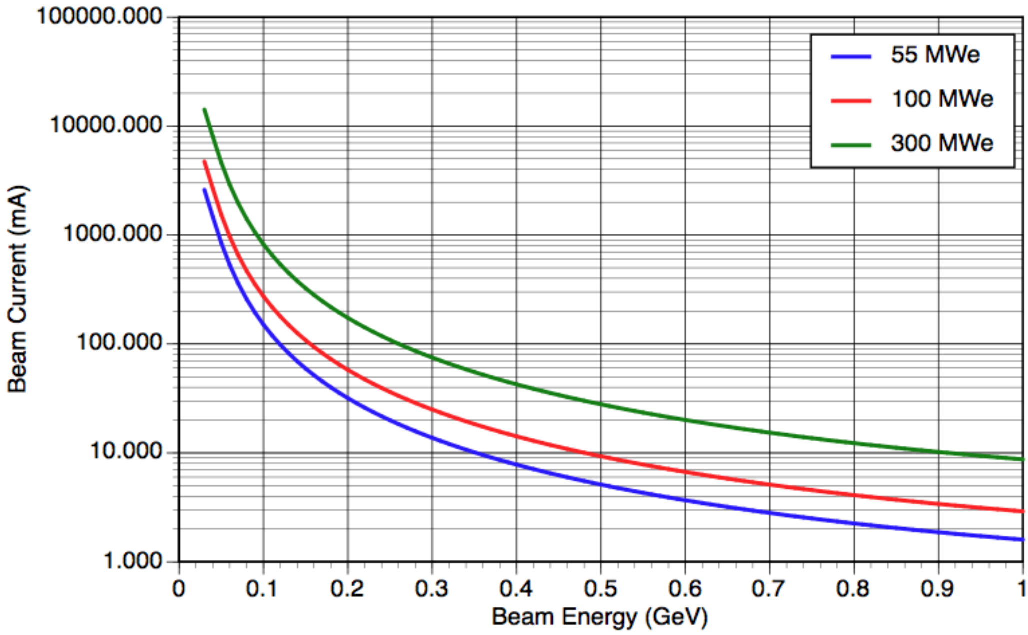


Figure 4: Beam current as a function of beam energy for three electric power output cases:300 MWe, 100 MWe and 55 MWe. The 100 MWe case corresponds to the option discussed in the text for NFRP-05, the other cases are given here for comparison.

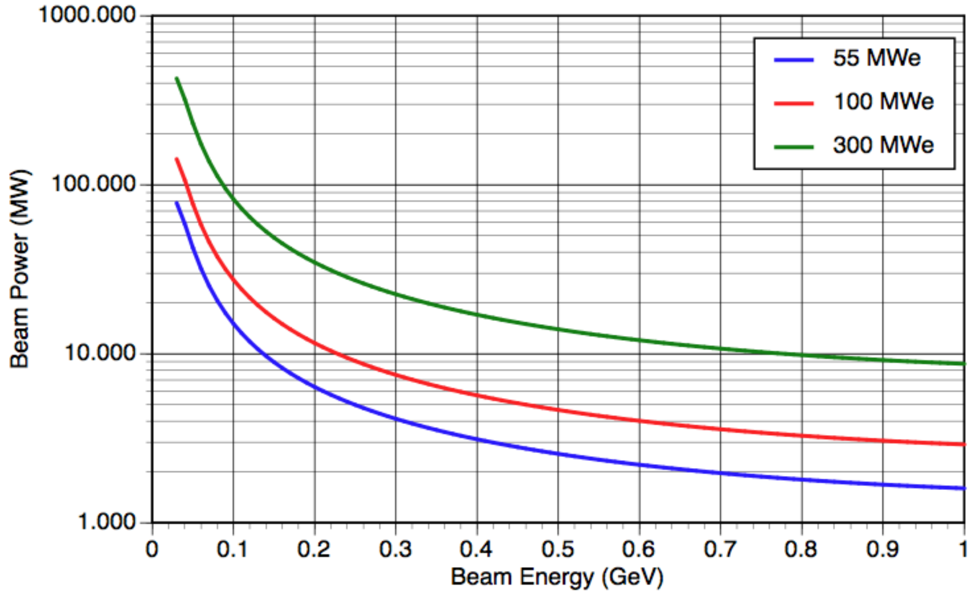


Figure 5: Beam power as a function of beam energy for three electric power output cases: 300 MWe, 100 MWe and 55 MWe. The 100 MWe case corresponds to the option discussed in the text for NFRP-05, the other cases are given here for comparison.

General description of ADS

The main components of the ADSMR system are: accelerator, subcritical core and spallation target. The requirement of subcriticality of the reactor implies that during operation the neutrons necessary to sustain the fission must be continually supplied to the core. This is achieved with the accelerator, producing proton impinging on the spallation target. For each of the system components, technology benchmarks are available and diverse solutions for the layout exist. More than 40,000 accelerating machines are deployed today in the world, with applications as diverse as medical therapy and diagnosis, manufacturing processes (EB-welding, ion implantation, radioisotope production etc.) and research (particle physics, synchrotron radiation, material science etc.). Based on such widespread applications and the available long duration OPEX data, we can consider the corresponding technology scenario to be mature (although continuously and fast developing towards more and more innovative solutions). In the process of producing neutrons from an accelerator-based spallation neutron source, the accelerator plays an important part in the facility to achieve the maximum number of neutrons. ADSMR will investigate an accelerator of the cyclotron type, because its relative compactness enhances the characteristics of a SMR, which by definition needs to be size effective. Defining the requirements of safety and reliability for the ADSMR accelerator will be based on the experience of the PSI cyclotron (50 years in operation, a world record in its power class) and the experience of design, construction and operation of the Large Hadron Collider at CERN, the largest circular collider in the world. The reactor core of a SMR can be considered a simplified, scaled version of the equivalent NNP. Spallation is the process of producing neutrons by causing particles from an accelerator to impact a heavy metal target. In order to achieve the highest rate of neutron production, the target material of the spallation process has to be composed of an element, which has a high atomic number along with a reasonable thickness. The physics of neutron spallation off thick and heavy targets is extremely well understood, from the physics point of view. Many detailed measurements are available (see for instance Figure 6). Results are well described by current simulation codes such as FLUKA [18], for instance, and many others. The FEAT and TARC experiments at CERN have shown that FLUKA reproduces extremely well neutron yields. Therefore, we can assume that the simulation of the neutron spallation process is reliable.

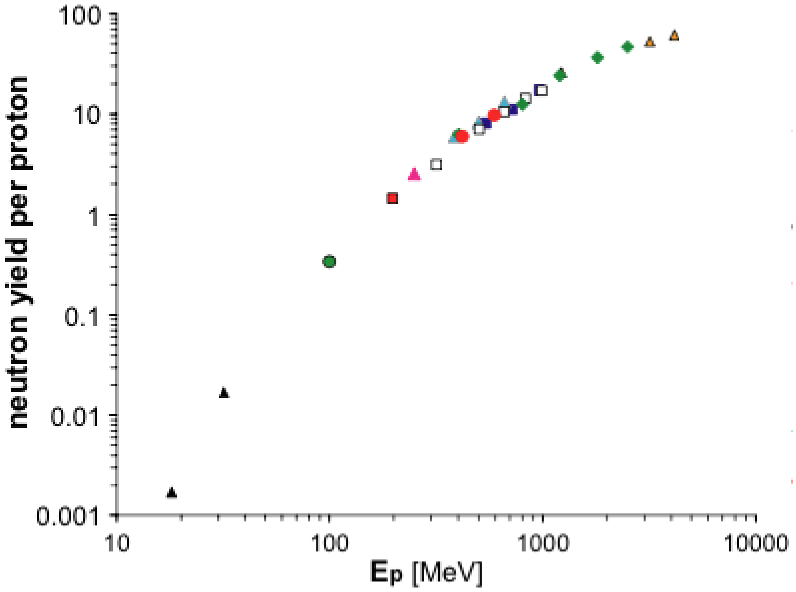


Figure 6: Compilation of thick-target neutron yield values for protons hitting a lead and a lead/bismuth target as a function of proton incident energy, taken from [19].

Neutron multiplicity, defined as the number of neutrons produced by spallation per incident particle (n/p), is a crucial parameter for showing the performance of applications of an accelerator driven neutron source. Neutron multiplicity is a function of beam energy and target materials, linearly dependent on the target mass number (in the range 12 < A < 238) and slowly increasing with incident proton energy (in the range 0.2 < E < 2 GeV).

[18] FLUKA simulation code reference: A. Ferrari, P.R. Sala, A. Fasso, J. Ranft, FLUKA, A Multiparticle Transport Code, SLAC-R-773, October 2005.

[19] K. van der Meer et al., Spallation Yields of Neutrons Produced in Thick Lead/Bismuth Targets by Protons at Incident Energies of 420 and 590 MeV, NIM B, vol 217, Issue 2 (2004), p 202-220.

The spallation target that we will consider will be based on pure liquid Lead or liquid Lead Bismuth metal eutectic (LBE), this will be decided at the beginning of the project, based on different economic-safety-technological criteria. Of course, we will consider in our analysis the experience and OPEX accumulated (MEGAPIE[20] was using the same technology, and MYRRHA will be adopting this technology as well).

For the ADSMR system, we will produce a reference layout and, at the same time, we will produce the requirements and safety documentation that are demanded for a full LP. It will serve as a "**simulated licensing exercise**", calibrated and proof-checked on a valid specific layout, because the LP is concept-dependent, and because safety-by-design is part of the process. To get the most out of the project and to make the exercise realistic and useful it is necessary to include all design aspects, from the starting point, that otherwise will be hidden in the folding of the documentation.

The ADSMR collaboration will interface with the MYRRHA community in SCK, as well as with the community of nuclear engineers and scientists at CERN, PSI, CIEMAT, ENEA and INFN.

The licensing process requires the applicant to submit a detailed demonstration of safety, which is reviewed by independent regulators, according to nationally applicable laws. It should be the responsibility of the regulator to provide guidance, safety objectives, criteria and the format of the documents to be produced (generally a Safety Analysis Report, SAR). For this reason, and also in consideration of the innovative type of plant for which little regulatory experience exists, we deem necessary to work according to a well-defined stakeholders scheme, where the regulatory functions shall interface with the technical counterparts and with the implementing actors, and where the public and policy makers also have a defined role. An early involvement of regulators in a process like the one depicted here is critical to prevent delays. Our partner **NINE will mirror the regulator action**, providing the guidance and steering of the exercise process.

According to the hierarchy of safety standards for innovative reactors, prepared in the framework of the SARGEN-IV project, as reported in Figure 7 [21], it will be necessary to ensure that the safety standard of LEVELS I, II and III are fulfilled already before submission of a safety analysis report (SAR).

[20] G. S. Bauer, M. Salvatores, and G. Heusener, "MEGAPIE, a 1 MW pilot experiment for a liquid metal spallation target," J. Nucl. Mater., vol. 296, no. 1–3, pp. 17–33, 2001.

[21] Sargen-IV: Consideration on the possible content of the safety analysis report for innovative ESNII reactors – Nuclear Engineering and design 300 (2016) 453-466

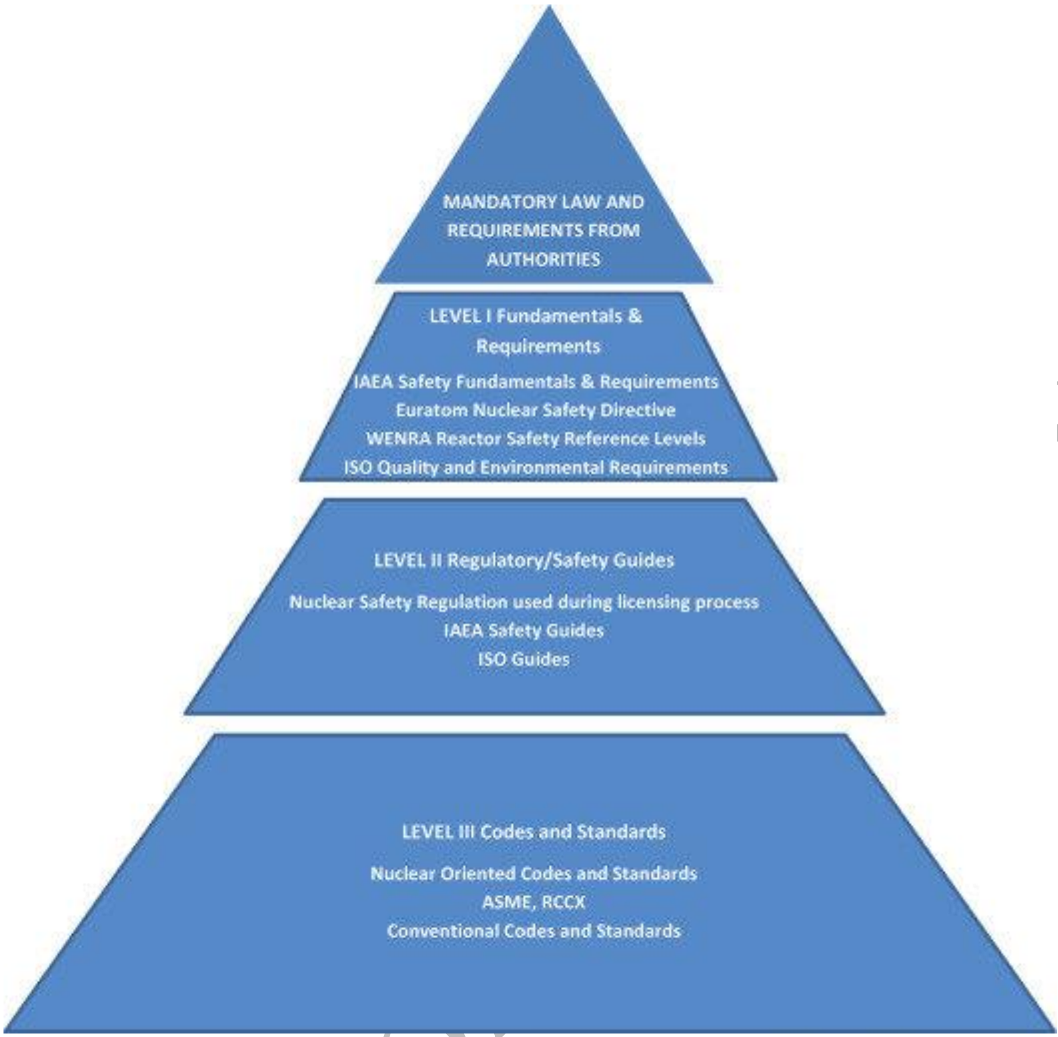


Figure 7: Hierarchy of safety standard for innovative reactors.

Well before the submission of the license application, it would be also requested for the regulators to meet with the licensees, the designer and with the prospected operator. The Consortium will prepare, in the framework of WP8, led by NINE, our "internal regulator", the documentation according to the general structure of the SAR:

1- General Design Aspect, safety objectives and engineering design requirements
2- Simulation
3- Design of systems, structures and components
4- Reactor, reactor coolant and connected systems
5- Accelerator and beam losses
6- Spallation target and window, qualification and experimental data.
7- Safety features
8- Decay heat removal system
9- Containment system
10- Habitability system
11- Instrumentation & control
12- Electric power and power conversion system
13- Radioactive waste management and Radiation protection

Site characteristics, operational conditions, human factors engineering and management systems, which are also normally included in the SAR, will only be treated on general terms, because they are either geography dependent, or depending on the experience of the specific operator, that, at the moment, is not defined and not part of the work.

1.4 Ambition

We have the ambition, by demonstrating a possible safe and rapid licencing process, to provide important contribution to the acceptability by society of nuclear energy in the future energy mix, that requires massive increase of electricity production with no CO_2 production, no air pollution, no proliferation risk and a reasonable management of nuclear waste.

The combination of nuclear engineering with accelerator technology and superconductivity, applied to the specific licencing process, will advance the innovation potential. In fact interaction and synergies between the sectors will help the definition of a LP able to advance the development and quick deployment of the ADSMR, paving the road to new products and businesses.

2. Impact

The impact that our project is pursuing is to facilitate efficient, cost-effective and predictable licensing of SMRs and more specifically, ADS SMRs, in Europe and possibly elsewhere. ADSMR is a system in principle able to produce clean, safe, cost-effective and proliferation resistant energy, while at the same time minimizing the waste produced, by combining accelerator and subcritical reactor technologies. By developing our project as a dummy exercise of licensing ADSMR, we want to produce an impact example to be used as a foundation and benchmark in the process for licensing SMRs.

2.1 Expected Impact

Estimations made by several renowned agencies about the future energy demand in the world are pretty well known. Starting from different scenarios, using different assumptions, adopting different simulations and regressions, all the studies end up with the result that by 2050 the world will need 2 or even 3 times more energy than today [22]. At the same time, the effect of electricity generation on the global emission of CO_2, and the need to reduce practically to zero the contribution of the human produced CO_2 in order to contain the global warming within acceptable limits for the life on the planet are also well known [23]. This challenge can only be met by a profound and rapid transformation of the full supply chain of energy production, also called "energy transition". Nuclear Energy has been indicated several times, as one of the factors of the energy transition. It has been analysed that any realistic assumption of carbon reduction requires at least a doubling of the Nuclear Energy production, based on 2016 data [24]. In other words, Nuclear Energy can be one of the many components of the solution if it is able to deploy quickly its capacity. However, a rapid expansion of nuclear technology faces stiff challenges: accidents raise public fears about safety, large cost overruns and protracted schedules deter investors, but even more important is the public concern about nuclear waste and weapon proliferation. This means that all these aspects need to be considered at the same time if we want Nuclear Energy to play the role it is requested to.

We believe the challenge can be successfully met by the combination of the SMRs and of ADS. The modular approach of SMRs, with reduced dimensions allowing an off-site and series manufacturing, driven by accelerator for a subcritical mode of operation, with passive safety by design, reduced inventories and transmutation capability, provides a comprehensive answer to the public request, in terms of improved safety and waste management, and of the planet in terms of cost-efficiency and carbon-free energy production. To this, the reduced CAPEX and the reduced time to deployment due to off-site, series manufacturing could also be added.

[22] BP Statistical Review of World Energy https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
[23] See IPCC report at https://www.ipcc.ch/
[24] Paris Agreement: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Regulation, however, can still be a barrier to deployment for this type of NP: the usually adopted design structure approval for SMRs is the same like for normal NPs, and existing regulation has been designed primarily for light water technologies; it is not easily adapted to the features and performance characteristics of advanced reactors, which rely on substantially different fuels, cooling systems, and safety strategies, and also exhibit novel operating characteristics [25]. In our view, the large investment necessary for the development and commercialization of a ADSMR would be much more easily committed in gradual steps, with each one of these steps bringing only a reduced part of the total financial and technical risk. We will bring evidence that an ADSMR can meet a reasonable licensing time compatible with the requirements of investors, which can increase their commitments as long as the risks are progressively reduced. We will provide a valuable impact by designing a step process where a small increase in a "pre-licencing" cost, will result in a lower cumulative investment and reduced time to completion.

Formal pre-licensing reviews should be conducted, with final regulator assessment giving the green light to proceed or not to the following stage of design. This could also be an opportunity for vendors to demonstrate useful progress to their investors. A "statement of pre-licensing feasibility" could provide the regulator and the vendor useful indications on how and where to focus efforts.

According to updated projections from NEA/IAEA (2014)[26], taking into account the developments that occurred between January 2013 and August 2014, the nuclear capacity in 2035 will be almost 700 GWe in the high-case scenario and about 400 GWe in the low- case scenario (see Figure 8). In the high-case scenario, almost 300 GWe of new nuclear capacity will be added in the next 20 years, about 245 of which in the period 2020-2035. NEA has estimated the share of the SMRs market potential into this new build, according to a conservative low-case scenario (not competitive cost), and an optimistic high-case scenario (competitive costs). In the low-case scenario, it is assumed that SMRs are more expensive to build and to operate (when compared to other power sources) than currently anticipated, and thus only a limited number of projects are completed, including prototypes and generating plants in remote/isolated areas with high electricity prices. In the high-case scenario, the share of SMRs is determined using the assumption that SMRs will be cheaper to build than advanced light-water reactors (ALWRs), but will have higher variable costs (operation and maintenance [O&M] and fuel costs). The quoted study from NEA concludes that optimal share of SMRs in the nuclear capacity will depend on the penetration level of the variable renewables and ranges between about i) 16% for no renewables and ii) 33% for a 30% market penetration level of variable renewables. According to this analysis up to about 9% of the nuclear new build, in the period 2020-2035, could be done with SMRs in the high-case scenario, and about 2.3% in the low-case scenario. In total, about 21 GWe of nuclear new build could be done with SMRs in the high-case scenario (NEA/IAEA, 2014), i.e. SMRs will count for about 3% of the total installed nuclear capacity in 2035, see Figure 9.

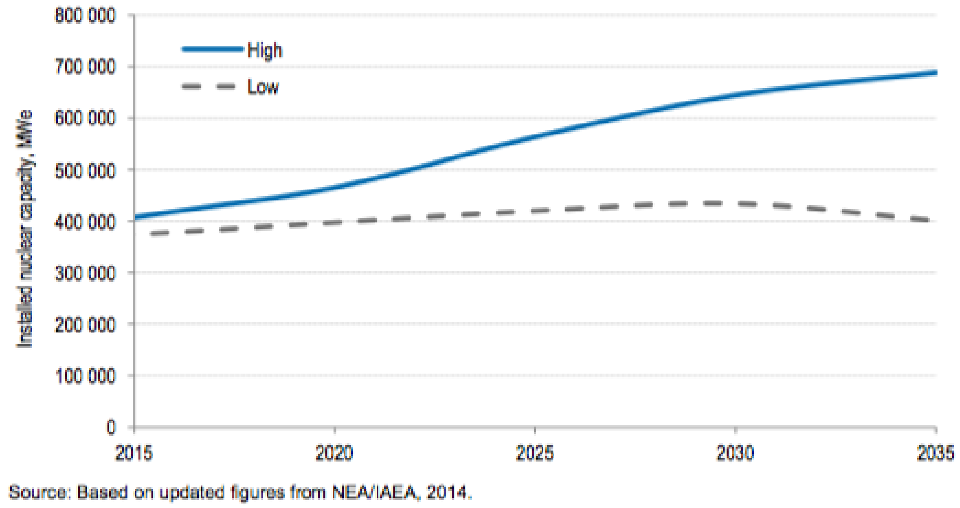


Figure 8: Installed Nuclear Capacity – Projections up to 2035.

[25] Nuclear innovation Alliance: Enabling Nuclear Innovation – Strategies for advanced Reactor Licensing, A.E.Finan, April 2016.

[26] NEA No.7213, OECD 2016

Less conservative / more optimistic estimations [UK National Nuclear Laboratory (NNL, 2014: 3): "The size of the potential SMR market is calculated to be approximately 65-85 GW by 2035 [...] if the economics are competitive."] also exist. But what interests here, in order to broadly evaluate the impact of deployment of this technology, is the claim that considering a typical unit of 300 MWt, the number of SMRs to build could be in the high-case scenario more than 200 and that such a production level indicates the possibility of off-site manufacturing that could be competitively viable and bringing in the effect of scale economy, especially if few SMR designs are deployed simultaneously. Impact on the environment is known to be huge: carbon-free energy produced with a reference figure of almost 1000 metric tons of CO_2 rejected in the atmosphere for each 1 GW of electricity produced with fossil fuel.

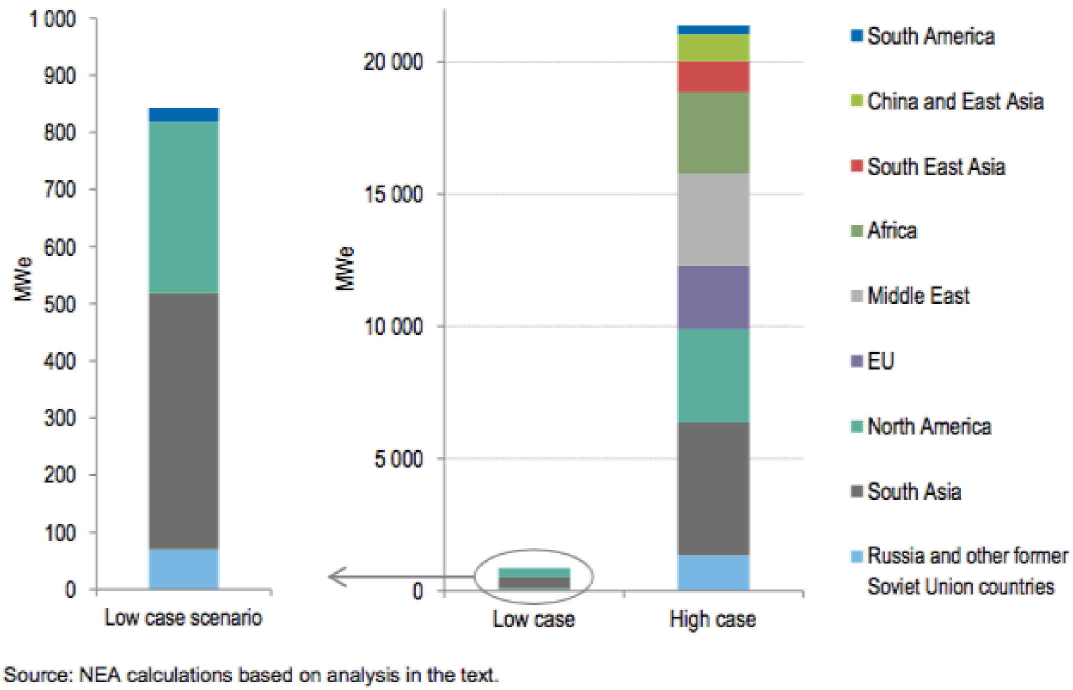


Figure 9: Estimated SMR Capacity by region - Projections up to 2035.

A wide access to **nuclear research infrastructures** to qualify and characterize components is crucial to develop a fast licensing process. Many components (beam windows, multi-injection lines, material properties, just to mention a few) will have to be qualified and the presence in the consortium of laboratories like CERN, INFN, ENEA, CVR that can each mobilize unique facilities and infrastructures for the running of necessary qualification campaign and experimental tests is an important support and guarantee. The facilities and infrastructures available at the partners' premises for specific tests are described in Section 4.

The ADSMR project will have a significant impact in the way European laboratories, nuclear industries, regulators and universities conduct a joint development of a novel class of SMRs, by fostering collaboration between different actors in different countries. ADSMR will further enhance this process by collaborating with industrial partners from the beginning and by increasing the number of research infrastructures made available for experimental support activities. In this way, the project is expected to also achieve economies of scale and optimization of resources.

Training of a new generation of nuclear scientists and engineers

WP9 "Training, Communication and Outreach" will increase the European pool of trained and well-informed students in the area of nuclear science and accelerator technology. It will enhance the communication of achievements and opportunities within the field, as well as increase the flow of trained individuals into industries, laboratories and universities where there is a skills-shortage in Europe. The Consortium partner KTH has a long and successful record of training and education of both PhD student and Postdocs. Working together with CERN and Stuttgart University, a wide and coordinated programme of training will be prepared. A dedicated task in WP9, for example, will produce an e-learning course on SMRs, with a series of open lectures on several sub-topics, aimed at students. The goal is to deliver an introduction to the SMRs concepts and nuclear science, ADS engineering and technology, in order to give students throughout Europe access to training in this technology. The course will provide sufficient exposure to also allow undergraduates to make informed career choices regarding industrial or academic careers in the nuclear (and related) sector(s).

ADSMR will also give young researchers and engineers the opportunity to strengthen their scientific training and to gain practical experience by participating in R&D in leading accelerator laboratories and universities in Europe. **About 4 PhD students** are expected to contribute to the project activities; the PhD opportunities will be widely advertised to all partners of the consortium, with the goal of favouring exchanges in particular for students coming from smaller universities. Working in renowned academic institutes, participating in the workshops organised by the project, and interacting with industrial partners may provide job opportunities for PhD students in academic and industrial sectors after the end of the project.

Knowledge sharing across fields and between academia and industry

ADSMR will be a European multi-disciplinary forum where the expertise and know-how on particle accelerator technologies, nuclear science and engineering is shared within and outside of the nuclear reactor's community. ADSMR will create and enhance cooperation and knowledge exchange along two different axes: (i) between accelerators for particle physics, nuclear industries, neutron sources; (ii) between regulators, universities, industrial partners and nuclear industry associations for exploiting market applications and to increase public acceptance of nuclear technologies.

ADSMR is based on a consortium of 12 beneficiaries from 7 countries and 1 international organization that will be working on a common ambitious programme for advancing the licensing process of safe and of innovative SMRs and accelerator science and technology in Europe and possibly in the world. By bringing together key actors from the nuclear and accelerator communities, ADSMR will effectively implement a joint programme in nuclear science and technology at European level. It is important to observe that all participants, including industrial partners, will bring significant resources of their own (matching resources).

Strengthening competitiveness and growth of European companies

In a moment when European nuclear industry is substantially stagnant, ADSMR aims at providing a competitive advantage to European industries in the novel sector of ADS accelerator-based nuclear sector. This may result in opening new market opportunities with the consequent creation of jobs and economic growth. At the same time, technologies developed for fundamental research, like the accelerators for particle physics, will demonstrate they can have an impact that goes beyond accelerator science: transmutation of nuclear waste and production of Carbon-free energy are high on the agenda of all governments, both in developed that underdeveloped world. WP7 will specifically target, also from the economic point of view, the fuel cycle models and the waste production, management, transmutation.

The development of more safe, economic and quick to deploy SMRs reactors will also directly impact and enhance industrial applications like water desalinization and hydrogen production, in addition to the direct impact on society originating from the carbon-free energy production and the mitigation of nuclear waste management.

2.2 Measures to maximize impact

a) Dissemination and exploitation of results

Draft plan for dissemination and exploitation of project results

The dissemination and exploitation activities of ASDMR will be coordinated in the framework of WP1 and WP9 "Training, dissemination and outreach".

Regarding dissemination, ADSMR aims to provide timely information about the results, from advancing of the design to licensing activities, to both the nuclear community and to European industry.

Regarding exploitation, ADSMR aims to promote exploitable results that have potential for commercial applications, and make them available to interested parties within and beyond the ADSMR consortium, while protecting the legitimate interests of all ADSMR beneficiaries that have been involved in producing these results. This process will surely go beyond the duration of the project.

To reach these goals, the draft Dissemination and Exploitation Plan of ADSMR includes the following objectives:

1. To foster inter-sectorial knowledge exchange and improve relations between industrial and academic participants;

2. To enhance contacts and relations with European industries for the identification, follow-up and exploitation of project results;

3. To advance the technology readiness levels, propose safer nuclear systems and licensing processes in order to enable the uptake and exploitation of specific technologies developed in ADSMR by the industrial participants in the project or other industrial partners.

Objectives 1 and 2 will be achieved, inter-alia, by the organization of events, in a workshop format, open to academia and industries within and outside of the consortium.

Knowledge management and protection

Access to Results and Background and ownership of Results will follow the principles set out in the EC Grant Agreement. The implementation of these principles will be detailed in the Consortium Agreement, which will be signed before the start of ADSMR. In this Consortium Agreement, the beneficiaries will identify and agree on the Background needed to carry out the project and which may have to be made available to other beneficiaries. Access rights to Background or to Results needed for use of ADSMR results for research purposes beyond the project duration by other beneficiaries will be granted on a fair and reasonable basis, within the terms agreed in the Consortium Agreement.

ADSMR aims to implement efficient management of Intellectual Property Rights (IPR), which is essential for successfully exploiting the research results of the project and for protecting the interests of the institutes and companies that have produced these results. A staff member of the Knowledge Transfer Group at CERN will act as a liaison between the beneficiaries to ensure that ownership of new IP is adequately distributed and protected.

The beneficiaries of ADSMR will endeavour to publish any results as swiftly as possible in conference proceedings and/or scientific journals as appropriate. The Consortium Agreement will define in detail the procedures for publication, which will take into account the potential for commercial exploitation and/or the need for protection of IPR of the results concerned, with due consideration of the IP practices of all participants.

The table below summarizes the key impact targets of the ADSMR project.

Table 2: Dissemination and other impact targets of ADSMR.

Impact objectives	ADSMR target
Scientific dissemination	5 journal publication, 3 conference contributions
General communications and news	1 workshop, 5 articles in media channels

Training of PhD scientists and nuclear engineers	4 PhD students
Cross border cooperation	12 beneficiaries from 7 countries
Knowledge sharing in the community	50 project members in 11 Work Packages

b) Communication activities

The communication plan of this project builds upon experience and lessons learned from similar EU projects coordinated by CERN (e.g. QUACO, AIDA-2020, ARIES) and is based on the EC guideline document "Communicating EU Research & Innovation" [27].

The main goals of the communication activities of ADSMR are to:

- implement effective knowledge sharing among the participants (internal) and with the wider nuclear scientific community (external);
- enhance the knowledge exchange between regulators and industry;
- increase public awareness of ADS and SMRs and their joint applications;
- demonstrate the benefits, in terms of enhanced safety and cost, of the project collaboration to the public and policy makers.

The project results will be widely **shared and openly accessible** to all stakeholders, thus demonstrating that the project is on track and its objectives are being achieved.

Target audiences and their needs

The project members constitute the internal audience, and the external audience consists of the wider scientific community in related fields, industry, funding agencies and the general public. These audiences have different needs and means of engagement with the project, so therefore different communication strategies and channels will be used.

Target group	Description	Identified needs	Communication measures	Expected impact
Project members (individuals)	Scientific and administrative contacts of the participants	Project information, list of participants, contacts, events, results, deliverables, outreach materials	Website, mailing lists, annual and work package meetings	Enhanced information flow, greater efficiency, better motivation
Related projects from other nuclear scientific communities	Scientific and industrial audience	Information about the project, contacts, workshops, papers, joint events	Dissemination channels of other projects (e.g. via EURATOM channel), conferences, open events	Identifying common challenges, sharing knowledge, fostering future collaborations
European Industry	Companies with relevant specific activities and/or products	Publications, information on technologies being developed by the project	Targeted industry-academia events organised by ADSMR	Two-way knowledge exchange, technology transfer, secondments, joint R&D

27 http://ec.europa.eu/research/social-sciences/pdf/communicating-research_en.pdf

National funding agencies and national regulators	Responsible for nuclear development programmes	Recommendations, information on state-of-the-art, future projects, summary of results, best practices	General public website, brochures	Demonstration of return of investment in ADS and SMRs technologies; paving way for future projects; roadmaps
General public	Interested public, including students and teachers	General information, how accelerator S&T is relevant to daily life of European citizens	E-learning package developed in WP9, social media channels, brochures, videos, public talks	Demonstrating societal impact of the project and benefits of fundamental research

Communication tools and activities

The following information channels will be used to achieve good coverage of the different audiences' needs:

- Project website
- Annual meeting
- Intranet collaborative workspace
- Project mailing lists
- Annual report

Project website

Most of the key tools used for communication in ADSMR will be online-based. The project website will be the open portal to ADSMR, and will contain public areas with explanations of what the project is about, what its objectives are, as well as a summary of its main results. A set of outreach materials will be developed, mainly intended for use by the project members in their outreach and public engagement activities, whether as direct use or as inspiration for other communication activities.

The project website will also serve as the central information hub for project members, with dedicated sections about the activities of ADSMR, upcoming and past events, recent publications, as well as news and announcements. The Deliverable reports of the project will be made available on the public website.

Intranet collaborative workspace

In addition to the public website, a collaborative workspace will be accessible to project members, enabling online collaboration, sharing of technical and administrative documents and results, and meeting organisation. This intranet will require authentication and will enable selective dissemination of information to the internal audience.

Project mailing lists

Supplementing the intranet, will be a managed set of mailing lists for the project, as a whole along with separate e-mail lists for each work package and each task within each work package. CERN will create and manage all e-information tools and make them available to all participants of the project.

Annual meetings

Annual meetings are opportunities for all members of such a big project to meet, share and discuss their ideas and results, with scientists and students invited to present their work. These meetings also serve to improve networking between tasks and work packages.

Brochures and outreach material

Information about the project will be provided in the form of periodic reports to the members of the Governance structure of the ADSMR project, and short status reports will be made to international science decision-making bodies such as the CERN Council[28]. Links with the European Commission and EURATOM will be maintained, in particular via consultations, meetings and specific workshops, enhancing their innovation potential and relations with industry. Where appropriate, information on the scope, objectives and results of the project in the form of a dedicated brochure will be conveyed to European funding agencies in a tailored fashion.

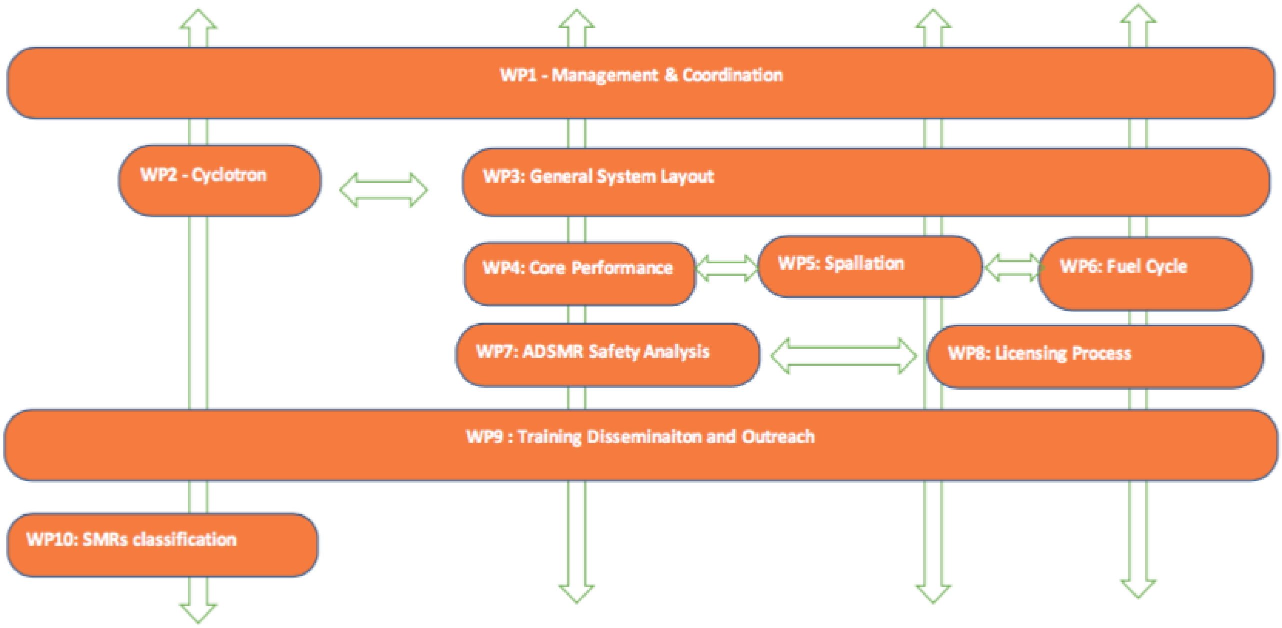
[28] The European Strategy Council Sessions of CERN are attended by delegates from its 23 Member States, as well as by delegates from its Associate Members and observer countries and organisations, including the European Commission.

3. Implementation

3.1 Work plan – Work packages, deliverables

Table 3: List of Work Packages

Work package No.	Work Package Title	Lead Participant No	Lead Participant Short Name	Person-Months	Start Month	End month
1	**Project Management and Coordination**	**1**	**CERN**	**18**	**M1**	**M36**
2	**Concept of accelerator for ADSMR**	**9**	**INFN**	**56**	**M1**	**M36**
3	**General System Layout**	**8**	**HNE**	**53**	**M1**	**M36**
4	**Core performance and safety assessment**	**2**	**ENEA**	**73**	**M1**	**M36**
5	**Spallation Target**	**3**	**CVR**	**60**	**M1**	**M36**
6	**Fuel Cycle Evaluation**	**2**	**CIEMAT**	**50**	**M1**	**M36**
7	**Safety Analysis**	**4**	**NINE**	**52**	**M1**	**M36**
8	**Licensing Process**	**4**	**NINE**	**42**	**M1**	**M36**
9	**Training, Dissemination and outreach**	**10**	**KTH**	**32**	**M1**	**M36**
10	***Present SMRs classification***	**6**	**UNIGE**	**32**	**M1**	**M36**
				Total PM ***468***		



The description of each Work Package is in the tables provided below.

Work Package number	**WP1**			**Lead Beneficiary**	**CERN**	
Work Package Title	Project management and coordination					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	CVR	NINE	ENEA	UNIGE
Person-months per participant	**14**	2				
Participant number	7	8	9	10	11	12
Short name of participant	PSI	HNE	**INFN**	KTH	UNSTATT	**iThEC**
Person-months per participant			1			1
Start month	M1			**End month**	M36	

Objectives: This WP led by the Project Coordinator (PC), will fulfil all tasks required by EURATOM and the tasks of management, coordination and technical integrations among Work Packages.

Description of Work: WP led by CERN, includes a number of management and coordination activities carried out by the Project Management Team. The management duties are carried out within the overall managerial structure of the project, as described in section 3.2. These include the overall coordination and continuous monitoring of the programme of work, the organisation of the Governing Board and Steering Committee meetings, the preparation of the Annual Meetings and the Mid-term Review, as well as the regular communication with the EURATOM on administrative and technical aspects of the project. The administrative, financial and contractual follow-up of the project, according to the EURATOM Grant Agreement and its annexes are also included in this WP. This work covers the preparation of the periodic and final activity reports and the reviewing of the Deliverable and Milestone reports. The financial follow-up consists of distribution and payments of the EURATOM funding, resource utilization control, internal cost reporting and collection, review and submission of the Certificates on the Financial Statements by the beneficiaries. As Coordinator, CERN takes the responsibility for providing appropriate Information Technology (IT) tools in order to ensure the effective management of the project. A specific task in this WP disseminates the project results outside of the consortium via the usual channels: internal – such as periodic technical reports, and external – such as conference presentations, journal publications and monographs. Ph.D. students working within the project are encouraged to present their research results in key talks or poster sessions at the Annual Meetings. These meetings also foresee accelerator science and nuclear technology tutorials aimed at a student-level and post-graduate audience.

Task 1.1. Management: Effectively manage and steer the whole project, including administration, IPR, contractual and financial follow-up and report. Monitor the overall scientific and technical progress; Contractually and financially follow-up of project use of resources. Interfacing with EURATOM.

Task 1.2. Internal communication and dissemination, scientific publications and monographs: Establish a communication web-based tool for facilitating exchange of information and documentation on the project; Coordinate the publication efforts of the project community; Monitor the status of publications of the project; Communicate the publication status to project leaders; Publish and disseminate a series of scientific monographs on accelerator science; Organise workshops 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.

Deliverables: D1.1: 1st Annual meeting Report – (M12); D1.2: 2nd Annual Meeting Report –(M24); D1.3: Final report - Project scientific achievements and Licensing process for ADSMR system" (M36); D1.5 Data Management Plan; D1.6:

You should include a deliverable on dissemination & communication

Work Package number	**WP2**			**Lead Beneficiary**	**INFN**	
Work Package Title	Concept of Accelerator System for ADSMR					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	CIEMAT	CVR	**NINE**	ENEA	UNIGE
Person-months per participant	**4**			2		
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	HNE	**INFN**	**KTH**	**UNSTATT**	**iThEC**
Person-months per participant	29		18		2	1
Start month	M1			**End month**	M36	

Objectives: The goal of the WP is to provide the study and the preliminary design of the accelerator delivering high power proton beam for small modular reactors.

Description of Work: WP led by INFN, will provide the concept of the proton driver accelerator. The work consists on the main definition of the parameter and performance of the cyclotron based accelerator. Once the main requirements are fixed, the design study of different items will be carried on: magnet and cryogenics study and design, accelerating cavity modelling, beam dynamics, injection and extraction design, ancillary systems definition. The activities foresee the extensive use of beam dynamics dedicated codes, 3D Finite Element Method (FEM) code for Electro-Magnetic (EM) and Mechanical simulation and modelling of structures. The accelerator design will pay attention to the enhancement of safety features by the systems analysis of the critical parts. Improvement of beam control system and machine protection system will be implemented.

Task 2.1. Accelerator main parameters definition (INFN-PSI-CERN): Definition of main parameters and requirements of accelerator system (beam, energy, average current, magnetic configuration).

Task 2.2. Accelerator components study and design (INFN-UNSTUTT): Study and preliminary design of main parts of the accelerator: magnet, RF cavities, injection and extraction systems. Beam transport optics.

Task 2.3. Beam dynamics and control (PSI): Beam dynamics. Beam losses evaluation and plan for beam loss mitigation. Start to End Beam dynamics model and beam transport control optimization. The goal is halo and beam loss mitigation, matching requirements of the spallation target and the analysis shall be fed-back to the other WPs all along the project duration.

Task 2.4. Safety improvement and system integration (INFN-NINE-CERN-USTUTT): Integration with ADS system. Accelerator Control System (ACS) and Machine Protection System (MPS) analysis for safety enhancement and license requirements compliance.

Deliverables: D2.1: Accelerator system parameters and performances (M6); D2.2: Magnet conceptual design (modeling and simulation) (M24); D2.3: RF cavity conceptual design (modelling and simulation) (M18); D2.4: Injection and Extraction System (M12); D2.5: Beam dynamics evaluation (M24); D2.6: Safety enhancement: beam monitoring and control system; machine protection system definition (M18).

Work Package number	WP3	Lead Beneficiary				HNE
Work Package Title	General System Layout					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	**CVR**	**NINE**	**ENEA**	**UNIGE**
Person-months per participant	**3**	6	3	2	6	9
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	**HNE**	**INFN**	KTH	**UNSTATT**	**iThEC**
Person-months per participant	2	18	1		2	1
Start month	M1	**End month**				M36

Objectives: Definition of the subcritical system configuration including general arrangement inside the reactor building of accelerator, beam line and reactor block characterized by an integrated and compact configuration of the primary system with spallation target, core, primary pumps, steam generator and heat exchangers of the decay heat removal systems inside the reactor vessel.

Description of work: Reactor Assembly Configuration will be defined complying with the interfaces among cyclotron, beam line, target, subcritical core and main components of the primary system. Functional coupling of the innovative cyclotron with the target and subcritical core via spallation process will be considered including power transfer, with pure lead coolant, from the core and target via SG and DHR systems. The core will rely on the innovative mechanical configuration developed by HNE for the LFR-AS-200 to simplify refuelling system and to manage the large inventory of fission gases produced by MA containing fuels.

Task 3.1 Primary system configuration. This task aims at providing a consistent primary system configuration, characterized by simplicity and compactness to reduce the cost, by natural circulation of the primary lead for decay heat removal, by the minimum requirement of ISI and by a simple refuelling system. Simplicity and compactness will be achieved by suppression of components, typical of LMR and no more necessary in the innovative proposed configuration.

Task 3.2 Shielding and activation. This task aims at providing the shielding needs of the beam pipe, the core shielding and the activation of the lead coolant and primary systems structural materials.

Task 3.3 Decay heat removal systems.

This task aims at providing two redundant and diversified systems for decay heat removal. Both systems will be passively operated and at least one will be also passively actuated and able to control the temperature of lead in the cold collector of the reactor without any connection to automatic systems and logics to be proof of cyber-attacks.

Task 3.4 Functional interface with core, target and auxiliary reactivity control systems. This task aims at providing the process parameters necessary for the functional and safety analyses of the subcritical system. The various operating conditions will be identified based on the design objectives and constraints resulting from the main interfaces among the several components/systems.

Task 3.5 Reactor building general layout.

This task aims at providing the general arrangement of the various components inside the reactor building. Differently from a linac, a cyclotron, thanks for its compactness, can be installed inside the reactor building without jeopardising the containment function. Relative position of reactor block and Cyclotron will be optimized for a simple beam line and for minimizing the interference with the refuelling system.
Deliverables: D3.1 (**HNE**, ENEA): Report and Drawings of the primary system configuration D3.2 (**CIEMAT**, INFN): Shielding needs and activation D3.3 (**UNIGE**, HNE, NINE): Report and Drawings of the DHR systems D3.4 (**ENEA**, HNE, CERN): Operating conditions of the subcritical system and main process parameters D3.5 (**HNE**, CVR, INFN, NINE): Report of the reactor building general layout

Work Package number	WP4		Lead Beneficiary		ENEA	
Work Package Title	Core performance and Safety Assessment					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	CVR	**NINE**	**ENEA**	**UNIGE**
Person-months per participant	**4**	19		2	16	12
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	**HNE**	**INFN**	**KTH**	**UNSTUTT**	**iThEC**
Person-months per participant	2	2	5	8	2	1
Start month	M1		**End month**		M36	

Objectives: The goal of the WP is to provide the study and the preliminary design of the core system of the reactor, optimized for the target waste transmutation performance in the envisaged fuel cycle perspective, with the objective to defining the graded and optimized licensing process

Description of Work: WP led by ENEA, will provide the core design, the definition of the fuel for aimed transmutation performance. Neutronics and thermal-hydraulics analysis of the core and the spallation target will be performed, covering some transients to support safety assessments, and providing the validation of the heat balance calculations for the primary circuit. Neutronic calculation as necessary for fuel definition and core optimization, and for reactivity and safety parameters evaluation in different conditions (BOL, EOL, some DBA) will be carried out. The WP will be delivering the development, tuning and validation of hadronic interaction packages describing the spallation region to make sure that, in particular, the neutron yield is described correctly. CERN will implement an integrated Monte Carlo simulation with Geant and/or MCNPX of spallation and particle transport for ADS system, in the range from 100 MeV to 10 GeV. Simulation of 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 of spallation target. Feedback on overall performance of the machine and cost analysis.

Spallation target calculations will be performed to optimize the target size and position in function of beam intensity, heat and damage deposited, spallation target wastes. → this should go in WP5 ????

Nuclear data analysis will support with sufficient quality the licensing assessments and the conceptual design of the reactivity monitoring and system control; Assessment of the nuclear data induced uncertainties and safety margins as impact of uncertainties on the licensing procedures.

Task 4.1. Core design (X-X-X): Definition of fuel for aimed transmutation performance

Task 4.2. Neutronics and thermo-hydraulic analysis (X-X-X): Study and preliminary analysis of core and spallation target

Task 4.3. Spallation target design (X-X-X) *this should go in WP5 ????*

evaluation and mitigation solution. Beam transport control optimization. Beam diagnostics improvement.

Task 4.4 Nuclear Data analysis (X-X-X):

Deliverables: D4.1:

General Planning of WP4: Core performance and safety assessment						
years	I		II		III	
semesters	M6	M12	M18	M24	M30	M36
deliverables						
D4.1						
D4.2						
D4.3						
D4.4						
D4.5						
D4.6						
Final Report						

Work Package number	**WP5**		**Lead Beneficiary**	CVR		
Work Package Title	Spallation Target					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	**CVR**	NINE	**ENEA**	**UNIGE**
Person-months per participant	**3**	4	36		3	6
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	**HNE**	**INFN**	KTH	**UNSTUTT**	**iThEC**
Person-months per participant	3	1	2		2	1
Start month	M1			**End month**		M36

Objectives: The goal of the WP is to first identify and then evaluate those characteristics of the Spallation target that are most relevant to the safety and licencing of an ADSMR. The WP will:

1. Identify key characteristics of the spallation target that have a major influence on licensing.
2. Evaluate the relative safety-relevant merit of different design options for the spallation target,
3. Provide the influence of the spallation target geometry on the overall reactor physics.
4. Confirm experimentally the viability of some detailed aspects of the spallation target such as the heat exchangers or the beam window.

Description of Work: WP led by CVR, will provide safety-relevant data pertaining to the design and definition of the spallation target.

Task 5.1. Target reliability M12

Lead: CVR

Partners: PSI?

Review systematically as-built spallation targets from different facilities such as in PSI built primarily for research and evaluate the catalogue of accident/incidents from the available documentation. (CVR)

Radiochemical evaluation of the different coolant options such as water, heavy-water, Lead, LBE, w.r.t. safety, source term and back-end options. (PSI)

Provide a list of safety-critical components, along with a qualitative and wherever possible a quantitative evaluation of their contribution to safety. CVR will concatenate and analyse from a safety engineering point of view experiences collected in facilities such as PSI.

Task 5.2. Target architecture M20

Lead: CVR

Partners: CERN

CVR is to provide a schematic of at least two proposed design options and a list of associated Initiating Events completed by a qualitative deterministic analysis of DBAs (Design Base Accidents) originating in the spallation target. Follow up these two most favourable design options by thermal, hydraulic and stress analysis as well as neutronics calculations (CERN) to derive objective safety-critical data, such as expected lifetime of a component, maximum temperatures, corrosion losses, radiological source-term. Tools to be used include Finite Element Analysis and Computational Fluid Dynamics for safety-critical components as well as systems-level codes for accident analysis.

To maximise the reliability of each key component and minimise its contribution to the foreseeable DBA, objective criteria shall be used such as failure probabilities per reactor-year of operation.

Task 5.3. Target integration M20

Lead: CVR

Partners: HNE

Cooperate with the WP3 (HNE) to identify and resolve interface issues between the reactor and the spallation target. Interfaces are key contributors to initiating events and toe radiological release paths. These safety-critical items shall be listed and assessed. Criteria could include for instance, the dimensions, back-pressure and radiological source terms at a given interface. Schematics of safety barriers under different design option may be provided.

The neutronics aspect of integration are to be considered. The input suitable for integration of the spallation target into the global neutronics model shall be provided. A simplification of the engineering design shall be derived to focus only on those aspects relevant to reactor physics.

In terms of systems analysis, the spallation target design shall be sufficiently simplified to derive a model suitable for integration into a standard nuclear safety thermal-hydraulics code such as TRACE or RELAP5.

Task 5.4. Deterministic and probabilistic safety analysis M26

Lead: University of Stuttgart

Partners: CVR

Integration aspects of the target with the reactor and the accelerator design relevant to licensing. The approach taken in integrating the target will be major contributor to the DBA. Hence all aspects from operational to maintenance, repair should be examined. The evaluation shall be based on a deterministic and probabilistic analysis.

A deterministic analysis (Uni Stuttgart) of the CVR target design shall result in a re-evaluation of the DBA catalogue to include target-initiated accidents. The preceding task 5.3 provides a source of initiating events which can be followed through to their impact on the reactor, the fuel and hence a likely consequence in radiological terms.

The PSA (Probabilistic Safety Analysis) evaluation by Uni Stuttgart of the different CVR target design shall allow to distinguish the relative importance to overall safety of each target-initiated DBA. Building on the prior deterministic analysis, PSA will lead to categorisation of the DBA that are specific to the target as an Initiator. The outcome shall be a PSA fault tree based on a first estimate of failure probabilities derived from Task 5.2

From the summary of all the analysis relevant to licensing, the task shall derive an overview of testing needs, focusing on those tests that are most likely to provide resolution of the uncertainties brought about by the integration of a spallation target in the overall safety case.

Task 5.5. Validation Experiment M32

Lead: CVR

Prior task 5.4 shall define the testing needs that would reinforce significantly the safety case for an ADSMR and which at this stage cannot be defined precisely. Hence it is deemed enough at this stage to list *possible* detailed investigations of a few components which are already known to contribute significantly to Initiating Events originating in the spallation target such as:

- High-heat flux testing under cycling using the HELCZA facility of some representative window options in different nominal beam and/or off-axis accidental cases. Cooling can be achieved either by water or liquid metal, subject to availability within the cost structure allowed by the project. For this subtask, an envelope for the additional hardware of 70k€ is proposed. The expected output is a validation of the lifetime predictions for the beam window
- Leak-test in a representative heat exchanger module between primary and secondary fluid. For this subtask, an envelope for the additional hardware of 30k€ is proposed. The expected output is the source term in terms of primary release into the secondary side for deterministic analysis of a DBA involving a rupture in the heat exchanger (equivalent to an IE known as a Steam Generator Tube Rupture in conventional Nuclear Power Plant)
- Loss of cooling pump in a spallation target is strongly influenced by the buoyancy of liquid metal used as coolant. An experiment can be proposed by reconfiguring existing hardware to replicate the thermal hydraulics in the target system under such an accidental scenario. The needed hardware costs of 50 k€ covers a representative segment of the hydraulic path inside the target, which would be connected to existing Liquid Metal testing infrastructure.

As shown in the three examples above, the cost of the chosen experiment can vary quite widely. In fine, the exact hardware costs will be determined by the needs identified in Task 5.4. At this stage, we propose to reserve hardware costs equivalent to the average of the sums derived above, roughly 50 k€.

Deliverables: D1:

Work Package number	WP6		Lead Beneficiary			
Work Package Title	Fuel Cycle Evaluation					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	**CVR**	NINE	ENEA	**UNIGE**
Person-months per participant	**14**	22				9
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	**HNE**	**INFN**	KTH	**UNSTUTT**	**iThEC**
Person-months per participant			2		2	1
Start month	M1			**End month**	M36	

Objectives: The goal of the WP is to provide the characteristics of the ADSMR fuel cycle and implications relevant to the safety and licencing of an ADSMR. The WP will evaluate the performance of specific fuel cycle scenarios associated to the particular use of the ADSMR (waste transmutation and electricity production with U/Pu and Th fuels) resulting on different fuel and waste compositions, recycling operations and cooling times. Then the implications on safety parameters of the reactor at different conditions, waste inventory, decay heat of spent fuel and reprocessing streams at different locations and stages will be evaluated using detailed simulation tools. Finally the results will also be provided to other WPs to contribute to the safety file (identifying initiators and realistic values for reactor parameters), to a realistic deployment strategy for both clusters of ADSMR or individual instances depending on the use, and to assess the compatibility of the licencing strategy with this deployment strategy.

Description of Work: WP led by CIEMAT, will provide the detailed characterization of the fuel cycle scenario including ADSMR so that the implications and possible requirements in terms of fuel cycle safety and licencing derived from the ADSMR implementation in Europe can be obtained.

The work will consist on the definition of realistic fuel cycle scenarios at the European level using the ADSMR concept developed in the previous WPs, considering different scenarios for the fuel cycle for the most relevant TRUs (multiple recycling or disposal at specific stage of the fuel cycle) and different operational parameters of importance such as variations on the fuel composition, the external contributions to the fuel (for transmutation applications) and the higher flexibility in the management of fuel or wastes. A set of indicators will be defined to evaluate these scenarios. Then, the irradiated fuel and the generation of nuclear waste in the different fleets will be assessed, considering also the spallation system of the ADSMR that can provide special long-lived intermediate level waste.

Later, the fuel cycle scenarios will be assessed using computer simulations, optimizing the scenarios in terms of several metrics such as costs, availability of resources or waste generation, evaluating the dimension of the different facilities involved in the fuel cycle.

The evaluation of each of the selected optimized scenarios will include the detailed calculation of the relevant parameters that can affect the safety of the reactor or of the fuel cycle facilities, the deployment strategy and the licencing strategy.

The propagation of uncertainties in the input parameters to the output indicators will be taken into account to avoid underestimation or overestimation of the capacity of facilities, the inaccuracy to calculate the amount of wastes to manage, economic risks and broken scenarios, i.e., there is a lack of material to be reprocessed or fabricated when needed.

Once the fuel cycle scenario is fully characterized, an economic assessment will be done using the most adequate set of input unit costs, comparing the results with reference cycles.

Finally, the benefits and challenges from ADSMR in the fuel cycle scenario will be converted into requirements or implications to be taken into account in the fuel cycle safety, deployment and in the licencing process.

Task 6.1. Fuel cycle scenarios including ADSMR (M4-M8)

Lead: CIEMAT, Partners: CERN?, ENEA, UNIGE, INFN

The aim of this task is the definition of realistic fuel cycle scenarios including ADSMR for the subsequent study of the implications relevant to the safety and licencing of these ADSMR. Several fuel cycle scenarios will be defined in this task and 3 to 4 of them will be then studied in detail. The global characteristics of the scenarios initially considered are:

- A reference open cycle scenario, with Gen II and Gen III LWR.
- A closed fuel cycle for all the minor actinides, where electricity production is made by a fleet of Gen II and Gen III LWRs and the transmutation is made by ADSMR.
- A closed fuel cycle for all the TRUs, where electricity production is made by a fleet with a mix of thermal and fast critical reactors reusing Pu and dedicated transmutation is made by ADSMR.
- A closed fuel cycle for U, Pu and Am with ADSMR dedicated to transmutation of Am and part of Pu.
- A closed fuel cycle for electricity generation using the Th fuel cycle.

The design developed in the previous WPs will be used as ADSMR concept. The definition of the realistic fuel cycle scenario will take into account different operational parameters which can be of importance from a safety or licencing points of view, such as the European nuclear mix, the existence of a legacy TRU stock, the date and rate of ADSMR implementation in the nuclear park and the coexistence of ADSMR with the current and future fleet of LWR.

Finally, a set of indicators/criteria to assess the impact of the ADSMR technology and fuel cycle on the reactor operation (fuel cycle isotopy as a function of burnup, decay heat, radioactivity and doses) and in the waste management strategy (inventories, reprocessing capacity, decay heat, gallery length required in the final repository, etc.) will be defined to evaluate these scenarios in the following subtasks.

Task 6.2. Characterization of irradiated fuel and nuclear waste (M6-M18)

Lead: ENEA?, Partners: CIEMAT, UNIGE, INFN, others?

This task aims at obtaining by computer simulations the different streams of irradiated fuel for the selected reactors considered in the fuel cycle scenarios. Nuclear waste generated in the ADSMR spallation system will be also considered.

Several tools available from different partners will be applied to some of the selected scenario simulations to improve by comparison the reliability of the estimations and to complement the limitation of each of the simulating code systems. Most of the simulation codes included EVOLCODE (CIEMAT), … (ENEA?), … (REZ?), MCNP/MONTEBURNS (UNIGE) had been previously validated in international benchmarks performed in the framework of OECD/NEA, IAEA and previous EURATOM projects.

Task 6.3. Fuel cycle scenarios evaluation considering uncertainties and proper dimensioning of fuel cycle facilities (M8-M24)

Lead: CIEMAT?, Partners: CERN?, others?

The fuel cycle scenarios defined in Task6.1 will be assessed by means of computer simulation, using the results obtained in Task6.2 for the particular reactors. The optimization of these scenarios will be done in terms of parameters relevant to safety and licencing, such as costs, waste generation or others.

The uncertainties in the input parameters can lead to uncertainties in the output indicators which ultimately will be translated into the underestimation or overestimation of the capacity of facilities, the inaccuracy to calculate the amount of wastes to manage, economic risks, and broken scenarios in the case of optimized situations. The evaluation of the uncertainty propagation will be done by means of computer simulation. Sensitivity/Uncertainty methods will be employed. Uncertainties in the input parameters will be chosen from bibliography and expert judgement. The methods, tools and databases to be used will be the most recent and best available from the OECD/NEA and IAEA, which have been already used for advanced fuel cycle assessment in the mentioned international framework and in the EURATOM projects CHANDA and ESNII+.

The resulting uncertainties in the input parameters will be translated into uncertainties on the most critical safety and performance parameters of the fuel cycle. Then the implication of these uncertainties on the safety and licencing of ADSMR and associated fuel cycle elements will be assessed.

Task 6.4. Economic assessment (M12-M22)

Lead: ?, Partners: CIEMAT, others?

Once the fuel cycle scenario is fully defined including the characterization of the nuclear material streams and the properties of the different facilities, the safety, licencing and waste management related parameters will be complemented with an economic assessment of selected fuel cycles. The assessment will take into consideration the potential advantages of clustering ADSMR, economy of scale, and progressive licencing on multiunit installations. A comparison with the open cycle scenario (Gen II-III scenario) will also be done. Due to the scarcity of detailed and reliable economic information publicly available, available databases will be searched from the bibliography, including at least the one provided by the OECD/NEA.

Task 6.5. Implications of ADSMR scenarios in fuel cycle safety and licencing (M10-M26)

Lead: CIEMAT, Partners: NINE?, UNIGE, others?

All the implications of the previous tasks on the safety or licencing of the ADSMR and the associated on-site facilities derived from the operation of the ADSMR and its fuel cycle will be collected by this task, assessed, classified and passed to the WP7 (Safety), WP8 (licencing) or WP10 (Deployment).

Some examples of expected parameters are:

- The isotopic composition of the recycled fuel, its decay heat, radioactivity, etc., as a function of number of recycling steps, fuel scenarios and irradiation burnup;

- Characteristics and limitations of potential initiators of DBA, BDB and SA accidents from the ADSMR reactor;

- Characteristics and limitations of potential initiators of DBA, BDB and SA accidents from the on-site facilities required by the fuel cycle;

- On-site inventories in terms of mass, radioactivity and decay heat of actinides and HLW and its distribution;

- Cost implications of selecting options to minimize some of the previous parameters.

licencing

Deliverables:

D6.1 (**CIEMAT**): Report on definition of fuel cycle scenarios with ADSMR.

D6.2 (): Report on Characterization of irradiated fuel and nuclear waste.

D6.3 (): Report on Implications of fuel cycle scenarios evaluation and uncertainties.

D6.4 (): Report on Economic assessment.

D6.5 (**CIEMAT**): Report on Implications of ADSMR scenarios in fuel cycle safety and licencing

Work Package number	**WP7**	**Lead Beneficiary**			NINE	
Work Package Title	Safety Analysis					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	CIEMAT	CVR	**NINE**	ENEA	UNIGE
Person-months per participant	**4**	3		20		
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	HNE	**INFN**	**KTH**	**USTUTT**	**iThEC**
Person-months per participant	2		1	3	18	1
Start month	M1			**End month**	M36	

Objectives: The ADSMR is a subcritical system whose chain reaction is sustained by the accelerator that can be promptly shut down enhancing the safety aspects of the plant. Moreover passive systems are included in the plant design. Despite such special safety features make the reactor (in principle) less prone to relevant accidents, a safety analysis (covering the whole plant operating spectrum conditions) is requested to demonstrate the compliance of the ADSMR plant with the licensing requirements. Till now a consolidated list of accidents aimed at demonstrating the ADSMR safety in the different operational conditions is not available. The selection of the Postulated Initiating Events (PIEs) should consider their relevance and consequences in order to define a classification similarly to that adopted in LWR technology where the postulated accidents are subdivided in Design Basis Conditions (DBC, further internally ranked), Design Extension Conditions (DEC, further internally ranked) and Severe Accidents (SA). The final output of the WP7 is a demonstrative SAR Chapter 15 (accident analysis chapter) addressing the most challenging PIEs (between 3 to 5 cases) aimed at checking the applicability of the licensing framework developed within the WP8.

Description of Work: the WP 7 will be led by NINE and will provide an example of safety analysis for the ADSMR from a licensing point of view. The content of SAR Chapter 15, based on the list of Postulated Initiating Events, will be proposed. Finally selected sections of the Chapter 15 will be written to provide example and guidance for a potential licensing application and to demonstrate the applicability of the licensing framework developed in the dedicated WP8.

Task 7.1. Development of the ADSMR SAR Chapter 15 Content

- **Task 7.1.a:** Compilation of Postulated Initiating Event list and proposal for their classification. The PIEs list will be prepared identifying similarities and differences in respect to PIEs and related classification applicable for LWR. It is intended to categorize the identified PIEs following the same approach adopted in LWR technology.
- **Task 7.1.b:** Development of SAR Chapter 15 list of content and addressing some key licensing aspects. A structure of the Chapter 15 will be proposed as well as some guidance and suggestions related to the content of the different subsections in view of a licensing application. Such general aspects will be consistent with the potentially adopted licensing approach and shall be elaborated to address the licensing requirements introduced in WP8.

Task 7.2. Preparation of SAR Chapter 15

- **Task 7.2.a:** Development of ADSMR Simulation Models. To provide evidences of the ADSMR safety features and responses against the selected PIEs, suitable licensing Simulation Models have to be developed and applied.
- **Task 7.2.b:** The SM developed for licensing purpose will be applied to predict the ADSMR responses against the selected PIEs. Being the focus of the WP7 on a licensing demonstration, a subset of PIEs identified within Task 7.1 will be considered possibly covering all the identified families. The selection will include the more challenging scenarios, it is anticipated to investigate between 3 to 5 safety cases.
- **Task 7.2.c:** Preparation of Chapter 15 subsections. A practical example of Chapter 15 subsections will be prepared to provide with guidance to interested licensees and to demonstrate the applicability of the licensing framework developed within WP8.

Deliverables: D7.1: M18 – M24; Development of the ADSMR SAR Chapter 15 Content (NINE, …..) Identification of PIEs to be considered in developing the ADSMR safety analysis and SAR Chapter 15 list of content.

D7.2: M24 – M36; Preparation of SAR Chapter 15 (NINE,….) Simulation model development and application for performing licensing oriented numerical simulation. Preparation of selected subsections of demonstrative SAR Chapter 15.

Work Package number	WP8	Lead Beneficiary			NINE	
Work Package Title	Licensing process					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	CVR	**NINE**	ENEA	UNIGE
Person-months per participant	**3**	3		30		
Participant number	7	8	9	10	11	12
Short name of participant	**PSI**	**HNE**	INFN	**KTH**	USTUTT	**iThEC**
Person-months per participant	1	2		2		1
Start month	M1			**End month**	M36	

Objectives: The licensing process is a thorough demonstration of plant safety according to national laws, which are typically taking principles from international standards. As a general approach the Regulatory Body provides guidance and criteria to be considered by the licensee. Taking into account the highly innovative type of plant and the consequent limited specific regulatory experience, the possible changes of the already existing licensing framework have to be identified. Within the WP8 the safety principles will be defined, and consequently the safety requirements for the ADSMR will be established with the final goal to respond to the fundamental safety objectives.

Description of Work: the present Work Package addresses the main licensing aspects regarding the ADSMR. The two main elements of the ADRSMR, namely the small modular reactor and the accelerator are initially separately considered, while in a second stage the licensing interfaces between the two main constituents are examined. Finally a gap analysis is performed to identify the needed improvements or additions to be implemented in an established general licensing framework to include the ADSMR licensing application. The proposed licensing framework will be tested through the technical activities performed within the WP7.

Task 8.1 Review of SMR Current Licensing Applications.

- **Sub-Task 8.1.a**: this subtask aims at providing a comprehensive description of the current status of SMR licensing, in order to evidence communalities and synergies. It will analyse data provided in D10.3. The already available processes will be the main reference for this task which in turns will provide inputs to the development of the ADSMR licensing framework.
- **Sub-Task 8.1.b**: critical aspects of the SMR connected with the licensing covering advantages and drawbacks connected with this kind of plant.

Task 8.2 Licensing Interactions between the Reactor and the Accelerator.

Sub-Task 8.2.a: the accelerator is an essential part of the ADSMR thus has to be included in the licensing process. The licensing of an accelerator is regulated by a well-established process that could be (partly) reflected in the overall **ADSMR** licensing framework. The aim of the Sub-task 8.2a is to identify which parts of the established accelerator licensing process should be included in the ADSMR licensing framework.

- **Sub-Task 8.2.b:** the interactions between the reactor and the accelerator need a specific investigation, notably to define precise requirements which are unique for this kind of plant. The purpose is to define the requirements that should be part of the ADSMR licensing framework with respect to the accelerator and reactor interaction.

Task 8.3 ADSMR Licensing Framework Main Aspects. • **Sub-Task 8.3.a:** considering the tasks 7.1 and 7.2 outcomes from the ADSMR licensing perspective a gap analysis, to identify the aspects related to the ADSMR not covered by the currently existing licensing framework, is performed. Sub-Task 8.3a provides the last element to build up a new licensing framework. • **Sub-Task 8.3.b:** identification of the licensing principles and requirements that should complement/update the actual framework to properly include the ADSMR. The final goal is to propose a licensing framework in which the ADSMR licensing application can fit in.
Deliverables: D8.1: M1 – M6; from data originated in D10.3, Identification of communal aspects in licensing of SMR (NINE) D8.2: M6 – M12; Licensing Interactions between the Reactor and the Accelerator (NINE,…) To identify the requirements regarding the interaction between the accelerator and the reactor. D8.3: M6 – M18; ADSMR Licensing Framework Main Aspects (NINE, ….) To propose a licensing framework in which ADSMR application can be submitted.

Work Package number	WP9		Lead Beneficiary		KTH	
Work Package Title	Training, Dissemination and outreach					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	CVR	**NINE**	ENEA	**UNIGE**
Person-months per participant	**3**	4		3		3
Participant number	7	8	9	10	11	12
Short name of participant	PSI	**HNE**	INFN	**KTH**	**USTUTT**	**iThEC**
Person-months per participant		1		12	5	1
Start month	M1				**End month**	M36

Objectives: WP9 involves the dissemination, training, and outreach activities within the ADSMR project.

The main goals of WP9 are to:

- Disseminate and exploit the projects results, outcomes, and events through (i) publications in Open Access journals, (ii) presentations and proceedings in conferences and workshops, and (iii) newsfeeds in social media
- Organize an international technical workshop on ADSMR
- Organize an open lecture series with e-learning on SMRs
- Coordinate the training and education of young researchers

Manage innovation and output generated from the project

Description of work

T9.1: Communication and dissemination plan and activities (M1-M36), CERN, KTH, all

The aim of this task is to disseminate the developments, results, achievements, news, and upcoming events of the project to all target audiences (i.e., specialists, non-specialists and the general public).

This task includes but is not limited to the following:

- Set-up of project public website
- Set-up of social media account

Internal communication within the consortium will be covered in WP1.

T9.2: Exploitation of results (M12-M36), **NINE?**, UNIGE, all

This task further exploits the results generated from the project through:

- Presentations in conferences and workshops, and
- Publications in Open Access journals

At least 2 joint publications will be targeted during the course of the project.

T9.3: Coordination of Training and Education of PhD students and Postdocs (M1-M36), **KTH**, UNIGE, all

A mobility programme will be set-up to facilitate the exchange of young researchers between the partners. Short-term (up to 2 months) and medium-term (2-6 months) visits will be organized. Visits to institutes outside of the Consortium will also be explored. The programme will provide training opportunity for young researchers as well as a way to widen their professional networks. Funding is covered by the sending partner. The host institute will provide office space and help in finding accommodation for the visiting researcher.

T9.4: International Technical Workshop (M24), **CIEMAT**, USTUTT all

An international workshop (2-3 days) on ADSMR will be organized and distinguished experts in the field will be invited to present their latest work. An emphasis is given on panel discussions. A poster session will be organized for PhD students and Postdocs. A working group will be set-up to develop a short research roadmap on ADSMR. Also international workshops (2-4 days) on Reliability and Safety basics will be offered by USTUTT

T9.5: Open lecture series and E-learning on SMRs (M30), **KTH**, all

A lecture series on SMRs will be developed and the sub-topics will be validated by the General Assembly. Distinguished experts will be invited to give short lectures which will be recorded. Each lecture will be of maximum 15 minutes with interactive approach. These lectures will be made available to the public through the project public website.

T9.6: Management of output data, common publications, and intellectual property (M1-M36), CERN, all

A management team will be set-up to manage the IP and output data generated from the project, in accordance with the ADSMR Consortium Agreement.

Deliverables:

D9.1: Communication and dissemination plan (M3) CERN, all

Defines all communication and dissemination activities of the project

D9.2: Project public website (M6), CERN

The public website provides information about the project, news and events, list of publications, and open materials

D9.3: International Workshop Proceedings (M28), [CIEMAT]

Proceedings of the International Technical Workshop on ADSMR

D9.4: E-learning material on SMRs (M32), [KTH]

A series of pre-recorded lectures on SMRs available for public consumption

D9.5: Data Management Plan (M6), [CERN, all]

Defines the archiving of data, rules of access, and IP management

Work Package number	WP10				Lead Beneficiary	UNIGE
Work Package Title	Present SMR classification					
Participant number	1	2	3	4	5	6
Short name of participant	**CERN**	**CIEMAT**	CVR	**NINE**	**ENEA**	**UNIGE**
Person-months per participant	**1**	4		2		20
Participant number	7	8	9	10	11	12
Short name of participant	PSI	**HNE**	INFN	KTH	**UNSTATT**	**iThEC**
Person-months per participant		1			3	1
Start month	M1				**End month**	M36

Objectives: Starting from the present SMRs scenario, this WP will classify the present SMRs designs according to their technical, reliability and licensing features. A special emphasis will be also put on the reliability, licensing, safety and fuel cycles features of an ADS SMR. Finally, WP10, also on the basis of the findings of the other WPs, will outline a grounded proposal for an ADS SMR that could be really licensed by the International Regulators Bodies.

Description of Work: WP10, led by UNIGE, will provide an overview of the current scenario of SMRs, and a classification of present designs, taking into account licensing processes and safety features, too. A system reliability comparative analysis will also be part of the scope of this WP. Finally innovative fuel cycles suitable for an ADS SMR will be exploited.

Task 10.1. Current scenario of SMRs (M1-M12) [UNIGE]**:** Overview of the current scenario and classification of present SMRs designs

Task 10.2. System reliability comparative analysis of present and proposed SMR (M9-M18) [USTUTT]**:** Study and preliminary comparative reliability analysis of present and proposed SMRs

Task 10.3. Licensing processes and safety features of present and proposed SMR (M9-M18) [NINE]**:** Classification into main categories of SMRS licensing processes. Proposal of a licensing model/route for ADS-SMR showing specific advantages from the safety and licensing point of views

Task 10.4. Implementation of innovative (mainly Th-based) fuel cycles in SMR (M12-M24) [CERN, iThEC?, UNIGE]: Analyses of potential innovative fuel cycles for SMR, with a special emphasis on Th-based fuel cycles

Task 10.5. Modular ADS design: ADS qualification as SMR (M15-M30) [UNIGE, CERN, all]**:** Identification the motivation for developing the specific ADS SMR design, detailing the benefit of compactness and modularity, in terms of reliability and safety. Starting also from the findings of the previous WPs a layout for the ADS SMR and its clusters that allows to validate and evaluate the licensing model and the advantages of the ADS SMR from the safety and licensing perspectives will be sketched.

Deliverables:

D10.1: Report on the current SMRs scenario (M6§), [UNIGE]

D10.2: Comparative analysis of the system reliability for present and proposed SMRs (M12), [USTUTT]

D10.3: Analyses of licensing processes and safety features of present and proposed SMRs (M12) [NINE]

D10.4: Innovative fuel cycles for SMR (M20) [CERN]

D10.5: Preliminary report on a modular ADS qualifies as SMR (M30) [UNIGE]

		Year 1												Year 2												Year 3											
Task	Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	Project management and coordination																																				
1.1	Management																																				D1.3
1.2	Internal communication and dissemination, scientific publications and monographs												D1.1												D1.2												
2	oncept of Accelerator System for ADSMR																																				
2.1	Accelerator main parameters definition (INFN-PSI-CERN)						D2.1																														
2.2	Accelerator components study and design (INFN-UNSTUTT)												D2.4						D2.3						D2.2												
2.3	Beam dynamics and control (PSI)																																	D2.5			
2.4	Safety improvement and system integration (INFN-NINE-CERN-USTUTT)																		D2.6																		
3	General System Layout																																				
3.1	Primary system configuration												M3.1																		D3.1						
3.2	Shielding and activation																								D3.2												
3.3	Decay heat removal systems												M3.2												D3.3												
3.4	Functional interface with core, target and auxiliary reactivity control systems												M3.3																		D3.4						
3.5	Reactor building general layout																																			D3.5	
4	ore performance and Safety Assessment																																				
4.1	Core design																																				
4.2	Neutronics and thermo-hydraulic analysis																																				
4.3	Spallation target design																																				
4.4	Nuclear Data analysis																																				
5	Spallation Target																																				
5.1	Target reliability												D5.1																								
5.2	Target architecture																				D5.2																
5.3	Target integration																				D5.3																
5.4	Deterministic and probabiliti safety analysis																										D5.4										
5.5	Validation experiment																																D5.5				
6	Fuel Cycle Evaluation																																				
6.1	Fuel cycle scenarios including ADSMR												D6.1																								
6.2	Characterization of irradiated fuel and nuclear waste																		D6.2																		
6.3	Fuel cycle scenarios evaluation considering uncertainties and proper dimensioning of fuel cycle facilities																								D6.3												
6.4	Economic assessment																								D6.4												
6.5	Implications of ADSMR scenarios in fuel cycle safety and licencing																														D6.5						
7	Safety Analysis																																				
7.1	Development of the ADSMR SAR Chapter 15 Content																								D7.1												
7.2	Preparation of SAR Chapter 15																																			D7.2	
8	Licensing process																																				
8.1	Review of SMR Current Licensing Applications						D8.1																														
8.2	Licensing Interactions between the Reactor and the Accelerator												D8.2																								
8.3	ADSMR Licensing Framework Main Aspects																		D8.3																		
9	Training, Dissemination and outreach																																				
9.1	Communication and dissemination plan and activities			D9.1																																	
9.2	Exploitation of results						D9.2																														
9.3	Coordination of Training and Education of PhD students and Postdocs						M9.1																														
9.4	International Technical Workshop																												D9.3								
9.5	Open lecture series and E-learning on SMRs																																D9.4				
9.6	Management of output data, common publications, and intellectual property						D9.5																														
10	Present SMR classification																																				
10.1	Current scenario of SMRs						D10.1																														
10.2	System reliability comparative analysis of present and proposed SMR							M10.1					D10.2																								
10.3	Licensing processes and safety features of present and proposed SMR							M10.2					D10.3																								
10.4	Implementation of innovative (mainly Th-based) fuel cycles in SMR														M10.3						D10.4																
10.5	Modular ADS design: ADS qualification as SMR																														D10.5						

Figure 3.2 Timing of the Work Packages and their components for WP1 to WP10

(Gantt chart, M=Milestone, D=Deliverable)

Deliverable number	Deliverable name	Task number	Lead Participant	Type[29]	Dissemination	Delivery Date
D1.1	Data Management Plan	T9.1	CERN	R	PU	M3
D1.2	Dissemination and Communication Plan	T9.2	CERN	R	PU	M6
D1.3	Final project report & ADSMR LP report	T1.1	CERN	R	PU	M36
D2.1	Accelerator system parameters and performances	T2.1	INFN	R	PU	M6
D2.2	Magnet conceptual design (modeling and simulation)	T2.2	INFN	R	PU	M24
D2.3	RF cavity conceptual design (modelling and simulation)	T2.2	INFN	R	PU	M18
D2.4	Injection and Extraction System	T2.2	INFN	R	PU	M12
D2.5	Beam dynamics evaluation	T2.3	PSI	R	PU	M24
D2.6	Safety enhancement: beam monitoring and control system; machine protection system definition	T2.4	INFN	R	PU	M18
D3.1						

Table 3.2 List of Deliverables

[29] R: Document, report. DEM: Demonstrator, pilot, prototype, plan designs. DEC: Websites, patents filing, press and media actions, etc. OTHER: Software, technical diagram

3.2 Management Structure, Milestones and Procedures

Describe the organisational structure and the decision-making (including a list of milestones (table 3.2a))

Figure 3.5 shows a schematic layout of the ADSMR management structure. Its main components are the Governing Board, the Steering Committee, and the Management Team. CERN as Coordinating Institution has substantial experience in leading large-scale collaborations involving many institutes from all over the world, and has coordinated more than 40 EU projects under FP7 and H2020. In particular, the Organization has the experience of coordinating successfully Integrating Activity projects, such as EGEE, AIDA-2020, ARIES, innovative procurement schemes for development R&D like QUACO, and has dedicated units and services to support such projects: EU Projects Office, EU Finance Service, legal advisors for EU affairs and intellectual property rights, as well as a Knowledge Transfer Group.

The management structure and procedures of ADSMR are based on the experience and best practice from the management of EU projects of similar size and complexity.

Figure 3.5 schematic layout of the ADSMR management structure.

Governing Board (GB)

The Governing Board is the top decision-making and arbitration body. It has one representative from each beneficiary and includes the Scientific Coordinator and the Deputy Coordinator (ex-officio without voting rights). Each beneficiary has one vote and the decisions will be taken by a qualified majority of the votes. The types of decisions and the corresponding voting procedure and rules will be described in the Consortium Agreement.

The GB has the authority to decide, upon Steering Committee proposals, on strategic issues, such as modifications of the programme of work (if necessary) and admission of new beneficiaries to the project. The GB will review the progress of the project at the annual project meetings, and, where necessary, will decide on changes in the work plan and budget allocation among the participants. In addition to the Annual Meetings, the GB Chairperson may call for intermediary tele/video-conference meetings. The Chairperson of the GB is elected by its members.

Steering Committee (StCom)

The StCom is composed of the Scientific Coordinator, the Deputy Coordinator, the Administrative Manager (all three from WP1 Management), and the Work Package Coordinators of all WPs. The StCom oversees and reviews the work progress, milestones and deliverables, consolidates the reports received from the Work Package Coordinators and discusses technical and scientific matters. The StCom will have regular meetings at least four times a year. The StCom brings strategic issues forward to the GB for consideration, e.g. possible modifications of the work programme or re-distribution of the EC funding among beneficiaries or work packages. The StCom is chaired by the Scientific Coordinator and each Work Package (including WP1) has a single vote.

Scientific Coordinator (SC)

The Scientific Coordinator is responsible for the technical management and overall coordination of activities of the ADSMR project, and monitors the deadlines, achievement of and quality of the deliverables and milestones, as well as the organisation of project reviews when needed. In his tasks, he is supported by a Deputy Coordinator. The SC is in charge of the communication with the European Commission on all scientific and technical aspects of the project. The tasks of the SC include the regular follow-up of the progress in all WPs, in collaboration with the Deputy Coordinator. The SC chairs and organises the Steering Committee meetings, and will be in charge of the preparation of the technical and management sections of the Periodic Reports and the Final Report. The SC leads the ADSMR WP1.

The designated Scientific Coordinator (SC) of ADSMR is Dr. Marcello Losasso (CERN), who has been performing this function in other H2020 projects. The SC maintains the communication with EURATOM on all administrative and contractual aspects of the project.

Administrative Manager (AM)

The AM is responsible for the administrative, financial and contractual follow-up of the project. The AM is in charge of financial issues, such as payments and distribution of EU funding received, collection of certificates on financial statements, of periodic reports and justification of costs, as well as of legal issues, such as the implementation of the Consortium Agreement and Intellectual Property Rights agreed by the beneficiaries. In addition, the AM monitors the proper application of gender equality practices in conformity with the European Charter and Code for Researchers.

Management Team

The Scientific Coordinator, the Deputy Coordinator and the Administrative Manager form a collegial Management Team in charge of the follow-up and management of the project. To this end, they are supported by the Project Support Office at CERN, which includes other staff (on a part-time basis), namely one Administrative and one Project Assistant, one Finance Officer, and one Communication Officer. The Project Management Team will receive additional professional support, whenever necessary, from various CERN services, such as the Legal Service, Knowledge and Technology Transfer, EU Finance and Accounting. The Project Management Team meets on a regular basis to follow-up closely the implementation of the project.

Work Package Coordinators

The WP Coordinators lead and coordinate the research activities in the framework of their own WP. They have the responsibility for ensuring the effective cooperation between the participants in each WP, for monitoring the progress of the tasks, and for reviewing the Milestone and Deliverable reports that are prepared by the Task Leaders within the respective WPs. The WP Coordinators prepare internal or other reports concerning their WP, as requested by the Management Team. They will make the results of the work available to the ADSMR collaboration and are in charge of providing the relevant dissemination materials to WP1 “Internal communication, dissemination, scientific publications and monographs”. They coordinate the review of all publications that will result from the work in their WP.

Decision-making mechanisms

Before the start of the project the participants will formally conclude a Consortium Agreement that sets forth the terms and conditions pursuant to which they agree to function and cooperate in the performance of their respective tasks in the project. The Consortium Agreement will specify the responsibilities of the Coordinating Institution and the terms of reference of the Governing Board and the Steering Committee, including the relevant decision making mechanisms and voting procedures.

Decisions concerning the implementation of the work programme within the WPs will be taken by the relevant Work Package Coordinators and Task Leaders. Issues concerning the overall work programme and interrelations between WPs will be discussed and decided upon by the Steering Committee. In the rare cases where significant modifications of the work programme and/or re-distribution of EURATOM funding are deemed necessary by the Steering Committee, such matters will be brought forward to the Governing Board for decision.

The project implementation will be aimed at taking decisions by consensus on most issues. Where this is not possible, decisions will be taken after voting by the Steering Committee or the Governing Board, depending on the character of the issue at stake.

ADSMR will use IT tools, e.g. a collaborative workspace, to guarantee the timely distribution and availability of all project related information and documentation to the participants, so that decisions can be taken with all necessary information available in advance.

The project milestones and critical risks relating to project implementation are provided in the tables below.

Milestone number	Milestone name	Related WP	Lead Participant	Due Date	Mean of Verification
M1.1	Kick-off-meeting	1	CERN	M1	Agenda, attendance list on indico
M1.2	Consortium agreement signed	1	CERN	M2	Final version released
M1.3	Forming all official bodies required by the governance	1	CERN	M4	Governing Board Approval
M1.4	1st Annual Meeting	1	CERN	M13	Agenda, attendance list on indico,
M1.5	2nd annual meeting	1	CERN	25	Agenda, attendance list on indico
M1.6	Final meeting	1	CERN	36	Agenda, attendance list on indico
M2.1					

Table 3.3 List of Milestones

Work Package(s) involved	Description of risk	Likelihood	impact	Proposed risk-mitigation measures
ALL	Change of management team or WP Coordinators during the project	Medium	Low	Anticipate potential staff changes in the project management and WP coordinators and select suitable replacements within the consortium as soon as possible.
ALL	Withdrawal of beneficiary (ies)	Low	Low	Other beneficiaries take over the responsibilities of the withdrawing partner or new beneficiaries are included in the project from the pool of collaborating institutes.
ALL	Reduced or undelivered contribution by one or more of the beneficiaries to the work programme of the project	Low	Low	Redistribution of work and budget to other members of the consortium, with possible rescheduling of milestones and deliverables if needed.
WP2	The superconductive cyclotron design is not reliable enough	Low	Medium	Adopt an alternative, resistive, design
WP3	The geometry of the target is not compatible with the proposed refuelling system proposed for the LFR-AS-200	Medium	medium	Adoption of an alternative support system of the fuel assemblies.
WP				
WP9	No lecturers will agree to have their lectures made freely available to the public.	Medium	Low	Limit the number of lectures and agree to a reasonable remuneration.

Table 3.4 Critical risks for implementation

3.3 Consortium as a whole

The consortium is composed of 11 partners from 7 European countries in a well-balanced mix of research laboratories, specialized manufacturing industry, and nuclear businesses, each leader in its key technological sector. The large research centers involved (CERN, PSI, INFN, ENEA, CIEMAT) have a wide range of competences covering several fields. All the partners have specific expertise related to the call as detailed in section 4.

Consortium coordination

Based on its 60 years' experience in the field of particle beams, CERN is ensuring the coordination of the consortium. This European research centre has substantial experience **in leading large multinational projects and in delivering results in time and within budget;** CERN holds the supporting administrative structure and experience required to manage large European projects. CERN has run the TARC and FEAT experiments, and has proposed the Accelerator Driven System concept already in the late '90s. .

Key areas of expertise, collaborative experience and complementarity in the Consortium

The ADSMR work packages involve typically from 4 to 11 partners; tasks or even subtasks involve several of them. The deliverables rely largely on collaborative efforts and depend on the success of the collaborations. Many of the partners in the Consortium have already worked together in successful collaborative projects, and in this way, valuable experience has been gathered since at least 20 years. The international reputation and experience of each of the member of the consortium indicate that they will easily integrate in the common work programme.

The main fields of expertise of the ADSMR partners are documented here below. For example:

INFN will carry out the innovative design of the cyclotron, with contributions from CERN and PSI that will bring the valuable expertise in modelling and operating the cyclotron with the largest power in the world.

NINE, with expertise and competence covering the whole licensing process, will run the role of the regulator. HNE, ENEA, INFN, iThEC, UNIGE, KTH and CIEMAT with their long record of solid technical expertise in nuclear technology, core and system design and safety analysis, complement the Consortium.

CIEMAT, an Organism of the Ministry of Education and Science, is a Public Research Agency for excellence in energy and environment, as well as in many vanguard technologies and in various areas of fundamental research. Since its creation in 1951, then as JEN, and since 1986 as CIEMAT, it has been carrying out research and technological development projects, serving as a reference for technical representation of Spain in international forums, and advising government on matters within its scope. These activities are complemented with education, technology transfer and technical services. The Nuclear Fission Division at CIEMAT, includes Units devoted to Nuclear Safety Research, Nuclear Waste Management Research and Nuclear Innovation. This division has been very active on the R&D on advance fuel cycles, partitioning and transmutation and the use of ADS for nuclear wastes transmutation from 1993, contributing to many EURATOM projects from FP4 to H2020 including MUSE4, PDS-XADS, EUROTRANS, EUROPART, Red-Impact, PATEROS, CP-ESFR, FAIRFUELS, JHR-CA, MTR-I3, CDT, ANDES, ARCAS, ACSEPT, ADOPT, FREYA,MAXSIMA,MARISA, ESNII+,MYRTE, ESFR-SMART, EURAD-EJP and others and coordinating ANDES, CHANDA and SANDA. The group has also contributed to FEAT and TARC projects at CERN.

All the other partners have specific competences that are intended to complement those of the large laboratories and provide added value to the project. In particular, the key competences can be grouped in the following way:

- *Communication, outreach, training*: KTH has a well established reputation in education and training initiatives and e-learning tools, for example the Summer Course on the Back end of the Nuclear Fuel Cycle is a well-established tradition[30]. On this education activity, it will collaborate with CERN that contributes with long experience in scientific communication and outreach, and with the University of Stuttgart that is active in developing thematic workshops. KTH is also running a very sophisticated Pb-Bi loop Tall 3D, which is technical relevant with the scope of this proposal.

- *Accelerator physics, operation reliability*: the leading partners in this domain are PSI, INFN and CERN, with several decades of experience in complex accelerator projects and their own networks of collaborations and

[30] https://www.dropbox.com/s/rpp10889lccp90u/Summer_Course_SH262V-Report-2017.pdf?dl=0

exchanges. Specific competences are brought by University of Stuttgart that is active in developing analysis of system reliability and PSI for beam losses analysis and mitigation.

- *Superconducting magnet technologies*: for accelerator magnets, CERN, INFN and PSI are leading laboratories in Europe and they have records of long collaboration, even before the LHC. Their outstanding competences are complemented by UNIGE, which hosts specialized teams in the design of sophisticated accelerator magnets.

- *Thermo-fluid-dynamics*: UNIGE has a long standing and demonstrated expertise in the fields of experimental and numerical thermal-fluid-dynamics as well as of nuclear engineering and technology. More specifically, a specific experience and expertise has been gained in applying CFD and multiphysics codes (like OpenFoam, Ansys, FEMLAB, etc.) to innovative and advanced nuclear systems. CIEMAT will also be involved into thermal-hydraulic calculations. A new powerful HPC farm will be available at DIME-TEC, that can be used for intensive CFD and multiphysics simulations. KTH has extensive expertise in both computational and experimental approaches on thermo-fluid dynamics. KTH will also contribute on thermal-hydraulics analysis of the primary circuit UNIGE’s main contribution to the ADSMR proposal will be in the frame of CFD and thermal-hydraulic calculations; UNIGE will perform simulations on the core, the target and, more generally, on the whole system grounded on its long-term experience in the use of well-known CFD codes (both commercial and open source) like ANSYS-FLUENT, OpenFOAM, etc.

- *Neutronics & Nuclear waste management*: the neutronics and physics aspects of the fuel cycle evaluation will be performed at CIEMAT, that will also design the ADS monitoring and control system, with the assessment of the nuclear data induced uncertainties and will participate on the experimental validations of key aspects of the design. In this activity, it will be joined by UNIGE and iThEC, an international, non-profit association, whose membership includes physicists, engineers, technicians, politicians, and concerned citizens. Several of the scientists in iThEC are former CERN collaborators of Nobel Prize Laureate Carlo Rubbia, who worked on the Energy Amplifier project. Professor Rubbia is the honorary president of the iThEC association, whose principal mission is promoting energy research based on thorium. iThEC’s main goal is the destruction of long-lived nuclear waste and the development of innovative, safe, clean and abundant energy sources, based on the thorium fuel cycle. iThEC collaborates with several research institutes, in particular INR Troitsk in Russia, on a proposal of a first fast neutron ADS experiment of significant power (≥ 1 MW), making use of an existing infrastructure.

- *Reactor engineering*: HNE will take care of reactor engineering. HNE is a recently established company specifically devoted to the nuclear field and in particular to the development of Lead-Cooled Fast Reactors (“LFR”). It holds a large number of patents in the sector of reactor engineering, and its ……

3.4 Resources to be committed

Budget overview

The overall budget of ADSMR is 4 M€ of requested EURATOM contribution.

The budget calculation follows the Horizon 2020 financial rules, including personnel costs, travel, material and other direct costs, and 25% overheads. Table 3.7 presents the resources per Work Package for the full duration of the project, including the corresponding person-months (PM). The total WP budgets and the requested EURATOM contribution are shown as well.

WP	PM	Personnel cost	Travel	Material & other direct cost	Sub-contracting	Indirect Costs	Total cost	Requested EURATOM contribution
WP1	**18**							
WP2								
WP3								
WP4								
WP5								
WP6								
WP7								
WP8								
WP9								
WP10								

Table 3.7 ADSMR budget per Work Package

Due to the current status of Switzerland as Associated Country to the Horizon 2020 Excellence Science Pillar, the Swiss beneficiary, PSI, requests partial contribution to their costs from the EURATOM funding, and commits to provide the rest in terms of matching resources

Resources to be committed by the beneficiaries

Table 3.8 shows the estimated staff effort in person-months, and Table 3.9 shows the estimated full costs of all beneficiaries in ADSMR.

Participant number	Short name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	WP10
1	CERN	14	4	3	4	3	14	4	3	3	1
2	CIEMAT	2		6	18	3	18		2	3	
3	CVR										
4	KTH				8			3	2	12	

5	PSI										
6	ENEA			6	16	3					
7	iThEC	1	1	1	1	1	1	1	1	1	1
8	UNIGE			9	12	6	9			3	20
9	INFN	1	18	1	5	2	2	1			
10	NINE		3	3	4			20	30	3	2
11	HNE			18	2	1			2	1	1
12	UNSTUTT		2	2	2	2	2	18		5	3

Table 3.8 Summary of staff effort

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

Please complete the table below for each participant if the sum of the costs for’ travel’, ‘equipment’, and ‘goods and services’ exceeds 15% of the personnel costs for that participant (according to the budget table in section 3 of the proposal administrative forms).

Participant 1 Short name: CERN	Cost (€)	Justification
Travel & subsistence	44444	Support to users on site: travel & subsistence for 6xx users and xx user days
Equipment	0.00	No equipment costs will be claimed to the EC
Other goods and services	4444	Cost of Audit Certificate (4,000 €) Special technical support for users
Total	4444.50	

Participant 2 Short name: CIEMAT	Cost (€)	Justification
Travel & subsistence	44444	Support to users on site: travel & subsistence for xx users and xx user days
Equipment	0.00	No equipment costs will be claimed to the EC
Other goods and services	4444	Cost of Audit Certificate (4,000 €) Special technical support for users
Total	4444.50	

Table 3.4c: Activities dedicated to Education and Training

Please complete the table below to show that at least 5% of the total action budget is dedicated to Education and Training activities for PhD students, postdoctoral researchers and trainees supported through the action. Personnel costs related to the work performed on the action by PhD students, postdoctoral researchers and trainees is considered to be part of education and training activities.

	WP number and description of tasks/activities	**Number of persons**	**Person-months allocated**	**Cost (€)**
Personnel costs (PhD students, Postdoctoral researchers, Trainees)	WP2 (beam losses analysis within the cyclotron design, PSI) WP5 (design and analysis for spallation target design, CVR) WP4 (Neutronics and simulation and code development, CERN) WP10 (support to SMR classification and analysis, UNIGE)	1 PSI (PhD) 1 CVR (PhD) 1 CERN (post-doc, PA) 1 UNIGE (PhD)	144	590400
Other education and training costs related to support for PhDs, postdoctoral researchers and trainees	11000 (trainee) KTH, 10000 (trainee) UNSTUTT			
Total cost			**611400 (€)** **15,2 % of total action budget**	

Section 4: Members of the consortium

4.1. Participants (applicants)

Org	Expertise	Role & Contribution to the Project
CERN	The site of the largest accelerator in the world. Physics simulation, accelerator technology, EU projects management. Expertise in ADS.	Project management, implementation & integration of engineering design
CIEMAT	The Nuclear Fission Division at CIEMAT includes Units devoted to Research on Nuclear Safety, Waste Management and has been carrying out R&D on advance fuel cycles, partitioning and transmutation and the use of ADS for nuclear wastes transmutation since 1993.	Neutronics and thermal-hydraulics analysis of the core and the spallation target, covering some transients to support safety assessments; nuclear data quality and needs to support with sufficient quality the licensing assessments; conceptual design of the reactivity monitoring and system control; evaluations of the implications of the ADS design for the associated fuel cycle (taking into account considerations of inventories, storage, disposal and reprocessing).
CVR	Experience from Megapie, Eurisol. More than 10 years of designing and testing spallation targets.	Spallation target and window design. Infrastructure supports to experiments to confirm aspects of the spallation target or the core design, instrumentation and operation.
NINE	A private company with extensive background experience in the area of Nuclear Reactor Safety Analysis. The company record services includes Licensing, Safety Analysis, Computer Codes development and validation, NPP design and optimization, Test facilities Design and Consulting.	In charge of the Licencing Process definition. "Dummy regulator" role. Preparation of simplified version of SAR ch.15. Safety objectives and engineering design requirements. Licensing as gradual approach process and safety demonstration from licensing perspective
ENEA	Leading Italian organizations in the development of the lead technology for application to nuclear systems. Nuclear expertise and thermo analysis, neutron physics	Thermo analysis of core, target. Classification of present SMR designs, according to Licencing process and safety features
UNIGE	demonstrated expertise in the fields of experimental and numerical thermal-fluid-dynamics as well as of nuclear engineering and technology.	CFD and thermal-hydraulic calculations; simulations on the core, the target. Ad-hoc experimental validations in support to the numerical simulations. Support to fuel cycles analysis by burnup evaluations.
PSI	A world-leading laboratory in nuclear physics, operating the highest power cyclotron in the world; based in Switzerland. Cyclotron	Beam transport design, beam losses and uncertainty analysis

	operation, simulation, modeling, design and related technologies	
HNE	Based in Luxemburg and in London, with long record in nuclear engineering and research and many patents of specific interest for this project; nuclear expertise	Reactor, reactor coolant and connected system design. Conceptual design of the primary circuit of the reactor, interface with the accelerator, the decay heat removal and the schematic diagram of the BOP, principles of operation with the schema of the principle of the regulations.
INFN	Nuclear and particle physics research institution, with long- standing expertise in cyclotron design (INFN Catania has constructed and operated the K800 INFN Cyclotron; INFN Genova has been working on ADS-related topics for a few years).	Cyclotron design, including aspects related to beam losses, and vacuum., Simulations of neutronics, energy deposition in the target and fuel evolution.
KTH	KTH is internationally acknowledged in LWR safety and severe accident research and has been active as both coordinator and participant in several European Union Projects from FP4 to H2020.	Support to the engagement, education and training of young generation of nuclear scientists LBE thermal hydraulics and reactor safety.
Stuttgart University		System reliability Analysis. Support to training
iThEC	A non-profit organization based in Geneva, active in the promotion of Thorium application in nuclear energy; Physics simulation and neutronics, ADS	Spallation and transmutation modelling

1. ***CERN: European Organization for Nuclear Research***	
General Description	CERN, the European Organization for Nuclear Research, is one of the world's largest centers for scientific research on fundamental physics. The instruments used at CERN are purpose-built particle accelerators and detectors. Accelerators boost beams of particles to high energies before the beams are made to collide with each other or with stationary targets. Detectors observe and record the results of these collisions. CERN employs just under 2,400 full-time employees and 1.500 part-time employees, and hosts some 10.000 visiting scientists and engineers, representing 608 universities and research facilities and 113 nationalities. The 60-year history of CERN is marked with impressive achievements in the construction and operation of powerful linear and circular accelerators and detectors developing forward looking detection and imaging technologies in close collaboration with industry. The technologies developed cover and encompass interdisciplinary fields such as micro and nano-electronics systems, high performance computing and big data analysis, IT network technologies and systems, photonics, high performance materials, etc. The above technology achievements of CERN led to revolutionary discoveries in particle physics, such as weak neutral currents (1973), W and Z weak bosons (1983) and the Higgs boson (2012), as well as technological innovations such as the World Wide Web, the development of imaging technologies for medicine (first PET scanner (1982), and today hadron therapy.
Role	Project Coordination and Technical Integration
Available technical equipment and facilities relevant to the project	CERN operates the largest and most advanced complex of particle accelerators in the world. The 60-year history of CERN is marked with continuous successes in the construction and operation of various types of accelerators, including the first cyclotron ever in operation in Europe. CERN offers unique infrastructures for the development of innovative particle accelerators and detectors. Seven general purpose test beam lines provide beams of electrons, muons and hadrons in a wide energy range for use at HL- LHC, CLIC/ILC or neutrino experiments. The experimental areas are large and extremely well equipped. CERN also operates a major computing infrastructure, with innovative technologies developed for LHC program, in particular LHC computing GRID.
Key persons	**Marcello Losasso** (m): Senior Applied physicist, MBA, responsible for industrial relations within the Knowledge Transfer Office, CERN. He is Project Coordinator of QUACO Pre-Commercial-Procurement, the development of Superconductive Quadrupoles for the upgrading of the Hi-Lumi LHC. He is Coordinator of WP14 (Promoting Innovation) in ARIES. He has been Head of Unit in F4E (the European Undertaking for ITER project) between 2008 and 2013, leading the European Contribution to ITER project, for the areas of Magnets, Vacuum Vessel, Remote Handling and Blanket system. He was Leader of the Magnet & Mechanics section at CERN between 2002 and 2008, Project Leader of LHCb detector magnet. **Svetlomir Stavrev** (m): PhD. in Electrical Engineering. Head of the EU Office of CERN since in 2008. 18 years of experience in EU projects under FP4, FP5, FP6 and FP7. In AIDA-2020, member of the management team, in charge of the administrative and contractual aspects, and leader of the Project Support Office in AIDA-2020. **Yacine Kadi** (m): PhD Nuclear Reactor Physics. Applied Physicist at CERN, primarily concerned with research in Nuclear engineering, nuclear physics, and accelerator technology. **Federico Carminati** (m): Responsible for the detector simulation activities in the Software Group of CERN Experimental Physics Department. Project leader for the development of a

	comprehensive radiation transport simulation program for simulating the response of High Energy Physics detectors. Coordinating the simulation effort for the project.
Selected publications	*M. Losasso as author or co-author in the following journal publications:* LHCb Collaboration, et al. (2000*). LHCb magnet: Technical design report.* CERN, Geneva. LHCb Collaboration, et al. (1998*). LHCb. Technical proposal*. CERN, Geneva. Tadashi, S. & Sihmimoto, S. (Eds.). (1990). *Zeus Magnets Construction Status Report*. 11th International Conference on Magnet Technology (MT-11). ISBN: 978-94-010- 6832-1 Fabbricatore, P. et al. (1988). *A prototype refrigerator for subcooled superfluid helium at 1.8 k. Design and tests.* Proceedings of the Twelfth International Cryogenic Engineering Conference Southampton, UK, 12–15 July 1988. ISBN: 9780408012591 Bonito Oliva, A. et al. (2014). *Progress in the F4E Procurement of the EU ITER TF Coils.* IEEE Transactions on Applied Superconductivity 24(3). DOI:10.1109/TASC.2013.2285930 Bellesia, B. et al. (2014). *He-Inlet of the Toroidal Field Coil: Qualification and Manufacturing Status.* IEEE Transactions on Applied Superconductivity 24(3). DOI:10.1109/TASC.2013.2290379 Boutboul, T. et al. (2014) *Status of the Procurement of the European Superconductors for the ITER Magnets.* IEEE Transactions on Applied Superconductivity 24(3). DOI:10.1109/TASC.2013.2288034 Jones, L. et al. (2012). *Manufacturing preparations for the European Vacuum Vessel Sector for ITER*. Fusion Engineering and Design 87(s 5–6). DOI:10.1016/j.fusengdes.2012.02.007 Losasso, M. et al. (2012). *Project management techniques used in the European Vacuum Vessel sectors procurement for ITER*. Fusion Engineering and Design 87(s 5–6). DOI:10.1016/j.fusengdes.2011.11.014 Barbero, E. et al. (2012). *Status of the F4E procurement of radial plate prototypes for the EU ITER TF coils.* IEEE Transactions on Applied Superconductivity 22(3). DOI:10.1109/TASC.2011.2175895 Barbero Soto, E. et al. (2011). *Progress on the ITER TF coil winding pack in EU.* IEEE Transactions on Applied Superconductivity 22(3). DOI:10.1109/TASC.2011.2178989 Aprili, P. et al. (2014). *Welding Challenges in the Frame of European Contribution to ITER Magnets*. Le soudage: maîtrise, simulation et contrôle. Paris, France.

2. ***CIEMAT: European Organization for Nuclear Research***	
General Description	CIEMAT, an Organism of the Ministry of Education and Science, is a Public Research Agency for excellence in energy and environment, as well as in many vanguard technologies and in various areas of fundamental research. Since its creation in 1951, then as JEN, and since 1986 as CIEMAT, it has been carrying out research and technological development projects, serving as a reference for technical representation of Spain in international forums, and advising government on matters within its scope. These activities are complemented with education, technology transfer and technical services.
Role	CIEMAT will participate in the project with neutronic and thermal-hydraulic calculations, fuel cycle evaluations, design of the ADS monitoring and control system, with the assessment of the nuclear data induced uncertainties and participating on the experimental validations of key aspects of the design.
Available technical equipment and facilities relevant to the project	The Nuclear Fission Division at CIEMAT, includes Units devoted to Nuclear Safety Research, Nuclear Waste Management Research and Nuclear Innovation. This division has been very active on the R&D on advance fuel cycles, partitioning and transmutation and the use of ADS for nuclear wastes transmutation from 1993, contributing to many EURATOM from FP4 to H2020 including MUSE4, PDS-XADS, EUROTRANS, EUROPART, Red-Impact, PATEROS, CP-ESFR, FAIRFUELS, JHR-CA, MTR-I3, CDT, ANDES, ARCAS, ACSEPT, ADOPT, FREYA, MAXSIMA, MARISA, ESNII+, MYRTE, ESFR-SMART, EURAD-EJP and others and coordinating ANDES, CHANDA and SANDA. The group has also contributed to FEAT and TARC projects at CERN. The Nuclear innovation group also participates in the NEA Working Party on scientific issues of Advanced Fuel Cycles, WPFC previously WPPT. CIEMAT has also contributed to several NEA/OCDE and IAEA related studies. CIEMAT is founder member of the European Technological Platform for Sustainable Nuclear Energy, SNETP, participating in the Executive Committee and the Governing Board, and of the Industrial Initiative ESNII.
Key persons	Dr. D. Cano-Ott (M), head of the Nuclear Innovation Unit an international expert in neutron cross section measurements, decay data, neutron detectors and gamma-ray detectors. He is spokesperson of the MONSTER collaboration. He is author of co-author of more than 200 international publications and has participated in most of the FP5, FP6 and FP7 nuclear data projects and coordinated WP8 of CHANDA. He is a regular consultant of international agencies like IAEA and OECD/NEA. He has also participated in several. Prof. Dr. E. Gonzalez-Romero (M), head of the Nuclear Fission Division, coordinator of CHANDA, ANDES and SANDA EURATOM projects, chairman of the n_TOF collaboration Board, former chairman of the SNETP Executive Committee and present member of the SNETP Board, member of the WPFC/NEA, member of the INDC of the IAEA. He has contributed to most of the EURATOM projects of the FP5, FP6 and FP7 related to ADS and advanced fuel cycles. He was the coordinator of the preparation of the 2013 update of the SNETP Strategic Research and Innovation Agenda. Dr. F. Alvarez (M), author of the EVOLCODE2 system, expert in the evaluation of nuclear data needs and fuel cycle calculations, and participant in various European projects such as IP-EUROTRANS, ANDES, CHANDA, CDT-FASTEF, CP-ESFR, ARCAS, ESFR-SMART. Dr. V. Becares (M), researcher. has a 5-year degree in Physics by the University of Salamanca and a PhD in Nuclear Science and Technology by the Polytechnic University of Madrid. He has been a member of CIEMAT's Nuclear Fission Division since 2008. His major research activities have been focused in the field of experimental nuclear reactor physics and the development of reactivity monitoring techniques for Accelerator Driven

	Systems (ADS). He has taken part in FP6 EUROTRANS, FP7 FREYA and H2020 MYRTE programs. Dr. D. Villamarin (M), responsible of the experimental activities in the experimental reactors, MASURCA and YALINA, and coordinating the participation of CIEMAT in the MYRTE and FREYA projects and responsible of the activities on integral experiments in ANDES and CHANDA.
Selected publications	

3. ***CVR: Centrum Vyzkumu Rez SRO***	
General Description	CVR is a privately run non-profit research organisation controlled by the national state electricty CEZ. Its purpose is to carry out applied research in applied sciences related to the energy sector with an emphasis on the nuclear sector, but not limited to it.
Role	
Available technical equipment and facilities relevant to the project	The Fusion Department in CVR will be participating in the project. It runs several facilities of interest to the joint project and has currently 17 employees, 10 of which are researchers and the remainder technicians
Key persons	Person 1: Samec, Karel Dipl. Ing. ETH; CVR Fusion Department Head Liquid metal technology, Thermo-hydraulics, technological development management 28 years experience, of which 15 in nuclear, prior work for PSI, CERN and the Swiss nuclear regulator Person 2: Prokůpek, Jan Ing.; Responsible for CVR participation in ITER Experience in requirements management, high heat flux testing, evaluation and instrumentation Employed since 2014 at CVR for the Helcza High Heat Flux Facility, lecturer in physics Person 3: Kordač, Michal Dr. Ing.; Responisble for the liquid metals group Experience in liquid metal loop, corrosion chemistry, and management of laboratory Employed since 2015 in CVR as liquid metal expert, previous 15 years researcher at technical university
Selected publications	*Design of a compact high-power neutron source—The EURISOL converter target DOI: 10.1016/j.nima.2009.04.052* *A Spallation-Based Irradiation Test Facility for Fusion and Future Fission Materials DOI: 10.13140/RG.2.1.2600.7129* *HELCZA—High heat flux test facility for testing ITER EU first wall components* *DOI: 10.1016/j.fusengdes.2017.03.059* *Megapie: international collaboration lead by PSI for designing an operating the worlds first liquid metal megawatt-level spallation target.*

	Eurisol: Design study culminating in the hydraulic testing of a 4-MW class liquid metal spallation target with a novel cusp beam window, object of the present demand for further testing under simulated beam. *CVR is integrated in Gen IV activities through its material testing activities in-pile with the LVR-15 reactor.* *Further nuclear activities concern Gas-cooled fast reactors, the ALLEGRO project in particular. Finally CVR is a participant in JHR where it provides the Hot cells, as well as the ITER project providing a High heat Flux testing facility which would be used in the current proposal.*

4. ***NINE: Nine Engineering***	
General Description	
Role	
Available technical equipment and facilities relevant to the project	
Key persons	program
Selected publications	*M*

5. ***ENEA: Ente Nazionale per le Nuuove tecnologie, Energia e sviluppo Economico***	
General Description	Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, ENEA, is the second major Italian research organization, with around 2700 staff employees distributed in its 9 research centers all over the national territory. The Agency's activities are mainly focused on Energy Efficiency, Renewable Energy Sources, Nuclear Energy, Climate and the Environment, Safety and Health, New Technologies, Electric System Research. ENEA's multidisciplinary competences and great expertise in managing complex research projects are put at the disposal of the Country system, and deployed in international programs. Specifically, its activities are devoted to: basic, mission-oriented, and industrial research exploiting wide-ranging expertise as well as experimental facilities, specialized laboratories, advanced equipment. ENEA also: develops new technologies and advanced applications; provides public and private bodies with high-tech services, studies, measurements, tests and assessments; delivers training and information activities aimed at providing greater public knowledge and awareness on the Agency's fields of competence, and a higher level of dissemination and transfer of research results, thus promoting their exploitation for production purposes.
Role	ENEA will contribute with the design of the core of the sub-critical system and with the safety analyses of the plant
Available technical equipment and facilities relevant to the project	Experts with more than 20 years of experience in the fields of core design and analysis, fuel cycle (including transmutation and fuel management), safety analyses, with a specific focus on fast reactors (critical and sub-critical), and lead-cooled ones in particular. State-of-the-art codes and tools for the complete analysis of a fast reactor in support to its design and verification. The methodologies, codes and models have also undergone a preliminary verification and validation process, leveraging on the availability of unique experimental facilities operating in representative environment and relevant conditions.
Key persons	**Giacomo Grasso** (m): Researcher, coordinator of core design activities and related R&D program. Research in fast reactors core design, fuel cycle analysis. **Paride Meloni** (m): Head of Division for Nuclear Safety and Sustainability (SICNUC). Research into thermal/hydraulic and safety analyses.
Selected publications	L. Cinotti *et al*. (2011). *Lead-cooled Fast Reactor (LFR) design: safety, neutronics, thermal hydraulics, structural mechanics, fuel, core and plant design*. In: D.G. Cacuci (Editor), *Handbook of Nuclear Engineering* (pp 2749-2840). DOI: 10.1007/978-0-387-98149-9_23. C. Artioli *et al*. EFIT fuel cycle analysis by deterministic and Monte Carlo methods. In *First International Conference on Physics and Technology of Reactors and Applications* (*PHYTRA1*), Marrakech, Morocco, March 14-16, 2007, on CD-ROM, (2007). G. Grasso *et al*. On the Effectiveness of the ELSY Concept with respect to Minor Actinides Transmutation Capabilities. In *Tenth Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation* (*IEMPT10*), Mito, Japan, October 6-10, 2008. C. Artioli, G. Grasso and C. Petrovich. A new paradigm for core design aimed at the sustainability of nuclear energy: the solution of the extended equilibrium state. *Ann. Nucl. En.* **37**:915-922 (2010) DOI: 10.1016/j.anucene.2010.03.016.

	G. Grasso. The Adiabatic Reactor Concept: An effective strategy for recycling all actinides. In *43èmes Journées des Actinides* (*JdA2013*), Sestri Levante, Italy, April 6-9, 2013. L. Mansani *et al*. The European Lead-cooled EFIT plant: an industrial-scale accelerator-driven system for minor actinide transmutation. *Nucl. Technol.* **180**(2):241-263 (2012).

6. ***UNIGE: Universita' di Genova***	
General Description	The University of Genoa is one of the most valuable cultural and scientific heritage of the Mediterranean and the Italian north-western area. It is deeply interconnected with the city of Genoa and its economic framework. The University of Genoa plays a leading role in the fields of research, innovation and technology transfer in an increasingly competitive environment at national and international level. The University of Genoa takes part in national and international programmes, it selects funding channels and promotes many relations with local and regional authorities and companies. Departments and University centres carry out scientific researches in collaboration with professors, researchers, postdoc researchers, technical and administrative employees and PhD students of 28 PhD courses, 2 of which are joint initiatives with international institutions. DIME-UNIGE has participated to several EC projects relevant to this call: HTR-N and HTR-N1 (5th EU FP), GCFR, PuMA and RaPHaEl (6th EU FP), CHANDA, GENTLE and GoFastR (7th EU FP)
Role	CFD, Thermal hydraulics of core and target, burnup evaluations, SMRs state of the art analysis
Available technical equipment and facilities relevant to the project	DIME-UNIGE has a long standing and demonstrated expertise in the fields of experimental and numerical thermal-fluid-dynamics as well as of nuclear engineering and technology. More specifically, a specific experience and expertise has been gained in applying CFD and multiphysics codes (like OpenFoam, Ansys, FEMLAB, etc.) to innovative and advanced nuclear systems so as in burnup evaluations by ad-hoc codes (e.g. MCNP, MONTEBURNS, etc.). Additionally, a new powerful HPC farm will be available at soon at DIME-TEC, that can be used for intensive CFD and multiphysics simulations.
Key persons	**Person 1** Name: Guglielmo Lomonaco Title: Assistant Professor Responsibility in the company: Coordinator of GeNERG (Genoa Nuclear Energy Research Group) at DIME (Department of Mechanical, Energy, Management and Transportation Engineering) of UNIGE Field of excellence, Research area: Nuclear Engineering Short curricular reference: Guglielmo Lomonaco is Assistant Professor of Nuclear Plants at DIME/TEC - University of Genova. He has a M.Sc. in Nuclear Engineering and a Ph.D. in Electrical and Thermal Energetics. He has been working for more than 15 years in the field of nuclear engineering, with a special emphasis on innovative/advanced nuclear reactors design. He is member of the International Board of Advisors for Environmentalists for Nuclear (USA Section) since November 2016. He is/has been member of ACS, AIFT, AIN, ANS, ApP, ASME, CNeR, UIT, etc. He has participated to various EURATOM funded projects. **Person 2**

	Name: Mario Misale Title: Full Professor Responsibility in the company: Coordinator of Bachelor's Degree Course Board in Mechanical Engineering at UNIGE Field of excellence, Research area: Experimental thermal-hydraulics Short curricular reference: Mario Misale received his degree in mechanical engineering at University of Genova in 1981 informing the thesis "Influence of morphology and thermophysical properties of the surface on pool boiling process". Then he worked as development engineer at Ansaldo (Italy). In 1983 he becomes a full researcher at Energy and Environmental Conditioning Department of the University of Genoa and since 1992 he was associate professor and since 2004 is full professor at the same Department. His works in the field of experimental thermal hydraulics (especially on natural circulation loops) are considered as a reference in the frame of the international scientific community. He is also the responsible of the PITH (Passive Increment Heat Transfer) laboratory at DIME (selected worldwide by the IAEA as a reference laboratory to perform a series of test cases on natural circulation). **Person 3** Name: Francesco Devia Title: Assistant Professor Responsibility in the company: DIME-TEC Section Coordinator at UNIGE Field of excellence, Research area: Computational Fluid Dynamics (CFD) Short curricular reference: Francesco Devia is Assistant Professor at DIME-TEC since 1995. He has gained a long experience and expertise in the application of CFD codes to various industrial and civil systems, ranging from nuclear plants to environmental conditioning.
Selected publications	G. Lomonaco, W. Borreani, M. Bruzzone, D. Chersola, G. Firpo, M. Osipenko, M. Palmero, F. Panza, M. Ripani, P. Saracco, C. M. Viberti. Initial thermal-hydraulic assessment by OpenFOAM and FLUENT of a subcritical irradiation facility. THERMAL SCIENCE AND ENGINEERING PROGRESS, vol. 6, p. 447-456, ISSN: 2451-9049, doi: 10.1016/j.tsep.2018.03.003 (2018) G. Lomonaco, G. Alessandroni, W. Borreani (2018). Partial Redesign of an Accelerator Driven System Target for Optimizing the Heat Removal and Minimizing the Pressure Drops. ENERGIES, vol. 11, p. N/A, ISSN: 1996-1073, doi: 10.3390/en11082090 (2018) W. Borreani, D. Chersola, G. Lomonaco, M. Misale. Assessment of a 2D CFD model for a single phase natural circulation loop. INTERNATIONAL JOURNAL OF HEAT AND TECHNOLOGY, vol. 35, p. 300-306, ISSN: 0392-8764, doi: 10.18280/ijht.35Sp0141 (2017) M. Lizzoli, W. Borreani, F. Devia, G. Lomonaco, M. Tarantino. Preliminary CFD Assessment of an Experimental Test Facility Operating with Heavy Liquid Metals. SCIENCE AND TECHNOLOGY OF NUCLEAR INSTALLATIONS, vol. 2017, Article ID 1949673, doi: 10.1155/2017/1949673 (2017)

	D. Castelliti, G. Lomonaco. A preliminary stability analysis of MYRRHA Primary Heat Exchanger two-phase tube bundle. NUCLEAR ENGINEERING AND DESIGN, Volume 305, Pages 179-190, doi: 10.1016/j.nucengdes.2016.05.019 (2016) G. Lomonaco, O. Frasciello, M. Osipenko, et al. An intrinsically safe facility for forefront research and training on nuclear technologies — Burnup and transmutation. EUR. PHYS. J. PLUS 129: 74. doi: 10.1140/epjp/i2014-14074-6 (2014)

7.***PSI: Paul Scherrer Institut***	
General Description	The Paul Scherrer Institut, PSI, is the largest research institute for natural and engineering sciences within Switzerland. The institute performs world-class research in three main subject areas: Matter and Material; Energy and the Environment; and Human Health. By conducting fundamental and applied research, the institute works on long-term solutions for major challenges facing society, industry and science.
Role	The contribution will be in the crucial part of halo characterization and mitigation through the unique expertise in working with the highest intensity accelerator in the medium energy range, allowing as well benchmarking of the model with data from the PSI machines.
Available technical equipment and facilities relevant to the project	PSI will support ADSMR project with non-linear beam dynamics models in order to estimate, characterize and mitigate halo during the beam transport in the cyclotron and beam lines. The PSI Ring cyclotron, with world record intensity of 1.4 MW on target will provide us with the best test bed for the models we intend to develop for this project. The obtained results will enable also to improve the existing facility and obtain a better understanding of halo mitigation.
Key persons	**Andreas Adelmann** (m): Senior scientist and Head of the Accelerator Modeling and Advanced Simulation group. Primary research area in non-linear beam dynamics. **Rudolf Dölling** (m): Senior scientist, primary research area in proton beam diagnostics. **Chistian Baumgarten** (m): Senior scientist and coordinator of proton beam dynamics studies.
Selected publications	Bungau, A., et al. (2012). *Proposal for an Electron Antineutrino Disappearance Search Using High-Rate Li8 Production and Decay*. Phys.Rev.Lett. 109(141802) Yang, J. J., et al., (2013). *Beam dynamics simulation for the high intensity cyclotrons.* NIM-A 704: 84-91 Baumgarten, C. (2011). *Transverse-longitudinal coupling by space charge in cyclotrons*. Phys. Rev. STAB, 14(114201) Alonso, J. et al. (2010). *Expression of Interest for A Novel Search for CP Violation in the Neutrino Sector: DAEdALUS*. (arXiv:1006.0260) Abs, M. et al. (2015). *IsoDAR@KamLAND: A Conceptual Design Report for the Technical Facility* (arXiv:1511.05130)

8. HNE***: Hydromine Nuclear Energy S.a.r.l.***	
General Description	Hydromine Nuclear Energy S.a.r.l. ("HNE") is a subsidiary of Hydromine, Inc. ("Hydromine"), which is located at 230 Park Avenue, Suite 950, New York, NY 10169-0950. Hydromine is a project development company principally involved in a variety of natural resources, power generation and infrastructure development projects throughout the world, including mining, infrastructure and traditional and renewable power generation technology projects. HNE is a recently established company specifically devoted to the nuclear field and in particular to the development of Lead-Cooled Fast Reactors ("LFR"). HNE is in the process of validating the SME declaration status by the EC.
Role	HNE is strongly committed to the development of the LFR and, for the first time at a symposium held on July 12, 2016 at Imperial College London, presented its project (the LFR-AS-200) to a select audience of nuclear experts, politicians and embassy officials. The outstanding safety features and the drastic simplification in the design of the primary system were appreciated by the audience in London, and this adds to the aroused international interest in the LFR-AS-200. In particular, its primary system specific volume, a key-parameter of cost estimate, is less than 1m3/MWe, a value that corresponds to a reduction of about factor 4 in comparison to the sodium-cooled fast reactor SPX1, and even, compared to the other LFR projects developed so far at international level. Most of the design simplifications developed for the LFR-AS-200 are applicable to the primary system of the ADS and this is of great importance for the success of the prospective ADS design. In HNE´s opinion, the ADS projects developed to date are prohibitive in terms of cost, mainly because resulting from a combination of an expensive accelerator with too expensive nuclear facility. The combination of a compact cyclotron with a compact, simple reactor is both a condition and an opportunity for the deployment of ADS systems. HNE has a small team of engineers with over 30 years experience in fast reactor design, including participation in the development of the SPX1 and LFR. The HNE team is currently developing the LFR-AS-200 project. The extensive activity of the HNE team led to the identification of numerous innovations to improve safety, simplicity and cost- competitiveness of the LFR. The result is a design that solves key safety issues of the LFR, in particular the issue related to the installation of the steam generator inside the reactor vessel. After joining HNE in 2013, the activity has been focused on the LFR-AS-200, developed on a private basis and presented for the first time at the July 12, 2016 symposium at Imperial College London.
Available technical equipment and facilities relevant to the project	The HNE innovations embodied in the LFR-AS-200 project are certified by 12 patent applications (including seven in 2016), which include the: (i) raised (102016000069589), Spiral-Tube Steam Generator (PCTIB2008002170) with integrated Primary Pump, having a short, large shaft filled with lead; (ii) the Extended- Stem Fuel Assemblies (PCTIB20080025019), supported at their heads (102016000045589) in the cover gas space (no in-vessel fuel handling machine, no diagrid and strongback); and (iii) the Amphora-Shaped Inner Vessel, that allows the elimination of the shielding assemblies. The HNE

	team uses the codes SOLIDWORKS for 3D modeling, fluid dynamics calculations and finite elements thermal-mechanical calculations, AUTOCAD for drawings and COMPRESS for mechanical calculations according to ASME code. HNE is a Luxembourg company and also uses Hydromine Inc.'s London office.
Key persons	**Luciano Cinotti** (m): Chief Nuclear Engineer. His primary research area is in nuclear systems design. **Giuseppe De Antoni** (m): Responsible for licensing of LFR-AS-200. Research in safety and commissioning of fast reactors, including design, construction, test and decommissioning the reactor SPX1. **Leonardo Presciuttini** (m): Responsible for mechanical design His research is in mechanical design, stress analysis, thermalhydraulics. Responsible for the mechanical design of the LFR-AS-200 at HNE.
Selected publications	Members of the current HNE team produced more than 30 patents in the nuclear field and many publications, and in particular on LFR: L. Cinotti, p. Briger and G. Grasso. Simplification, the atout of LFR-AS-200. *Id 140, Proc. Int. Conf. Fast Reactors and Related Fuel Cycles (FR17),* Yekaterinburg, Russian Federation, June 26-29, 2017. G. Grasso, G. Bandini, F. Lodi and L. Cinotti. The core of the LFR-AS-200. *Id 185, Proc. Int. Conf. Fast Reactors and Related Fuel Cycles (FR17),* Yekaterinburg, Russian Federation, June 26-29, 2017. Cinotti, L. et al. (2011). *Lead-cooled Fast Reactor (LFR) design: safety, neutronics, thermal hydraulics, structural mechanics, fuel, core and plant design*. In: Cacuci, D. G. (Editor), *Handbook of Nuclear Engineering* (pp 2749-2840). DOI: 10.1007/978-0-387-98149-9_23 Smith, C.F. & Cinotti, L. (2016) *Lead-Cooled Fast Reactors*. In: Pioro, I. (Editor), *Handbook of Generation IV Nuclear Reactors*, Elsevier. ISBN: 9780081001493. Cinotti, L. et al. (2011) *Lead-cooled system design and challenges in the frame of Generation IV International Forum*. Journal of Nuclear Materials, 415(3):245-253

9. **INFN*: Istituto Nazionale di Fisica Nucleare***	
General Description	The National Institute for Nuclear Physics (INFN) is the Italian research agency dedicated to the study of the fundamental constituents of matter and the laws that govern them, under the supervision of the Ministry of Education, Universities and Research (MIUR). It conducts theoretical and experimental research in the fields of subnuclear, nuclear and astroparticle physics. All of the INFN's research activities are undertaken within a framework of international competition, in close collaboration with Italian universities on the basis of solid academic partnerships spanning decades. Fundamental research in these areas requires the use of cutting-edge technology and instruments, developed by the INFN at its own laboratories and in collaboration with industries. Today, some 5,000 scientists are either employed by or are research associates with INFN, whose work is recognized internationally not only for their contribution to various European laboratories, but also to numerous research centres worldwide. INFN also promotes the economic valorization of its competences and infrastructures and favors the adoption by the productive world of new and cost- effective technologies generated by its own research.
Role	INFN will take care of the cyclotron design. It will also support CERN in organizing meetings and discussions within WP1 and will contribute to ADS simulations and neutronics.
Available technical equipment and facilities relevant to the project	People at LNL (Legnaro National Laboratory) and LNS (National Southern Laboratory) units have long standing and demonstrated expertise in accelerator design and operation, in particular cyclotrons. People at Genova unit have experience using Monte Carlo codes for neutron transport calculations like MCNP. A powerful HPC farm is hosted by the Genova unit, featuring 10 machines, each with a 64 core Intel KNL processor, that can be used for intensive Monte Carlo simulations.
Key persons	**Mario Maggiore (m)**. Mario Maggiore is Technologist at Istituto Nazionale di Fisica Nucleare (INFN). Presently he works at Laboratori Nazionali di Legnaro (LNL) as responsible (since 2016) of operation of the high power SPES cyclotron (50 kW beam power). He has been working for 10 years in Accelerator Physics field as researcher at Laboratori Nazionali del Sud (LNS) involved in the design of high power cyclotrons (ADS and Daedalus collaboration) and accelerator for medical application (SCENT project). In 2010 he has been involved in the SPES project (exotic beams facility) of INFN and moved at LNL as member of team in charge of design and build the SPES facility, in particular the high intensity beam area which include the cyclotron and the beam transport lines. He partecipated in the design and construction of the Cyclotron made by canadian BEST Theratronics company. He was the director of the installation and the commissioning of the SPES accelerator and beamlines at LNL which was concluded successfully in 2017. At the present he is also responsible of the upgrade phase of the high intensity facility which is expanding with the installation of new beamlines dedicated to the production of new radioisotopes for medicine (LARAMED project). Meanwhile he has gained knowledge and expertise on design and realization of charged particle beam handling devices to be used in nuclear physics and applications (ELIMED project and COOLBEAM project). Actually he is the responsible of the RF beam cooler device construction foreseen for SPES project. **Marco Ripani (m).** Marco Ripani is Director of Research at the Istituto Nazionale di Fisica Nucleare(INFN). He works at the INFN Genova unit since 1992. He has been working for nearly 20 years in the field of experimental nuclear physics, is author or co-author of almost 250 papers on international refereed journals and co-author (with E. De Sanctis and S. Monti) of the Book "Energy from Nuclear Fission" (Springer, 2016). Currently he leads the "INFN-Energy" strategic project, aimed at developing applied nuclear science in the field of

	radioactive waste management, homeland security and future fission and fusion reactors. Within INFN-Energy, he performs research on fast lead-cooled accelerator driven subcritical systems (ADS) and on innovative solid-state neutron detectors. Among others, he is a member of the Expert Committee on art. 37 of the Euratom-Treaty on radioactive waste disposal and a member of the Euratom Program Committee as governmental expert. He participated to the EURATOM funded projects FREYA and CHANDA (7th EU FP). In the latter he led a Task denominated "New infrastructure for studies of transmutation and fast systems concepts". **Luciano Calabretta (m)** Dr. Luciano Calabretta is Director of Research at the National Institute for Nuclear Physics (INFN). He works at Laboratori Nazionali del Sud (LNS) in Catania since 1981. From 1984 to 1995 he studied, designed and commissioned: the injection and extraction beam line for the LNS superconducting cyclotron; the system of beam transfer line from the accelerators room to the experimental rooms; the bunching system for the proper injection of the tandem beam into the cyclotron. From 1995 up to 2002 he designed and commissioned the new beam line complex to distribute the beam at the new experimental area of the LNS. In the years 1997-1998 he participated to the design study of the injection beam line and of the central region of the cyclotron. These improvements allow to operate the cyclotron in the stand alone mode avoiding the beam injection from the tandem. In 1998, in cooperation with the Italian company Ansaldo Energia he developed a project to build a cyclotron-based accelerator complex, able to feed a subcritical reactor of about 80 MW. This preliminary design was a step towards the executive project for a full scale Accelerator Driven system dedicated to transmutation of the nuclear waste and/or to energy production. In 2002 he was member of a scientific committee in charge to evaluate the project of AIMA for a superconducting cyclotron for the project TRADE led by ENEA. Since 2010, he is a member of the DAEdALUS collaboration, for the measurement of CP violation in the neutrino sector. He is studying the cyclotron complex to produce a proton beam with maximum energy of 800 MeV and peak intensity of 10 mA. He has studied a 60 MeV/amu normal conducting cyclotron and a 6 sectors superconducting cyclotron ring.
Selected publications	A multi megawatt cyclotron complex to search for CP violation in neutrino sector, L.Calabretta, M. Maggiore et al, arXiv:1010.1493 (2010) Cyclotrons and FFAG Accelerators as Drivers for ADS, L. Calabretta and F. Méot, Reviews of Accelerator Science and Technology, Vol. 8 (2015) p. 77-98 SPES: A new cyclotron-based facility for research and applications with high-intensity beams, M. Maggiore et al.; Modern Physics Letters A (2017) 32, 17 High intensity cyclotrons for neutrino physics, D. Winklehner et al., Nuclear Instruments and Methods in Physics Research A, (2018) 907 231-243 Influence of reflector materials and core coolant on the characteristics of accelerator driven systems; F.Panza, et al.; Annals of Nuclear Energy 109 (2017) 162 An ADS irradiation facility for fast and slow neutrons; F. Panza, et al.; Eur. Phys. J. Plus 134 (2019) 195

10.***KTH:***	
General Description	The Royal Institute of Technology (KTH) in Stockholm has grown to become one of Europe's leading technical and engineering universities, as well as a key centre of intellectual talent and innovation. We are Sweden's largest technical research and learning institution and home to students, researchers and faculty from around the world. Our research and education covers a wide area including natural sciences and all branches of engineering, as well as architecture, industrial management, urban planning, history and philosophy. Research and teaching conducted at the Department of Physics span from basic science topics in condensed matter physics, nuclear, particle and astro-particle physics to applied areas such as medical imaging, nuclear engineering and nuclear power safety. The Division of Nuclear Power Safety (NPS) at KTH is internationally acknowledged in LWR safety and severe accident research and has been active as both coordinator and participant in several European Union Projects related to Severe Accidents in the fourth, fifth, sixth and seventh Framework Programs, and H2020. NPS-KTH coordinated the MVI, the ISARRP Projects and participated in the MFCI and CSC Projects of EU's 4th and 5th Framework Programs, RASPLAV and MASCA programs of OECD, and also coordinated the ARVI Project and participated in the Projects ECOSTAR, EUROCORE, PDS-XADS and TECLA. In the 6th Framework, NPS-KTH participated in the SARNET Project, the nuclear education project NEPTUNO, and the HLM related projects of IP EUROTRANS, VELLA and ELSY. In the 7th Framework, NPS-KTH participated in the projects of SARNET2, NURISP, LEADER, THINS, NURESAFE, MAXSIMA, SILER, and SAFEST. In the H2020, NPS-KTH participated in the IVMR project. In addition, NPS-KTH is active in the Swedish project of Accident Phenomena of Risk Importance (APRI), the Nordic Safety Project (NKS), and the Nordic Thermal Hydraulic Network (NORTHNET). Furthermore, NPS-KTH holds close connections with industrial partners both in Sweden and abroad performing experimental and computational studies in safety of LWRs. During the last decade NPS-KTH research activities were focused on LWR hypothetical severe accident phenomena which have extreme thermal-hydraulic conditions as well as on liquid metal thermal-hydraulic phenomena that is related to the design and safety of an accelerator driven system. These experiences and knowledge naturally fit to extend our activities to investigate the safety and thermal-hydraulics of advanced next generation reactors, such as Accelerator Driven Small Modular Reactors.
Role	KTH will lead the Training, Dissemination, and Outreach. KTH will contribute in reactor safety analyses and can also provide computational and/or experimental support in addressing identified issues concerning thermal-hydraulics of heavy liquid metal systems.
Available technical equipment and facilities relevant to the project	The SWECOR (Swedish Corium Research) experimental platform at KTH is a unique platform of experimental facilities to study different phenomena of corium-water interaction, jet fragmentation, melt spreading, debris formation and coolability as well as heavy liquid metal thermal-hydraulics. The platform integrates several well-equipped infrastructures and facilities using corium simulants. One of these facilities is the TALL large-scale infrastructure that was designed to study thermal-hydraulics of heavy liquid metal (lead-bismuth eutectic) which is a potential candidate for both coolant and spallation target of accelerator-driven systems (ADS), as well as a coolant candidate for FBRs. The facility is scaled 1:1 in height with a volumetric scaling based on a single heat exchanger

	tube, compared with an experimental ADS design. The experiments on TALL were carried out in order to support the design and safety of ADS and lead-cooled fast reactor (LFR).
Key persons	Walter Villanueva (male) is Senior Researcher at the Division of Nuclear Power Safety, KTH. He received his PhD in Mechanics from KTH Mechanics Department in 2007 and a postdoctoral stint at the National Institute of Standards and Technology from 2007-2009. He joined the Division of Nuclear Power Safety at KTH in 2009. His current research interests include thermal stratification and mixing in suppression pools, CFD, containment analysis, thermo-mechanical analysis, spray cooling, metallic and oxidic molten pool convection, melt spreading, and metallic melt penetration into porous debris. Weimin Ma (male) is Associate Professor at the Division of Nuclear Power Safety, KTH. He received his PhD in Mechanical Engineering from Xi'an Jiaotong University (Xi'an, China) in 1996. He joined in KTH in 2001 is the leader of the group on Severe Accident Risk Assessment and Management (SARAM) at the Division of Nuclear Power Safety. He had many years of research experience on safety of LWRs and HLM-cooled systems. His current research focuses on boiling, multiphase flow and nuclear power safety. Sevostian Bechta (male) is Professor and Head of Division of Nuclear Power Safety, KTH. He received his PhD in Nuclear Power Plants and Installations, CKTI, Russia, in 1996 and Doctor of Sci. in Nuclear Power Plants and Installations, St. Petersburg Polytechnic State University, Russia, in 2004. He was manager of several projects and coordinator of several international ISTC projects (2000-2011), as well as coordinator of several projects of Russian Fund of Fundamental Research (2001-2009), and assistant coordinator of MASCA OECD program (2004-2009). He joined KTH as NPS Division Head in 2011. He participated in and contributed to several research projects for ex-vessel corium behavior and stabilization: SIRMAT, ECOSTAR, SARNET, APRI and others. He is one of the authors of SAMG concept of VVER 1000 and 1200 reactors and of the ex-vessel core catcher.
Selected publications	*1.* Marti Jeltsov, Walter Villanueva, and Pavel Kudinov, "Steam generator leakage in lead cooled fast reactors: modeling of void transport to the core," *Nuclear Engineering and Design*, 328:255-265, 2018. *2.* Alexander Konovalenko, Per Sköld, Pavel Kudinov, Sevostian Bechta, and Dmitry Grishchenko, "Controllable Generation of a Submillimeter Single Bubble in Molten Metal Using a Low-Pressure Macrosized Cavity," *Metallurgical and Materials Transactions* B, 48:1064-1072, 2017. *3.* Dmitry Grishchenko, Marti Jeltsov, Kaspar Kööp, Aram Karbojian, Walter Villanueva, and Pavel Kudinov, The TALL-3D facility design and commissioning tests for validation of coupled STH and CFD codes, *Nuclear Engineering and Design* 290: 144-153, 2015. *4.* Weimin Ma, Aram Karbojian and Bal Raj Sehgal, "Experimental study on natural circulation and its stability in a heavy liquid metal loop," *Nuclear Engineering and Design* 237:1838-1847, 2007. *5.* Weimin Ma, Evaldas Bubelis, Aram Karbojian, Bal Raj Sehgal and Paul Coddington, "Transient experiments from the thermal hydraulic ADS lead bismuth loop (tall) and comparative TRAC/AAA analysis," *Nuclear Engineering and Design* 236:1422-1444, 2006. *6.* Marti Jeltsov, Walter Villanueva, and Pavel Kudinov, "Seismic sloshing effects in lead-cooled fast reactors," *Nuclear Engineering and Design*, 332:99-110, 2018. Marti Jeltsov, Walter Villanueva, and Pavel Kudinov, "Parametric Study of Sloshing Effects in the Primary System of an Isolated Lead-Cooled Fast Reactor," *Nuclear Technology*, 190:1-10, 2015.

11. ***USTUTT: University of Stuttgart, Institute of Machine Components***	
General Description	The Institute of Machine Components (IMA) is an institute with approx. 40 academic employees of the Faculty of Design, Production and Automotive Engineering at the University of Stuttgart. The Institute for Machine Components has worked together with numerous industrial partners on more than 60 projects in recent years. Our research areas are drive technology, CAD, sealing technology and reliability technology. The Institute of Machine Components (IMA) keeps close contact to several companies in the form of expertise advice and management consultancies.
Role	Training on reliability aspects in the field of accelerators. Further networking in the accelerator community. Introduce scientifically proven methods to the accelerator development to ensure high availability during operation. Institute of Machine Components (IMA) has a long history of seminars for several industry partners, that has shown to be very important to have a common basis for all kinds of studies regarding reliability and availability of systems. IMA wants to include seminars into the project to enable the other contributors performing reliability studies for subsystems on their own. A seminar including current reliability issues and regular workshops to have a collaboration and collate all necessary information. The variety of projects has shown that there is a lack especially in common knowledge base of methods for analysis and simulations in industry. Working in a project collaboration a common understanding is absolutely necessary. Having this intensive collaboration, data, suitable methodologies and modelling tools, IMA will be able to conduct reliability studies on system level and encourage the other contributors to intensify the integration of reliability modelling and analysis into their day-to-day operations. Also requirements for component reliability that has to be demonstrated can be set by considering complexity, experiential knowledge on existing technologies, application and cost.
Available technical equipment and facilities relevant to the project	Several test stands and computer pools support the employees in reliability studies of systems, components, as well as in reliability analysis and assurance, functional safety and security and modelling and simulation of systems.
Key persons	**Person 1** <u>Name:</u> Dazer, Martin <u>Title:</u> M. Sc. <u>Responsibility in the company:</u> Head of Reliability Department <u>Field of excellence, Research area:</u> Test planning, Design of Experiments <u>Short curricular reference:</u> Martin Dazer studied Mechanical Engineering at the University of Stuttgart in Germany and received his academic degree Master of Science in 2014. He is working as the head of the reliability department at the Institute of Machine Components. He is pursuing his PhD studies with a focus on life testing. **Person 2** <u>Name:</u> Herzig, Thomas

	Title: M. Sc. Responsibility in the company: Field of excellence, Research area: Test planning Short curricular reference: Thomas Herzig studied Mechanical Engineering at the University of Stuttgart in Germany and received his academic degree Master of Science in 2015. He is working as a research assistant in the field of reliability engineering at the Institute of Machine Components. He is pursuing his PhD studies with a focus on life testing. **Person 3** Name: Müller, Frank Title: M. Sc. Responsibility in the company: Field of excellence, Research area: Modelling and Simulation, Petri Nets, Availability, Confidence Bounds Short curricular reference: Frank Müller studied Technology Management at the University of Stuttgart in Germany and received his M. Sc. in 2015. Since 2016, he is working as a Research Assistant in Reliability Engineering at the Institute of Machine Components at the University of Stuttgart and pursues his PhD studies.
Selected publications	*M*

12. ***iThEC: International Thorium Energy Committee***	
General Description	iThEC is an international, non-profit association, whose member includes physicists, engineers, technicians, politicians, and concerned citizens. Several of the scientists member of iThEC are former collaborators of Nobel Prize Laureate, Carlo Rubbia, on the Energy Amplifier project. C. Rubbia is the honorary president of the association whose principal mission is promoting energy research based on thorium. Its goal is the destruction of long-lived nuclear waste and the development of innovative, safe, clean and abundant energy sources. iThEC is collaborating with several research institutes to carry out the first ADS experiment at significant power (≥ 1 MW), at INR Troitsk and has been active organizing important international conferences like ThEC13: “Thorium energy for the world” at CERN.
Role	iThEC will contribute to the neutronic and transmutation design analysis, and to the spallation target optimization, including optimizing the cyclotron beam footprint.
Available technical equipment and facilities relevant to the project	iThEC members are accelerator experts and have participated in key ADS experiments at CERN (FEAT, TARC), including the development of a cyclotron concept for ADS, and therefore, they hold unique expertise in the field of ADS. They also participated in the development of innovative simulation code, based on particle physics simulation methods, that was applied to ADS. iThEC members have been installing the n_TOF facility, which is now in operation at CERN, producing valuable nuclear data. iThEC members who are also CERN personnel have normal access to the CERN computing systems and infrastructure.
Key persons	**Jean-Pierre Revol** (m): Primary research in particle physics (UA1 discovery of W and Z bosons, ALICE experiment at the CERN LHC), detector design and construction, data analysis, nuclear physics, accelerator-driven systems, specifications of accelerator parameters for ADS and other industrial application, energy policy. Former faculty at MIT Physics Department. Ensuring coordination of scientific support for all the partners. **Maurice Bourquin** (m): Professor Emeritus at University of Geneva, former President of CERN Council, over 30 years of experience in particle physics. Former positions at Columbia University, Fermilab and DESY. Involved in the development of accelerator-based methods for medical applications. **Ranjana Nath Magnani** (f): Sustainable energy specialist, environmental engineer (EPFL)
Selected publications	Revol, J.-P. et al. (2013). *Thorium Energy for the World*. Proceedings of the ThEC13 Conference, CERN, Geneva, Switzerland. Edited by Springer Rubbia, C. et al. (1995). *Conceptual Design of a Fast Neutron Operated High-power Energy Amplifier*. CERN AT/95-44 (ET). FEAT Experiment: Andriamonje, S., et al., Phys. Lett. B *348*, 697–709 (**1995**) TARC experiment: Abánades, A., et al., Nucl. Instrum. M. Phys. Res. A *478*, 577–730 (**2002**)

	C. Rubbia et al., "A High Resolution Spallation Driven Facility at the CERN-PS to Measure Neutron Cross Sections in the Interval from 1 eV to 250 MeV", CERN/LHC/98-02 (EET), 30 May 1998; "A High Resolution Spallation Driven Facility at the CERN-PS to Measure Neutron Cross Sections in the Interval from 1 eV to 250 MeV: A Relative Performance Assessment", CERN/LHC/98-02 (EET)-add. 1, 15 June 1998; S. Abramovich et al., "Proposal for a Neutron Time of Flight Facility", CERN/SPSC 99-8, SPSC/P 310, 17 March 1999. The CERN n_TOF facility performance: Gunsing, F., *Nuclear Data for the Thorium Fuel Cycle and Transmutation*, in Thorium Energy for the World, ThEC13 Proc., CERN Globe of Science and Innovation, Geneva, Switzerland (October 27–31, 2013), Springer, Berlin (**2016**) Conjat, M., Mandrillon, J. & Mandrillon, P. (2016*). Cyclotron Drivers for Accelerator-Driven Systems*. Proceedings of the ThEC13 Conference, CERN Globe of Science and Innovation, Geneva, Switzerland. Edited by Springer

Section 5: Ethics and Security

5.1 Ethics

⚠ *For more guidance, see the document "How to complete your ethics self-assessment".*

If you have entered any ethics issues in the ethical issue table in the administrative proposal forms, you must:

- submit an ethics self-assessment, which:
  - describes how the proposal meets the national legal and ethical requirements of the country or countries where the tasks raising ethical issues are to be carried out;
  - explains in detail how you intend to address the issues in the ethical issues table, in particular as regards:
    - research objectives (e.g. study of vulnerable populations, dual use, etc.)
    - research methodology (e.g. clinical trials, involvement of children and related consent procedures, protection of any data collected, etc.)
    - the potential impact of the research (e.g. dual use issues, environmental damage, stigmatisation of particular social groups, political or financial retaliation, benefit-sharing, misuse, etc.).
- provide the documents that you need under national law(if you already have them), e.g.:
  - an ethics committee opinion;
  - the document notifying activities raising ethical issues or authorising such activities

⚠ *If these documents are not in English, you must also submit an English summary of them (containing, if available, the conclusions of the committee or authority concerned).*

⚠*If you plan to request these documents specifically for the project you are proposing, your request must contain an explicit reference to the project title.*

5.2 Security[31]

Please indicate if your project will involve:

- activities or results raising security issues: (YES/NO)
- 'EU-classified information' as background or results: (YES/NO)

[31] See article 37 of the Model Grant Agreement. . For more information on the classification of Information, please refer to the Horizon 2020 guidance: https://ec.europa.eu/research/participants/data/ref/h2020/other/hi/secur/h2020-hi-guide-classif_en.pdf.