DEN 4698–BALI C30701

IMPLEMENTING AGREEMENT

ON

"Sodium spray fragmentation and its consequences on combustion behavior"

BY AND BETWEEN

THE INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH of the Department of Atomic Energy, Government of India located at Kalpakkam – Tamil Nadu – India, duly represented by its Director Dr. Arun Kumar Bhaduri, Indira Gandhi Centre for Atomic Research,

Hereinafter called as "**IGCAR**"

AND

THE COMMISSARIAT À L'ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, a French state-owned research entity with a scientific, technical or industrial activity duly organised under the laws of France and having its registered office located at Bâtiment Le Ponant D - 25, rue Leblanc - Paris 15ème (France) - and declared at the Paris, Register of Commerce and Trade ("Registre du Commerce et des Sociétés de Paris") under the following registration number : R.C.S. PARIS B 775 685 019, duly represented by Mr. Philippe STOHR acting as Director of the Nuclear Energy Division and duly authorised for the purpose hereof,

Hereinafter referred to as "**CEA**",

Hereinafter also referred to as individually as a "Party" or collectively as the "Parties"

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WHEREAS the Government of the French Republic and the Government of the Republic of India signed on September 30, 2008 an Agreement on the Development of Peaceful Uses of Nuclear Energy (hereinafter "the Framework Agreement");

WHEREAS the Government of the French Republic and the Government of the Republic of India signed on December 6, 2010 an Agreement concerning intellectual property rights on the development of the peaceful uses of nuclear energy(hereinafter "the Intellectual Property Agreement");

WHEREAS CEA and IGCAR endorsed in November, 2005 a cooperation agreement in the field of Liquid Metal Fast Reactor Safety, which expired on November 2010,

WHEREAS CEA and DAE signed on December 6, 2010 an agreement in the field of nuclear science and technology for peaceful uses of nuclear energy with the aim to establish a general framework for their cooperation (hereinafter "Cooperation Agreement"),

WHEREAS CEA and IGCAR have common interest to co-operate in the field of safety related to sodium cooled fast reactor, and more particularly in the field of sodium fires, considered as a key issue of the safety of SFRs,

WHEREAS IGCAR has developedtwo facilities, named MINA and SOCA, to study sodiumfires for Fast Reactor applications,

WHEREAS CEA has carried out in the past several experimental programs dedicated to Na fires in the ESMERALDA platform and has implemented a new research program, dedicated to the improvement of models describing the influence of various parameters among them the sodium spray fragmentation,

WHEREAS CEA and IGCAR have decided, pursuant to articles 4 and 5 of the Cooperation Agreement, to establish an Implementing Agreement to prepare the bilateral cooperation on a joint research project titled "sodium spray fragmentation and its consequences on combustion behaviour",

Whereas the Parties consider that no nuclear incident can occur from the cooperation between the Parties subject to the Implementing Agreement within the meaning of the Civil Liability for Nuclear Damage Act, 2010 in force in India or the Paris Convention on Third Party Liability in the Field of Nuclear Energy of 29th July 1960 as implemented by legislation in force in France, and that, as a consequence, the Implementing Agreement is not subject to nuclear civil liability.

Now therefore, in consideration of the foregoing and mutual covenants contained herein, the Parties agree as follows:

ARTICLE 1 - DEFINITIONS

The words defined in Article 1, have the same meaning in this Implementing Agreement.

(i)**"Implementing Agreement"** means the present agreement, its annexes and its prospective amendments.

(ii) "**Own Information and Technology**" means without limitation any know-how, data, studies, software, specifications or any information whether patented or not, in any and all medium belonging to one Party prior to the effective date of this Implementing Agreement or acquired or developed thereafter independently of this Joint Research Project of this Implementing Agreement,

(iii) "**Joint Results**" means any and all document and information whether in written form or not including but not limited to manuals, drawing, know-how, trade secrets, trademarks, copyrights, manufacturing process data, studies, software, designs, specifications, technical description and data whether patentable or not generated during the Joint Research Project.

ARTICLE 2 - OBJECTIVES OF THE IMPLEMENTING AGREEMENT

2.1 Safety analysis of Sodium Fast Reactors requires the evaluation of sodium fires consequences, especially in the case of more severe scenarios of spray fires, when a sodium leak occurs in a liquid sodium circuit. The combustion rate of liquid sodium in air is directly related to the interfacial surface area that is developed between the liquid sodium spray and the air atmosphere. The description of the liquid sodium fragmentation during the spray expansion, is then a topic of major interest since it should be used as an input data for the simulation of sodium combustion and its consequences.

2.2 The objective of this Implementing Agreement is to co-operate on a balanced basis on the production of scientific knowledge related to the sodium fragmentation, relevant for modelling sodium fires.

2.3 The Parties agree to cooperate pursuant to the terms of this Implementing Agreement according to the provisions of the Cooperation Agreement unless otherwise specified herein. The present implementing agreement could be later amended or completed by other implementing agreement(s) or to update the planning of actions of this Implementing Agreement.

ARTICLE 3 – SCOPE OF THE COOPERATIVE ACTIVITY

Modelling of sodium spray fires is based either on the assumption of initial size distribution of the sodium droplets, or on empirical correlations defined from experimental measurements used for the determination of combustion rate values (which is the approach of calculation tools used by CEA up to now). Nevertheless, the fragmentation of liquid sodium spray depends on ejection conditions of the leak scenario, and in the case of a very large breach

(such as a cross break of secondary circuit in a SFR) only a reduced fraction of the liquid leak is fragmented into droplets. The dependence of liquid sodium fragmentation rate has to be studied in function of ejection conditions such as sodium velocity and mass flowrate, shape and cross section of the breach, and inclination of sodium ejection.

The modelling development started at CEA is based on a semi-empirical approach:

- First atomization should be simulated by an empirical description established from experimental tests that will be performed at CEA (Cadarache) with water as a model liquid in a wide range of ejection flowrates (from small values ≈ 5 m^3/h to higher values up to 300 m^3/h). The transposition to liquid sodium behaviour will be obtained by a similitude approach but will need experimental validation by characterization of sodium spray fragmentation at lower flowrates compatible with IGCAR facilities.

- Secondary atomization will be described by a physical model implemented in a CFD calculation tool and will need also experimental validation with sodium tests.

The aim of experimental tests will be, for several ejection conditions, to characterize the velocity and the size distribution of liquid droplets and their evolution along the spray trajectory. The similitude transposition between water and sodium behavior is defined by non-dimensional criteria such as liquid Weber number, Ohnesorge number and Froude number, and experiment conditions will be chosen to settle common values for these criteria and for both liquids, in the range that will be studied with sodium (and compatible with IGCAR facility)

IGCAR operates three facilitiesforNa fire characterization: SFEF, SOCA and MINA. The two last facilities could be used to contribute to this Implementing Agreement.

The cooperative activity is divided into four main steps (see Appendix):

Step 1: Definition of technical options of experiments

Step 2: Confirmation of conditions range and experimental program

Step 3: Tests of sodium sprays

Step 4: Analysis of results and validation of sodium fragmentation modelling

ARTICLE 4 – MILESTONES - DELIVERABLES

1- Definition of technical options of experiments	T0 + 6 months
2- Confirmation of conditions range & experimental program	T0 + 9 months
3- Preliminary Na tests	T0 + 15 months
4- Presentation of tests carried out with water	T0 + 15 months

5- Presentation of CEA model describing liquid fragmentation	T0 + 18 months
6- Experimental Tests with sodium (inert conditions, combustion)	T0 + 21 months
7- Synthesis report of experiments	T0 + 24 months
8- Validation of sodium fragmentation modelling with experimental data	T0 + 33 months
9- Technical Meeting to review modelling results	T0 + 40 months
10- Common synthesis report	T0 + 48months

**T0: date of entry into force of this Implementing Agreement*

ARTICLE 5 – NOMINATED CORRESPONDENTS:

IGCAR	CEA
Dr D. PONRAJU SED/PCAS IGCAR Kalpakkam, PIN-603102Tamil Nadu - India Phone office : 044-27480211 E-Mail: pon@igcar.gov.in	Dr Th. GILARDI DTN C.E.A.DEN/Cadarache F-13108 Saint Paul les Durance, France Tel: +33 4 42 25 70 34 e-mail:thierry.gilardi@cea.fr

The technical correspondents have to report the cooperation activities tothe Joint Research Project to the Franco-Indian Joint Committee as stated in article 6 the Cooperation Agreement.

ARTICLE 6 –FINANCIAL PROVISIONS

Both Parties agree that all activities done in the framework of this Implementing Agreement are to be done on a self-financing basis and equally reciprocating manner.

CEA will bear the cost of internal travel, allowance and accommodation of one IGCAR scientific officer for up to 2 weeks in France. IGCAR will bear the cost of internal travel, allowance and accommodation of one CEA scientific officer/trainee for up to 2 weeks in India.

Visits or meetings may be organised if necessary according to provisions of article 8.1 of Cooperation Agreement.

ARTICLE 7 – CONFIDENTIALITY

7.1. "Confidential Information" means:

i. Own Information and Technology and/or any type of written information and in whatever form or medium that one Party discloses, whether directly or indirectly, to the other Party and relating to the Implementing Agreement.
ii. The Results arising from the Joint Research Project.

7.2. Each Party undertakes

i. to disclose only Confidential Information it has the right to dispose of, according to the following;
ii. to keep strictly confidential and not to disclose nor to communicate to any third party, by any means whatsoever, any Confidential Information received from the other Party, unless the communicating Party has explicitly notified to the receiving Party that such proprietary information was not subject to secrecy, and
iii. to use such Confidential Information solely for the purpose of the Implementing Agreement.

7.3. Each Party shall use at least the same degree of care in protecting Confidential Information against disclosure to any third party as it exercises in protecting its own Confidential Information.

7.4. Each Party undertakes to disseminate Confidential Information only to its employees on "a need to know" basis to use it within the scope of the performance of the Implementing Agreement, and the receiving Party shall take appropriate measures with such employees to ensure that the latter should be bound by equivalent confidentiality provisions as those stipulated herein.

Notwithstanding the above provisions, each of the Parties has the right to communicate Confidential Information received from the other Party to its government authorities and its national safety authorities subject to appropriate protection of the Confidential Information by the receiving government authorities.

7.5. However, the provisions of this article shall not apply to Confidential Information for which the receiving Party can prove in writing that:

- Such Confidential Information is or has become publicly known through no wrongful act on its part;
- Such Confidential Information is available to the public and already known, at the time of disclosure by the disclosing Party;
- Such Confidential Information was rightfully received by the receiving Party from a third party without breach of any confidentiality obligation;
- Such Confidential Information was independently developed or discovered by the receiving Party without use of any Information received under the Implementing Agreement;
- Such Confidential Information is disclosed pursuant to a judicial order, a lawful requirement of government agency; or by operation of law, but then only to the extent so

ordered; in such case the receiving Party will make its best efforts to timely advise the disclosing Party prior to disclosure.

7.6. The provisions of this article shall remain in force during the term of this Implementing Agreement, and for ten (10) years after the expiration or termination of the Implementing Agreement.

7.7 Any scientific publication, presentation or release paper relating to all or part of the Confidential Information, all or part of the work carried out under the Implementing Agreement shall be submitted to the prior approval of the other Party, as the case may be through the Joint Committee. The other Party shall examine it promptly and notify the submitting Party of (i) its consent to the content of the paper or (ii) its request to amend and/or remove certain parts of the paper or (iii)to delay the paper publication, presentation or release as long as necessary to ensure adequate industrial and intellectual protection, provided that such period shall not exceed eighteen (18) months from the date of the receipt of the paper by the notified Party.

Any failure of the notified Party to communicate its decision to the submitting Party within thirty (30) calendar days shall be deemed as its consent and a waiver of any objection to the contents thereof.

Unless otherwise agreed between the Parties, any scientific publication, presentation or release paper by the submitting Party shall clearly mention the collaboration with the other Party.

ARTICLE 8 – CLAIMS RESULTING FROM INFORMATION TRANSFERRED

8.1. While the information (including Confidential Information as defined in article 7.1) given by one Party to the other under this Implementing Agreement is accurate, in the opinion and to the best of the communicating Party's knowledge, the communicating Party does not warranty the pertinence of such information to any use which may be made by the receiving Party or by a third party. The use of such information by the receiving Party (including the communication to a third party) shall be entirely at the receiving Party's risk.

8.2.No claim shall be made against a Party for any direct or consequential damages to its property, its personnel or to third parties, which might result from the use of information given to the other Party.

ARTICLE 9 – INDUSTRIAL PROPERTY AND RIGHTS OF USE

9.1 Ownership

9.1.1 Ownership of Own Information and Technology

Each Party shall remain the exclusive owner of its Own Information and Technology. As such, each Party shall be free to transfer to a third party its Own Information and Technology.

9.1.2 Ownership of Results

9.1.2.1 General principles

The Parties shall ensure adequate and effective protection of the Joint Results.

The Parties shall inform each other of any Joint Result which is likely to be protected and shall engage in a timely manner on ensuring protection for the Joint Results.

To this end, the Parties undertake not to oppose the seeking, by a Party, of protection of Results in countries authorising such protection.

Each Party shall on the basis of its respective domestic legislation grant the other Party non-discriminatory treatment regarding the property, allocation and exploitation of Joint Results.

9.1.2.2 Co-ownership instrument

Before any exploitation for industrial and/or commercial purposes by one Party, the Parties shall draw up a co-ownership instrument determining the rights of use of the said Joint Results, according to the following principles:

- The co-ownership instrument shall take into account the respective material, human, financial and intellectual contributions to the acquisition of the Intellectual Property of each Party, the benefits of exclusive and non-exclusive licences in each territory or field of use, the conditions required by the respective national legislation of the Parties or other factors deemed appropriate.

- If the Parties cannot reach agreement on instrument of co-ownership within a maximum of six (6) months from the date of expiry of the Implementing Agreement, each Party may directly or indirectly exploit Joint Results throughout the world subject to remuneration for the other co-owner. Each Party should notify the other Party of its intention to invoke this clause before beginning exploitation with industrial and commercial purposes with prior notice of at least two (2) months.

9.2 Rights of use

9.2.1 Rights of use of Own Information and Technology

Each Party undertakes to grant to the other Party a non-exclusive licence without the right to sublicense on its Own Information and Technology within the scope of this Implementing Agreement for the Joint Research Project. This licence shall be granted royalty-free.

Each Party undertakes to grant to the other Party a non-exclusive licence without the right to sublicense on its Own Information and Technology if needed for industrial and/or commercial exploitation of its Joint Results. This licence shall be granted with fair and reasonable conditions as agreed by the Parties in a specific agreement.

9.2.2 Rights of use of Results

Each Party shall have the right of free use of the Joint Results for research and development purposes.

The Parties shall facilitate the effective exploitation of the Joint Results. To this end, the Parties agree to conclude a co-ownership instrument before any industrial and/or commercial exploitation of Joint Results, as mentioned above in article 9.1.2.2.

ARTICLE 10 – LIABILITY

10.1. Personal damages to the staff of each Party

Each Party on its own account, is fully liable for the damages to its own staff, e.g. for the insurance coverage of its own staff for workmen's compensation and professional diseases, in accordance with the appropriate local regulatory and legal requirements. Consequently, each Party proceeds to the appropriate formalities, and sustains if any, all the costs associated to the insurances underwritten in order to cover its own staff against the risks.

Each Party shall inform the other Party of any claim or damage that has occurred during or consequent to any work, by the staff of other Party, employed by it, in order to proceed to the various regulatory and legal requirements.

Notwithstanding the above provisions, each Party is liable in compliance with the applicable law to damages caused by its staff to the staff of the other Party in case such damages were caused by or contributed to by the gross negligence or wilful misconduct of that staff.

10.2. Damages to the other Party's properties

Each Party keeps on its own account, without any right of recoveries against the other Party, the damages caused to its own property by the staff of the other Party when the staff thereof put to its disposal, unless such damages were caused by or contributed to by the gross negligence or wilful misconduct of that staff.

10.3. Third party liability

In accordance with the appropriate local regulations, each Party remains liable for damages to third parties caused by its own staff, except if this staff is under the management and/or the control of the other Party, unless such damages were caused by or contributed to by the gross negligence or wilful misconduct of that staff.

ARTICLE 11 – DURATION AND TERMINATION

11.1 Subject to the entry into force of the Cooperation Agreement according to article 16.1 of the said Cooperation Agreement, this Implementing Agreement shall come into force upon signature by both Parties and shall remain valid up to 5th Dec 2020.

11.2 Three months before the date of termination, the Parties shall consult each other in order to decide whether this Implementing Agreement shall be extended or not.

11.3 Termination of this Implementing Agreement for any reason whatsoever shall be without prejudice to the rights which may have occurred under this Implementing Agreement to either Party up to the date of termination.

11.4 This Agreement shall remain in force up to 5th Dec 2020. Thereafter it shall be extended for further periods (as indicated in Article 4) after mutual written consent of the parties unless terminated by the either party by giving a 3 (three) months written notice in advance to the other party of its intention to terminate this agreement through diplomatic channels. Extension of this Implementing Agreement after 5th Dec 2020 is automatic after mutual consent subject to renewal of the said Cooperation Agreement beyond 5th Dec 2020. (Mutual consent will be in the form of one letter mentioning all the relevant Implementing Agreements).

ARTICLE 12 - SETTLEMENT OF DISPUTES

The Parties agree that any dispute arising out of this Implementing Agreement will be settled amicably if possible with assistance of one or more independent experts.

All disputes which cannot be settled between the Parties will be finally settled under the Rules of conciliation and arbitration of the International Chamber of Commerce by one or more arbitrators appointed in accordance with the said Rules. Procedures of arbitration shall be conducted in English. The place of arbitration shall be in Geneva (Switzerland).

ARTICLE 13 - AMENDMENT

The Implementing Agreement may be amended by mutual consent in writing of the Parties.

ARTICLE 14 - LANGUAGE

This Agreement is drawn up and executed in two copies each in the English and Hindi languages.

Done at on day of 2019 in two originals each in Hindi and English languages, all texts being equally authentic. In case of divergence in the interpretation, the English text shall prevail.

For the Indira Gandhi Centre for Atomic Research	**For the Commissariat à l'Energie Atomique et aux Energies Alternatives:**
Full Name: Dr. Arun Kumar Bhaduri	Full Name: Mr Philippe STOHR
Title: Director, Indira Gandhi Centre for Atomic Research	Title : Director of the Nuclear Energy Division
Place and date: KALPAKKAM, 8th April 2019	Place and date: May 21. 2019
(Signature)	(Signature)

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APPENDIX

Study of sodium spray fragmentation and its consequences on combustion behavior

1. Introduction

Safety analysis of Sodium Fast Reactors requires the evaluation of sodium fires consequences, especially in the case of more severe scenarios of spray fires, when a sodium leak occurs in a liquid sodium circuit. The combustion rate of liquid sodium in air is directly related to the interfacial surface area that is developed between the liquid sodium spray and the air atmosphere. The description of the liquid sodium fragmentation during the spray expansion, is then a topic of major interest since it should be used as an input data for the simulation of sodium combustion and its consequences.

Modeling of sodium spray fires is based either on the assumption of initial size distribution of the sodium droplets, or on empirical correlations defined from experimental measurements used for the determination of combustion rate values (which is the approach of calculation tools used by CEA up to now).Nevertheless, the fragmentation of liquid sodium spray depends on ejection conditions of the leak scenario, and in the case of a very large breach (such as a cross break of secondary circuit in a SFR) only a reduced fraction of the liquid leak is fragmented into droplets. The dependence of liquid sodium fragmentation rate has to be studied in function of ejection conditions such as sodium velocity and mass flowrate, shape and cross section of the breach, and inclination of sodium ejection.

The modeling development started at CEA is based on a semi-empirical approach:

- first atomization should be simulated by an empirical description established from experimental tests that will be performed at CEA (Cadarache) with water as a model liquid in a wide range of ejection flowrates (from small values ≈5 m^3/h to high values up to 300 m^3/h). The transposition to liquid sodium behavior will be obtained by a similitude approach but will need experimental validation by characterization of sodium spray fragmentation at lower flowrates compatible with IGCAR facilities.
- Secondary atomization will be described by a physical model implemented in a CFD calculation tool and will need also experimental validation with sodium tests.

The aim of experimental tests will be, for each ejection condition, to characterize the velocity and the size distribution of liquid droplets and their evolution along the spray trajectory. The similitude transposition between water and sodium behavior is defined by non-dimensional criteria such as liquid Weber number, Ohnesorge number and Froude number, and experiment conditions will be chosen to settle common values for these criteria and for both liquids, in the range that will be studied with sodium (and compatible with IGCAR facility)

2. Objectives of the collaboration

The aim of the collaboration will be to perform a program of experimental tests of sodium spray characterization in order to validate the similitude transposition of water sprays experiments to sodium behavior, and consequently the extrapolation of fragmentation

modelling in conditions of larger leak flowrates. Two groups of experiments will be performed: a first group under inert atmosphere without combustion, a second group in air atmosphere and with sodium combustion.

For inert atmosphere study, experiments could be performed in MINA facility (140 m^3) if a gastight confinement is adapted for inert gas conditioning, and also in SOCA facility (21 m^3) in which inert gas conditioning should be possible without any adaptation..

The conditions of potential tests to be performed in IGCAR will be adapted to SOCA and MINA capacity (regarding temperature and overpressure limitations), this is why a 10 kg maximal amount of sodium ejected during the experiment will be respected. Nevertheless, in the case of inert atmosphere condition, it should be discussed whether it could be raised to a higher level (without temperature and pressure increase due to combustion).

The tests in inert conditions are necessary since they will give characterization results much more easily than sodium fire tests in air atmosphere (due to combustion, droplet characterization will be more difficult with fire lightening and sodium fire aerosols in suspension). This why the tests in inert conditions should be performed in a range of flowrates conditions covering at least lower values to be comparable with sodium fire tests in air. Consequently, in coherence with similitude analysis and water spray experiments, it will be mandatory to study at least sodium flowrates between 0,1 and 1 kg/s for comparative experiments in inert and in air atmosphere. In this range of sodium flowrates the similitude approach with water experiments (that should be performed in Cadarache at the beginning of 2018) requires to use a nozzle diameter around 2 cm for the sodium ejection. Moreover, it would be useful to study the opportunity to explore higher flowrate conditions with higher diameter in inert atmosphere, typically up to 5 kg/s for the sodium flowrate with a 5 cm nozzle diameter. In order to respect the security constraints of MINA or SOCA facility, the sodium ejection duration should be limited: 10 s can be considered for a preliminary sizing of experiments.

The inclination of the ejection nozzle should be adapted to the capacity design (MINA and/or SOCA) in particular to avoid spray impact on lateral walls. In any case a special ejectionsystem (nozzle + sodium supply piping) should be adapted to the experiments needs in the test facility.

The characterization technique based on the "shadowgraphy" principle will be adjusted at first on water sprays experiments in Cadarache. Its transposition to sodium droplet observation will have to be defined and precised using experimental feedback from water sprays studies. It will be important to check the technical feasibility of sodium droplets characterization with enough precision, comparable to water sprays experiments. In particular this feasibility has to be confirmed for air experiments, depending on the behaviour in the very first times of the combustion before the development of flame and aerosols screen which are detrimental to sodium droplets visualization. As far as possible, the high-speed video camera and the high intensity back lightening should be placed outside the test chamber in order to prevent from sodium projections and from equipment degradation. If it is not the case, protective

disposition should be studied for the characterization equipment that would be provided by CEA. The definition of this equipment integration in SOCA our MINA facility will have to be defined at the beginning of the collaborative study.

In a second time, the results of this experimental study would be used for the validation of a semi-empirical modeling of sodium spray fragmentation developed at CEA and scientific exchange could be carried out with IGCAR on the development of this calculation tool.

3. Scope of the collaboration

This collaboration should progress in 4 steps.

Step 1: Definition of technical options of experiments

First of all, a kick-off meeting in presence of technical actors who will be involved in the preparation and in the conduction of experiments will give the opportunity to present the objectives of the experiments and the technical options and conception intended for the integration of characterization equipment (in particular the high-speed video camera and the high intensity back lightening). The range of experimental conditions will be discussed and confirmed in order to match the security requirements and limitations associated to the facility that will be selected (MINA and / or SOCA).

The analysis of all these data and parameters, the technical adaptations potentially required for the equipment integration (positions, protections), and the conception constraints for experimental tests will be defined. The technical feasibility of the experiments will be confirmed after this analysis.

Step 2: Confirmation of conditions range and experimental program

The results of water spray experiments will be used to confirm the prediction of droplets sizes and the adaptation of characterization conditions to be extrapolated to tests in sodium. The analysis of water tests feedback will also be used for the confirmation of similitude analysis.

The definition of experimental program will be done with its scheduling (planning).

Step 3: Tests of sodium sprays

The adaptations for the equipment integration in the facility will be prepared at IGCAR and the characterization equipment (especially video camera and backlight system) will be provided from France by CEA.

After preliminary tests to check the behaviour of the Na facility and its instrumentation, the first part of the program with tests of sodium sprays in inert atmosphere will be performed and the post treatment of video recorded images will be initiated after the first test in order to check the settlings of optical measurement conditions and the correct viewing of sodium droplets (contrast, exposition, frequency, size of image field…). Once the settlings confirmed, the other experimental conditions will be tested.

Then the second part of the program with tests of sodium sprays in air atmosphere (with combustion) will be performed in the same way. In particular the possibility to distinguish the droplet contours on video recordings will be checked for the first test and at the very first instants of the spray development, before combustion initiation and important aerosols emission.

An experimental report will be produced in order to describe the evolution of sodium fragmentation in function of the different ejection conditions and also the evolution of pressure and temperatures that will be also measured during each experiment. A comparison will be made between inert and air conditions in order to characterize the coupling of combustion with fragmentation.

Step 4: Comparison and validation of sodium fragmentation modeling

In a final step, these experimental results will be used for comparison with the prediction of fragmentation modeling developed at CEA in order to complete its validation for the description of sodium spray fragmentation, in complement of the confrontation of the simulation with water spray tests performed preliminary at CEA. The validation of similitude approach will be checked in order to justify the possible extrapolation of modeling to higher leak flowrates for sodium in similitude with the higher flowrates investigated with water sprays. After a meeting to review experimental and modelling results, a common report will be produced and future perspectives will be discussed between CEA and IGCAR.

4. Milestones and deliverables

N°	Milestones and deliverables	Date	Organization
D1	Definition of technical options of experiments (minutes of the kick-off meeting)	T0 + 6 months	CEA
D2	Confirmation of conditions range and experimental program	T0 + 9months	IGCAR-CEA
M1	Preliminary tests in IGCAR facilities	T0 + 15 months	IGCAR
M2	Presentation of tests carried out with water	T0 + 15 months	CEA
D3	Presentation of CEA models describing liquid fragmentation	T0 + 18 months	CEA
M3	Experimental Tests of sodium sprays at IGCARin inert conditions and in air with combustion	T0 + 21 months	IGCAR
D4	Synthesis report of experiments in inert conditions and in air with combustion and scientific analysis	T0 + 24 months	IGCAR
M4	Validation of sodium fragmentation modelling with experimental results	T0 + 33 months	CEA
M5	Technical Meeting to review modelling results	T0 + 40 months	CEA & IGCAR
D5	Common synthesis report	T0 + 48months	CEA & IGCAR

**T0: date of entry into force of this Implementing Agreement*