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SUMMARY OF PROPOSAL FOR PUBLIC RELEASE (Use plain language.)
This plain language summary will be available to the public if your proposal is funded. Although it is not mandatory, you may choose to include your business telephone number and/or your e-mail address to facilitate contact with the public and the media about your research.

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Small modular reactors (SMR) feature unusual fuel compositions (e.g. plutonium, enriched uranium, reprocessed spent fuel), new physical fuel forms (hexagonal lattices, molten salts, TRISO particles, etc.) and different neutron energies in the core (fast spectra in Advanced Reactor Concept (ARC-100) and some molten salt reactors). A consequence of these differences is that unusual nuclear material accountancy is expected so that resulting spent fuel from SMR is expected to be very different when compared with spent fuel from Canada Deuterium Uranium (CANDU) reactors.
Over the last 40 years, Polytechnique Montréal has developed the computer codes DRAGON5 (lattice code) and DONJON5 (full-core simulation code) for deterministic nuclear reactor physics simulations.
This research proposal consists in extending and applying DRAGON5 and DONJON5 to new reactor physics applications specific to SMR. Specific contributions are expected:
(1) Gather information related to geometries, materials and operational data used in selected SMR concepts (sodium fast reactor,
high temperature fast reactor and molten salt reactor);
(2) Adapt the resonance self-shielding methodology in DRAGON5 to the specific SMR fuel (molten salt, TRISO particles, etc.);
(3) Apply the Bateman solver in DRAGON5 and DONJON5 to SMR fuel;
(4) Include SMR characteristics in the CLASS (Core Library for Advanced Simulation Scenarios) scenario simulator.
CLASS is a dynamic fuel cycle simulation code based on neural networks that can use DRAGON5/DONJON5 reactor models to produce nuclear data and physical quantities. CLASS allows the analysis of complex nuclear power plants and of their constituting components.

Other Language Version of Summary (optional).

Les petits réacteurs modulaires (PRM) présentent des compositions de combustible inhabituelles (par exemple, plutonium, uranium enrichi, combustible usé retraité), de nouvelles formes physiques de combustible (réseaux hexagonaux, sels fondus, particules TRISO, etc.) et différentes énergies neutroniques dans le coeur (spectres rapides avec le ARC-100 et les réacteurs à sels fondus). Le combustible usé résultant des PRM devrait être très différent de celui du combustible usé des réacteurs CANDU.
Au cours des 40 dernières années, Polytechnique Montréal a développé les codes de calcul DRAGON5 (code de réseau) et DONJON5 (code de simulation coeur-entier) pour effectuer des simulations déterministes en physique des réacteurs nucléaires.
Cette proposition de recherche consiste à étendre et appliquer DRAGON5 et DONJON5 à de nouvelles situations en physique des réacteurs, spécifiques à celles liées au PRM. Ces contributions sont:
(1) Recueillir des informations relatives aux géométries, matériaux et données de fonctionnement utilisés dans les concepts PRM sélectionnés (réacteur rapide à sodium, réacteur haute-température à gaz et réacteur à sels fondus);
(2) Adaptation de la méthodologie d'autoprotection des résonances dans DRAGON5 au combustible PRM spécifique (sel fondu, particules TRISO, etc.);
(3) Application du solveur de Bateman dans DRAGON5 et DONJON5 au cas particulier du combustible PRM;
(4) Inclure les caractéristiques PRM dans le simulateur de scénarios CLASS. CLASS permet l'analyse de parcs électronucléaires complexes et des unités les composant.
Les bénéfices combinés de ces recherches permettront d'optimiser le déploiement des PRM afin de minimiser les risques radiologiques, de réduire les problèmes de prolifération, d'évaluer les capacités de retraitement et de mieux comprendre l'issue d'un accident.

A. RESEARCH TEAM

- List the applicant, any co-applicants and key staff from any of the partner organizations.
- Explain how the knowledge, experience and achievements of each member of the research team provides the breadth and complementarity of expertise needed to accomplish the project objectives.
- Discuss the role of each individual and how their contributions will be integrated into the project.

- The research team includes the applicant and co-applicant (Alain Hébert and Guy Marleau), two external collaborators from University Grenoble-Alpes (Xavier Doligez and Adrien Bidaud) three M.Sc.A students (I. Trancart, is already involved in a sub-project related to molten salt reactors) and three Ph.D. students.
- Knowledge, experience and achievements of the (co)applicants and of the external collaborators are described below.
- Alain Hebert R&D focuses on lattice calculations, including resonance self-shielding models, and on full core simulation tools. He will be the academic director of all graduate students and closely supervise subproject B.4 on the application of resonance self-shielding methodologies to innovative SMR designs and of subproject B.5 on the application of the Bateman equation. Guy Marleau is involved with supervision of the three M.Sc.A. students (I. Trancart and the students assigned to subprojects B.1 and B.2) and with the supervision of subproject B.3 related to the CLASS scenario simulator. He manage communications with University Grenoble-Alpes on this subject. The two external collaborators are the authors of the CLASS scenario simulator and will play a software integration role.

A.1 Alain Hébert

Alain Hébert is a full professor at Polytechnique Montréal since January 1981. His career is devoted to mechanical statistics of elementary particles and nuclear reactor physics. His actual field of investigation is twofold: (1) Development of innovative computational techniques in nuclear reactor physics and, (2) the application of statistical mechanics to radiation treatment planning (RTP). Recently, he proposed an application of the legacy approach of nuclear reactor physics to medical applications such as radiation oncology and medical imaging. Alain Hébert will be the main director of every student involved in the Alliance project, with Prof. Guy Marleau as co-director. He will closely supervise subproject B.4, as resonance self-shielding methodologies is one of his legacy research subject. His main past contributions are:

A.1.1 Applied Reactor Physics

Applied Reactor Physics[1.1] is a textbook provided as support to graduate-level students at the Institut de génie nucléaire (IGN), introducing state-of-the-art approaches. Applied Reactor Physics is currently the only available textbook at graduate level that supports modern computational schemes used in industry. Starting in September 2010, the Massachusetts Institute of Technology is using it as main textbook for graduate students in Nuclear Science and Engineering.

A.1.2 The Version5 computer code distribution

Version5 (V5) is a recent distribution of the reactor physics codes developed at Polytechnique Montréal. This distribution contains a consistent collection of computer codes: DRAGON5 (lattice calculation), TRIVAC5 (full-core calculation) and DONJON5 (operation simulation).[1.2, 1.3] V5 components are released under the Lesser General Public License (LGPL) and are been used by tens of organizations across the world.

Many reviewed scientific contributions are related to components of V5 distribution.

1. Njoy-related cross section generation in Ref. [1.4] . This paper presents the new SHEM-361 energy mesh and the PyNjoy Draglib production system based on Njoy-2012.

2. Advanced resonance self-shielding in DRAGON5 using the subgroup equations. One important improvement in DRAGON5, as compared to DRAGON3, is the availability of a new approach, referred as the Subgroup Projection Method (SPM) is based on CALENDF probability tables and SHEM–295 (or SHEM–361) energy mesh. The SPM was introduced in DRAGON4 and further extended in DRAGON5 (see Refs. [1.5] and [1.6]).

3. A preliminary implementation of the method of characteristics (MOC) is available in DRAGON3, but has been enhanced in DRAGON4 and DRAGON5. It now features synthetic acceleration based on the algebraic collapsing method, improved quadratures and better integration with the other capabilities of the code. These contributions are presented in Refs. [1.7], [1.8] and [1.9].

4. The discrete ordinates method (S_N) is a legacy solution technique of the Boltzmann transport equation. The S_N method has been first implemented for solving 1D/2D/3D problems in Cartesian geometry and was further extended with the introduction of Discontinuous Galarkin discretizations and the generalization to hexagonal geometries (see Refs. [1.13], [1.14] to [1.16]).

5. The superhomogénéisation (SPH) method was generalized to non-fundamental mode conditions as presented in Refs. [1.12] and [1.11].

6. More specialized contributions to DRAGON5, DONJON5 and NJOY-2016 are reported in Refs. [1.19] to [1.22].

A.2 Guy Marleau

Guy Marleau is an expert on transport theory and reactor physics. He has been involved in the development and qualification of the code DRAGON since 1986. He has used codes such as DRAGON, DONJON, SERPENT and MCNP to model all types of power and small reactors including Canada Deuterium Uranium (CANDU), Pressurized Water Reactors (PWR), High Temperature Reactors (HTR), and two small reactors: ZED-2 and the SLOWPOKE-2. Moreover, along the years he has been involved in more remote projects such as 1) simulating and characterizing neutron detectors, 2) using charge transfer devices for muon detection (both in collaboration with CNL), and 3) characterizing the source term from CANDU reactors for a mobile nuclear laboratory of Health Canada. Starting in 2017, he has established a collaboration with the CLASS code developers from the IN2P3-CNRS research centre in Orsay, France leading to the coupling CLASS to DRAGON and DONJON for scenario analysis of PWR reactor fleet. This team is now in the process of adding to this fleet small PWRs.

Guy Marleau will act as co-director on many subprojects, including the supervision of the Ph. D. sub-project B.3 related to the CLASS scenario simulation package.

A.3 External collaborators

Two external collaborators from the University Grenoble-Alpes (IN2P3-CNRS research centre) will contribute to our projects. Among these, Xavier Doligez, a developer of the code CLASS has been involved in scenario studies for over 10 years, both for PWR studies and on recycling irradiated fuels in CANDUs. A second collaborator to the team is Adrien Bidaud, also a contributor to CLASS, that has recently been working on generalized perturbation theory in Monte Carlo neutron simulations for application to resonance parameters studies, PWR scenario with multiple recycling studies in CLASS as well as waste minimization in sodium-cooled fast reactors and thorium nuclear data for molten salt reactors.

B. RESEARCH PROPOSAL

- Describe your project and how it addresses one or more of the research challenges listed in the NSERC-CNSC Small Modular Reactors Research Grant Initiative.
- Outline the research objectives and describe the proposed activities. Include a detailed work plan, with milestones and deliverables, and provide approximate timelines for the proposed activities. You may use a Gantt chart, table or diagram.
- Describe how the project will be managed.

Nuclear reactor technologies are very serious options for energy production with low greenhouse gas (GHG) emissions and a reduced dependence on fossil fuels in the long term. Nuclear energy is characterized by extremely low lifetime GHG emission and very high capacity factor, especially when compared to other low-emission energy sources. The future of nuclear energy is, in part, related to the successful design of innovative reactor technologies. Canada's Small Modular Reactor (SMR) Action Plan is devoted to the development, demonstration and deployment of SMRs for multiple applications at home and abroad. This research proposal focuses on the simulation of three innovative types of SMR:

1. **The ARC-100 concept:** This is a modest scale up (5X) of the successfully operated (until mid 90's) EBR- II, a 100-MWe sodium fast reactor (SFR) featuring sodium coolant and metal fuel assemblies. Two specific types of fuel are investigated: enriched uranium and reprocessed mixed metal fuel.

2. **The MMR-5 and MMR-10 HTGR concept:** This is a high temperature gas reactor (HTGR) with fully ceramic micro-encapsulated (FCM) fuel that provides inherent reactor safety by being an ultimately safe fuel. Industry standard TRISO particles, which contain the radioactive byproducts of fission within layered ceramic coatings, are encased within a fully dense silicon carbide matrix.

3. **The Stable Salt Reactor concept from Moltex energy:** The molten salt reactor (MSR) is a fast reactor that uses recycled nuclear waste as fuel. This is a class of nuclear fission reactor in which the primary nuclear reactor coolant and/or the fuel is a molten salt mixture. A M.Sc.A. project is currently under way at Polytechnique Montreal to gather information about this reactor concept.[2.1]

Small modular reactors (SMR) feature unusual fuel compositions (e.g. plutonium, enriched uranium, reprocessed spent fuel), new physical fuel forms (hexagonal lattices, molten salts, TRISO particles, etc.) and different neutron energies in the core (fast spectra in ARC and some molten salt reactors). As a consequence of these differences, SMR nuclear material accountancy for spent fuel is expected to be very different from CANDU reactors. The proposed research proposal consists in extending and applying DRAGON5 and DONJON5 to new reactor physics applications specifically those related to SMR. **The combined benefits of this research will enable the optimization of the SMR deployment so as to minimize radiological risks, to reduce proliferation issues, to evaluate reprocessing capabilities and to better understand the outcome of an accident**.

Better support of SMRs requires advances on selected subjects, identified as B.1 to B.5. A Gantt diagram is presented in Fig. 1 for a 72-months R&D plan. Deliverables are of two types: (1) Commits of SMR-specific code extensions in DRAGON5 and DONJON5 (under strict quality assurance practices), and (2) technical reports, conference papers, articles and thesis defended according to the rules of Polytechnique Montréal. Note that the overall project length (72-months) is longer than the requested 3-year funding (36-months).

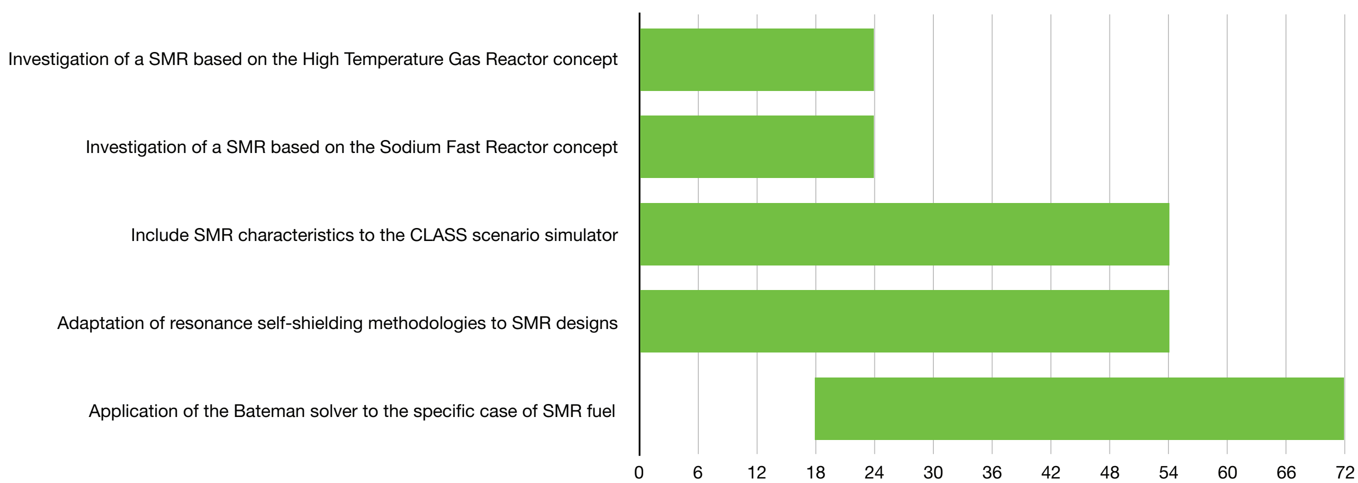

Figure 1: Gantt diagram (in months)

Modifications will be implemented in the latest release of the DRAGON and DONJON codes. From a coding point of view, DRAGON and DONJON are a unique and integrated software. Any solution technique can be used in both codes. Techniques based on the Method of Characteristics (MOC) are recommended for lattice calculation and the discrete ordinates (SN) technique or diffusion solvers are recommended for full-core simulations. However, this rule is not imposed by the code architecture.

The validation approach consists to assess the accuracy of the deterministic solutions in DRAGON5 and DONJON5 with respect to Monte Carlo solutions such as those obtained with SERPENT2.[2.5] Such Monte Carlo solutions are currently used for developing SMR concepts, but cannot be used for scenario studies over decades due to CPU-cost issues. Scenario studies must rely on deterministic solutions.

B.1 Investigation of a SMR based on the High Temperature Gas Reactor concept (M.Sc.A. 1)

The first need consists to gather information about SMR characteristics: Geometries, materials, operation data, etc. and to identify development requirements related to each of the three SMR concepts under investigation. A first M. Sc. A. sub-project, not funded by this Alliance project, is currently underway for understanding Moltex types of reactors.[2.1] The Moltex sub-project is nevertheless required by this Alliance proposal. The first sub-project focuses on the high temperature gas reactor (HTGR) where the fuel specificities should be addressed. A few specific developments are already available in DRAGON5 as a result of a past collaboration with the Institute of Nuclear and New Energy Technology (INET) in China.[3.1]. These developments were never used for in-house studies and remain to be validated by the DRAGON team. A list of HTGR-related development requirements is expected as a result of the validation exercise proposed in this sub-project.

B.2 Investigation of a SMR based on the Sodium Fast Reactor concept (M.Sc.A. 2)

The second sub-project focuses on the sodium fast reactor (SFR) where the fuel specificities should be addressed. Polytechnique Montréal has already made some contributions related to the ASTRID project in France.[4.1] In the context of this Alliance project, we will gather engineering data related to the ARC-100 reactor and perform related validation with respect to the Monte Carlo solution. The ASTRID reactor used Mixed Oxyde (MOX) fuel, whereas the ARC-100 uses metallic Uranium or Plutonium-Uranium metal fuel.

B.3 lnclude SMR characteristics to the CLASS scenario simulator (Ph.D. 1)

CLASS is a dynamic fuel cycle simulation code that uses DRAGON5 and DONJON5 reactor simulations with neural networks to analyse complex nuclear power plant operations from fuel fabrication to long- term storage or recycling of spent fuel elements. CLASS is an open source package of C++ libraries that performs simulations of entire fuel cycles based on several facilities: reactors, cooling pools, fabrication plants, storage and separation plants. It contains a fuel loading model that is used to fabricate fresh fuel from fissile materials. Reactors are simulated through two independent steps: fuel loading followed by irradiation. In conventional CLASS Pressurized Water Reactor (PWR) calculations, reactors are simulated by MLP (Multi Layer Perceptrons) predictors trained on databases generated by DRAGON (or any other cell code) for fresh fuel discharged after its irradiation cycle is completed. For these neural networks based approaches, no environment is taken into account. In the last five years, we have coupled CLASS and DONJON5 to perform nuclear scenario simulations involving Uranium Oxyde (UOX) and Mixed Oxyde (MOX) PWR core at equilibrium cycle conditions and we are in the process of modelling PWR based SMR. We now propose to extend this method to a combination of CANDU and MSR reactors.

The methodology at the core of this Ph.D. project is based on the following steps:

1. Build and validate DRAGON5 and DONJON5 reference models for the CANDU and Moltex MSR reactor design.

2. Generate with DRAGON5 the databases required for DONJON5 and CLASS executions.

3. Use CLASS to predict CANDU and MSR spent fuel compositions for definitive storage or after the fuel seperation plant using standard PWR fuel reprocessing options.

4. Validate and correct the CLASS models if required.

5. Propose an equilibrium scenario for using reprocessed CANDU fuel in Moltex MSR (number of CANDU per MSR) and evaluate quantity of fission products to vitrify after passing through reprocessing plant as well as the isotopic contents of the final wastes.

B.4 Adaptation of resonance self-shielding methodologies to innovative SMR designs (Ph.D. 2)

The accuracy of deterministic solutions of the neutron transport equation is strongly impacted by the quality of the resonance self-shielding method used to produce multigroup cross sections. All three types of SMR concepts bring challenges on resonance self-shielding implementations:

- A SFR deterministic solution is known to require more energy groups than a solution related to a thermalized neutron spectrum. For example, an ASTRID simulation uses 1961 energy groups at the lattice level and 35 energy groups for the full-core calculation.[4.1] The recommended self-shielding methodology for such reactor is the Tone method.[6.1, 6.2]

- The HTGR features a fuel matrix containing TRISO particles. DRAGON5 features three double-heterogeneity models adapted to perform resonance self-shielding and neutron flux calculations.[6.3, 6.4, 6.5] The geometry of these particles strongly impact the accuracy of the resonance self-shielding model. Recently, we made recommendations to the INET Institute in China to address this issue.[3.1]

- The Moltex fuel is characterized by a mixture of various isotopes and a fast neutron spectrum. Actually, most studies are based on Monte Carlo simulations, but operation, safety and scenario studies require a faster deterministic (and multigroup) approach.

The methodology at the core of this Ph.D. sub-project is based on a two-step validation process. For each type of reactor lattice,

1. Perform a reference Monte Carlo calculation based on Serpent2.[2.5]

2. Perform a self-shielding calculation in DRAGON5 based on ultra-fine multigroup data available in Draglib5 cross-section files.[6.6]

3. Perform a self-shielding calculation in DRAGON5 based on probability tables or based on the Tone method.[1.1, 6.2]

B.5 Application of the Bateman solver to the specific SMR fuels (Ph.D. 3)

Design of SMR concepts requires the careful evaluation of isotopic contents of fuels to minimize radiological risks, to reduce proliferation issues, to evaluate reprocessing capabilities and to better understand the outcome of an accident. For example, safety studies requires the knowledge of the source term, an evaluation of potential radioactive release in accidental cases.

This Ph.D. sub-project consists to make an accurate evaluation of the isotopic content in the full-core. Such evaluation is performed in the DRAGON5-DONJON5 platform, based on a solution algorithm of the Bateman equation. Typically, DRAGON5 solves the Bateman equations for all depleting isotopes included in the geometry definition. DONJON5 performs a micro-depletion solution of the same Bateman equations, but only for the isotopes under investigation. Finally, a software validation can be performed with the SERPENT2 Monte Carlo code, thanks to its integrated Bateman solver.

The target of this Ph.D. subproject is to construct computational schemes based on DRAGON5 and DONJON5 codes, to perform SERPENT2 validation, and to collaborate with the graduate student in charge of scenario simulations with CLASS.

C. RELEVANCE

- Describe how your research will generate new knowledge and scientific information to support government decision-making and regulatory oversight of SMRs.
- Describe the importance of the research results to Canada and the potential economic, environmental, and/or social benefits.
- Describe how the project will enhance the research capabilities at your institution.

Deterministic simulations in neutronics are based on two software components, one dedicated to the unit fuel assembly and the other dedicated to the full-core.[1.1] The more complex one is the lattice code based on a solution of the Boltzmann equation for neutrons. It is used for criticality safety and for reactor physics applications by feeding the full-core simulation code with multi-parameter databases. Over the last 40 years, Polytechnique Montréal has developed the lattice code DRAGON, now at V5, and a 3D full-core simulation code named DONJON based on a solution of the diffusion equation.[1.2] These two codes are widely distributed across the world under an open-source license and are used by many universities, safety organizations and as a fast prototyping tool by Framatome in France.[2.3]

- This Alliance project will generate new knowledge and scientific information to support government decision-making and regulatory oversight of SMRs. DRAGON and DONJON are important and unique components required to support safety assessment of CANDU reactors. The DRAGON3 code is a Industrial Standard Toolset (IST) component used in all safety analyses of CANDU reactors for computing incremental cross sections associated with reactivity devices. The Version5 distribution of DRAGON and DONJON (V5) is currently used by various universities and organizations across the world as reliable and professional software. V5 is considered by the *Candu Owner's group* (COG) as the next-generation lattice code and full-core simulation tool for CANDU support in the 2030–2060 timeframe. Initially, V5 will be used for safety assessment of CANDU reactors. However, the V5 codes have capabilities far beyond the simulation of CANDU reactors and COG plans to use it in a more general context. Recently, codes DRAGON5 and DONJON5 were used as fast prototyping tools to investigate heavy reflector issues in the Evolutionary Power Reactor (EPR) at Framatome, France.[2.2, 2.3] Consulting firms in Canada, such as Worley Parson, Kinectrics and SNC-Lavalin, are supporting V5 as next generation codes for future safety studies. Our proposal is to extend the applicability of V5 to SMRs.

- The importance of the research results to Canada and the potential economic, environmental, and/or social benefits are related to the success of future SMR projects. Our target is to provide software support, in the field of reactor physics, to any new project related to SMRs. We plan to provide the same level of support to SMR projects in Canada as we provide to CANDU reactors.

- Important advances in reactor lattice and full-core calculations related to the DRAGON/DONJON codes have been achieved, thanks to previous five NSERC/DG grants, the latter from April 2021 to April 2026. V5 is the available distribution in 2022 with important software upgrade and with the implementation of many NSERC/DG achievements. These contributions are made available to the scientific community through international database centers (RSICC in Oak Ridge and the NEA Data Bank in Paris) and on an open-source website (http://merlin.polymtl.ca/). Universities and safety organizations such as COG, IRSN and Framatome are becoming expert users of V5 codes and are currently developing complex computational schemes in the CLE-2000 script language available with these codes. However, they don't have the intent or the opportunity to upgrade the basic solution algorithms available in DRAGON.[1.2] Capability to develop, correct and maintain DRAGON and DONJON is presently available only at Polytechnique Montréal. The long-term objective is to provide software tools and computational schemes to the nuclear industry that will enable them to assess the performance and safety characteristics of existing and innovative types of nuclear reactors, including SMR and to train Highly Qualified Personal (HQP) so as to contribute to these codes in a Canadian context.

D. KNOWLEDGE MOBILIZATION

- Describe the knowledge mobilization plan. Explain how the research team will collaborate with knowledge users (e.g., government policy makers, local communities) to support policy-and decision-making related to the implementation of SMR technology in Canada
- Describe the team's past track record of transferring research results to a user sector.
- Include a data management plan, if applicable.

- The research team at IGN will collaborate with many actors related to code distribution, reactor physics in general and SMR specialists in particular:

1. We already are in relation with the Nuclear Data Bank (NDB) of the Organisation for Economic Co-operation and Development (OECD) in order to integrate V5 in their GetLab platform and to distribute V5 across the world.

2. We already are in relation with three Consulting firms (Worley Parson, Kinectrics and SNC-Lavalin) so as to provide support and to adapt V5 for CANDU reactors. We plan to extend this support to ACRs.

3. We plan to contact the vendors of the three SMR concepts selected in this Alliance proposal so as to gather reactor characteristics required to our simulations.

- In the past, we collaborated with industrial organizations such as national laboratories (Atomic Energy of CanadaLimited – AECL, Commissariat l'énergie Atomique – CEA, Idaho National Laboratory – INL), industries (Candu Owners Group–COG, Framatome, Électricité de France) and safety organizations (Institut de Radioprotection et de Sûreté Nucléaire – IRSN, Gesellschaft für Anlagenund Reaktorsicherheit – GRS). Most of our graduate students are performing 6 to 8 month internships in these organizations, working on their dissertation or thesis subject in an industrial environment. Advances made with the help of this Alliance proposal are therefore subjects of interest for the industry and training gained by the students is well-suited to fit industrial needs. The internship is covered by an Internship Agreement between Polytechnique Montréal and the organization. During the past six years, I personnaly trained more than 6 M.Ing. students, 17 M.Sc.A. students and 6 Ph.D. students. All our graduate students are involved in the use and/or development of the DRAGON and DONJON codes, bringing this knowledge towards the industry.

- Data management is performed under rigorous quality assurance (QA). V5 codes are maintained and developed using three QA practices: (1) source management under GitLab, (2) development-based issue tracking, and (3) continuous integration. Our implementation is Open Source and we strongly adhere to the FARE principles. The FAIR Data Principles (Findable, Accessible, Interoperable, and Reusable), published in Scientific Data in 2016, are a set of guiding principles proposed by a consortium of scientists and organizations to support the reusability of digital assets.

E. TRAINING PLAN

- Describe how the knowledge and experience gained by research trainees (undergraduates, graduates, and postdoctoral fellows) will contribute to increasing research capacity in the field.
- Describe any opportunities for enriched training experiences that will allow research trainees to develop relevant technical and professional skills (e.g., leadership, communication, collaboration and entrepreneurship).
- Explain how equity, diversity and inclusion are considered in the training plan.

- The knowledge and experience gained by the graduate students involved in this Alliance project will contribute to increasing research capacity in the field. It is our policy to pursue our research activities in close relationship with industrial partners. We provide specific training related to use, support and development/modification of DRAGON and DONJON codes. These codes are actually the only option available in Canada for supporting future needs in reactor physics. Other Canadian university use these codes, but Polytechnique Montréal is the only university in charge of continuous integration of new developments.

- This Alliance proposal will contribute to the training of two additional very qualified M.Sc.A. and three additional Ph.D. nuclear engineers will be trained and become available to the CNSC and the nuclear industry in Canada. Improving simulation tools is important for developing and implementing innovative SMR concepts. The nuclear industry is developing tools and capabilities to perform deterministic computations for the three final objectives in support to safety assessment: criticality studies, core simulation in normal operation and production of macroscopic cross-section libraries for multi-physics tools that are used in accident simulations. Scenario simulations based on neural networks will permit an optimal deployment of full-scale and SMR plants so as to manage uranium resources, reduce wastes and proliferation. The overall improvement in these simulation tools will provide a better understanding of the operation and of safety characteristics of nuclear reactors.

- In our groups, and in this collaboration, respect and communication are priorities and everyone involved has the right to express their opinions and live according to their cultures. Based on our institutional principles, we have established the 3 priorities in our collaboration with regards to EDI: 1) Recognize the importance of diversity within the collaboration. Our team combines various expertise: physics, engineering, and medicine. We insist that each professor be an example of inclusion for students in training to follow. 2) Correct inequalities. In order to give an equal opportunity to all students, whatever their identity, we need to enhance diversity in the composition of the HQP involved in the project, through open hiring policies and inclusive practices. 3) Respect the identity of each individual. Each member of our collaboration is invited to live openly and to respect others. We expect to accentuate the presence of HQP with non-traditional backgrounds. We support the retention and success of students with academic or personal vulnerability factors or belonging to underrepresented groups. Each of our areas of expertise has its own set of specific challenges. Under-represented groups face a variety of well-documented challenges, including stereotypes, unconscious biases, limited role models and mentoring, unfair recruiting, as well as bias in grants, awards, and speaker invitations. In particular, physics and engineering experience an under-representation of women at all university levels. Our challenge is therefore to help change this portrait. The Institut de Génie Nucléaire (IGN) features a diverse class of students (including females and visible minorities). We intend to maintain such a performance by continuing our dedicated efforts. Seamless integration is difficult for international students which face challenges like cold weather and difficulties with the English or French languages. We pair new international students with another international student in the IGN before arriving into our city to discuss integration strategies. Team members follow published best practices for hiring and retention. Trainees are recruited at different levels and programs for greater diversity. Presentations to various groups ensure visibility for these models and links to potential recruits.

F. REFERENCES

F.1 Alain Hebert specific contributions

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