**Proceedings of the INMM & ESARDA Joint Annual Meeting**
**22-26 May 2023**
**Abstract #347**

# NUCLEAR FUEL CYCLE-RELATED RESEARCH AND DEVELOPMENT UNDER THE ADDITIONAL PROTOCOL: AUSTRALIAN PERSPECTIVES

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## ABSTRACT

The combination of a comprehensive safeguards agreement (CSA) and an additional protocol (AP) equips the IAEA with the tools to develop a complete picture of a state's nuclear activities, ensuring a high standard of verification and providing confidence to the international community that non-proliferation commitments are being honoured. State regulatory authorities are required to declare nuclear fuel cycle-related research and development (NFC R&D) activities under articles 2.a.(i), 2.a.(x) and 2.b.(i) of the AP. This presents challenges because NFC R&D may not involve nuclear material, nuclear facilities, or even regulated equipment. How can an SRA in a state with a large and diverse research community identify and declare all NFC R&D activities? Drawing on Australia's 25 years of experience in implementing the AP, this paper will describe the approach taken by the Australian Safeguards and Non-Proliferation Office (ASNO) to declaring NFC R&D activities in Australia, including engagement with universities and research institutions, notification arrangements with relevant government agencies, and open source searches. By performing broad searches annually, using a spreadsheet to track patterns in institutions' publications and patents, and asking targeted questions of researchers, a state regulatory authority can build up a complete picture of existing NFC R&D activities and identify new NFC R&D activities as they emerge. In doing so, the state regulatory authority must overcome obstacles to communication with a diverse research community, including managing differences in the use of terminology. Maintaining a comprehensive picture of NFC R&D across the public and private sectors also has flow-on benefits for domestic regulation, providing an avenue to raise awareness among universities, research institutions and private companies about the requirement to apply for permits, if they wish to acquire nuclear material or export controlled goods as their research progresses.

## INTRODUCTION

The combination of a comprehensive safeguards agreement (CSA) and an additional protocol (AP) equips the IAEA with the tools to develop a complete picture of a state's nuclear activities, ensuring a high standard of verification and providing confidence to the international community that non-proliferation commitments are being honoured. This paper explains the rationale for including obligations to declare nuclear fuel cycle-related research and development (NFC R&D) activities under the AP. It analyses some of the challenges that state (or regional) regulatory authorities for safeguards implementation (SRAs) may face in ensuring that the state's obligation to declare NFC-related R&D activities is met consistently and comprehensively.

As the SRA for Australia, the Australian Safeguards and Non-Proliferation Office (ASNO) has 25 years of experience implementing the AP in a state with a wide variety of nuclear-related research activities of high technical complexity. ASNO is also Australia's national authority for

the implementation of nuclear security, the Comprehensive Nuclear-Test-Ban Treaty and the Chemical Weapons Convention. ASNO's IAEA Safeguards Section is responsible for Australia's compliance with Australia's CSA and AP and domestic safeguards regulation of entities that hold nuclear material and associated items. The IAEA Safeguards Section also coordinates the Australian Safeguards Support Program to the IAEA and Australia's support for regional safeguards outreach programs including the Asia-Pacific Safeguards Network.

Drawing on ASNO's experiences, this paper suggests some methods the SRA can use to gather information on existing and emerging NFC R&D activities throughout the state.

## HISTORY AND STRUCTURE OF THE ADDITIONAL PROTOCOL

Following revelations in the early 1990s regarding undeclared nuclear activities in a few countries (particularly Iraq's clandestine nuclear weapons program), the IAEA worked with member states to perform an evaluation of potential measures for strengthening safeguards, including "Programme 93+2". The IAEA identified strengthened safeguards measures that could be implemented within the IAEA's existing legal authority under CSAs, as well as measures that would require complementary legal authority in the form of new agreements. Throughout this time, member states (including Australia) assisted the development of new safeguards capabilities, such as environmental sampling and open source analysis techniques, to enable the IAEA to detect undeclared nuclear material or activities.

In 1997, the IAEA and member states completed the Model Protocol Additional to the Agreement(s) between States and the International Atomic Energy Agency for the Application of Safeguards to function as the model for these new agreements (Additional Protocols, APs). The AP contains obligations to:

- provide information (under article 2 in accordance with the timeframes and formats in article 3) on nuclear-related activities, supplementing the obligations in the CSA to provide information related to nuclear material accountancy and facility design;
- allow IAEA inspectors to access a variety of locations to perform verification activities (articles 4 to 10), adding to the obligations in the CSA to allow inventory inspections at facilities and LOFs and design information verification at facilities;
- accept simplified procedures for designation of inspectors (article 11), and
- provide multiple re-entry visas for IAEA inspectors (article 12).

Programme 93+2 identified that nuclear material production processes may involve a substantial R&D effort prior to first handling of nuclear material. For example, R&D on centrifuge rotors or lasers for uranium isotope separation could become quite advanced before any uranium is introduced. This could substantially increase a state's capability to produce unirradiated direct use material. For the IAEA to have a complete picture of a state's NFC capabilities, enabling timely detection of indicators of undeclared nuclear activities of potential proliferation significance, it is important that the IAEA has access to information on R&D.

Programme 93+2 identified that nuclear fuel cycle-related research with nuclear material taking place in a state with a CSA was already covered by the legal authority in the CSA. This research

should be reflected in inventory change reports (ICRs, via concise notes), physical inventory lists (PILs, via batch descriptions), design information questionnaires (for facilities) or LOF information questionnaires. For research and development activities, the "gaps" identified in the CSA by Programme 93+2 relate to:

- R&D not involving nuclear material;
- planned R&D activities; and
- R&D collaborations between in-state organisations and overseas organisations.

These are the "gaps" filled by AP articles 2.a.i, 2.a.x, and 2.b.i.

**Box 1** Extract of paragraphs of the Model Additional Protocol on R&D

Article 2

a. ..... shall provide the Agency with a declaration containing:

(i) A general description of and information specifying the location of *nuclear fuel cycle-related research and development activities* not involving nuclear material carried out anywhere that are funded, specifically authorized or controlled by, or carried out on behalf of,..... .

…

(x) General plans for the succeeding ten-year period relevant to the development of the nuclear fuel cycle (including planned nuclear fuel cycle-related research and development activities) when approved by the appropriate authorities in ..... .

b. .....shall make every reasonable effort to provide the Agency with the following information:

(i) A general description of and information specifying the location of nuclear fuel cycle-related research and development activities not involving nuclear material which are specifically related to enrichment, reprocessing of nuclear fuel or the processing of intermediate or high-level waste containing plutonium, high enriched uranium or uranium-233 that are carried out anywhere in ..... but which are not funded, specifically authorized or controlled by, or carried out on behalf of, ..... . For the purpose of this paragraph, "processing" of intermediate or high-level waste does not include repackaging of the waste or its conditioning not involving the separation of elements, for storage or disposal.

## R&D AS THE "HARD" PART OF ADDITIONAL PROTOCOL DECLARATIONS

Most of the paragraphs of the AP on provision of information correspond to activities that tend to be regulated by the SRA (see Table 1). These paragraphs relate to possession, production, operation or use of nuclear material, nuclear facilities, locations outside facilities where nuclear material is customarily used (LOFs), or specialised equipment/materials, each of which is likely to be covered under domestic legislation by a requirement to have a licence or permit from either the SRA or another regulatory authority that works closely with the SRA, such as a nuclear/radiation safety regulatory body or an export control regulator. For instance, in Australia, permits are required from ASNO for any nuclear material, facilities, "associated equipment", or "associated technology".[i] (Permits are also required for any heavy water or graphite collocated with a nuclear facility or otherwise in a nuclear activity.)

A simple way to collect information for the AP under these paragraphs is to make routine reporting (and facilitation of both domestic inspections and IAEA complementary access) on

nuclear-related activities a condition of the licence/permit. Provided that the SRA is making a consistent and effective effort to ensure that there is no nuclear material (or specialised equipment/materials) outside of regulatory control, it is relatively easy in principle to gather the necessary information to discharge these obligations under the AP.

**Table 1**: Paragraphs of AP article 2 corresponding to activities that require a licence or permit from the SRA under domestic law. The SRA can gather information on these activities by making reporting a condition of the licence or permit issued.

| Paragraphs of AP article 2 corresponding to activities that require a licence/permit | Number of entries in Australia's AP submissions for 1 Jan to 31 Dec 2022 |
|---|---|
| 2.a.(ii) operational activities of safeguards relevance at facilities or LOFs | 1 |
| 2.a.(iii) each building on each site (i.e. area delimited around a facility or LOF) | 268 |
| 2.a.(iv) Activities in AP Annex I: manufacture, assembly, construction, or upgrading of certain equipment and materials | 2 |
| 2.a.(v) Uranium mines, uranium concentration plants and thorium concentration plants | 6 |
| 2.a.(vi) Thorium or natural uranium that is before the point specified in CSA paragraph 34(c) (i.e. ore concentrates) | 7 |
| 2.a.(vii) Nuclear material exempted from IAEA safeguards | 4 |
| 2.a.(viii) ILW or HLW containing plutonium or HEU | 3 |
| 2.a.(ix) Export (or import) of equipment and materials listed in Annex II | 1 |
| 2.b.(ii) Activities functionally related to a site | 0 |

By comparison, article 2.a.i, 2.a.x and 2.b.i of the AP may not correspond to activities that require a licence or permit. NFC R&D activities do not necessarily require access to nuclear material or equipment, or access to restricted or classified information. For instance, an R&D project involving only computer simulations of a reactor could be conducted at a location that does not have any nuclear material, facilities, equipment or classified technology.

This problem may not be solvable by simply making it a requirement for organisations to obtain a permit prior to conducting any NFC R&D. Some researchers start out with the intention of performing NFC R&D activities but end up focussing their efforts elsewhere. Other research projects start out theoretical but find unexpected application in the NFC. Requiring researchers to apply for the SRA's approval in advance would not necessarily yield meaningful (or comprehensive) information of NFC R&D activities in the state.

Since the AP was developed in the mid-1990s, the technological barriers to starting a NFC R&D activity (not involving any nuclear material or equipment) on topics like fuel fabrication and reactor design have decreased. Today, anyone can purchase a computer with sufficient processor power to run numerical modelling and simulations of thermal radiation in reactors

with sufficient fidelity to potentially have direct application to reactor systems development. The SRA needs to have the resources to identify and describe these activities once they have occurred but the SRA's approval is not necessarily required beforehand.

Furthermore, R&D could be funded, authorised or controlled by the state in many ways. For example, R&D activities may be "authorised" or "controlled" by a government agency in the health, environment, industry, energy, resources, science and technology, or foreign affairs portfolios, each of which may be completely separate from the SRA. Similarly, R&D activities could be directly funded by a variety of agencies that may not be aware of the relevance of their funding to the state's safeguards obligations. R&D activities may also be funded indirectly, which is why, in Australia, ASNO's starting assumptions are that any research involving any Australian university is at least partially "funded" by Australia for the purposes of article 2.a.(i) and any research carried out on the premises of a government lab could be under the "control" of Australia.

**Table 2** Paragraphs of AP art 2 that do not necessarily correspond to activities that require a licence or permit from the SRA under domestic law.

| Paragraphs of AP article 2 that do not necessarily correspond to activities that require a licence/permit | Number of entries in Australia's AP submissions for 1 Jan to 31 Dec 2022 |
|---|---|
| 2.a.(i) NFC R&D activities funded, authorised or controlled by the state | 14 |
| 2.a.(x) 10-year plans related to nuclear fuel cycle, including R&D, approved by authorities in the state | 7 |
| 2.b.(i) NFC R&D activities related to enrichment, reprocessing, or processing HEU/Pu ILW/HLW not funded, authorised or controlled by the state | 0 |

For R&D not funded, authorised or controlled by the state, the obligation (in article 2.b.(i)) is qualified by the words "shall make every reasonable effort" and the geographical scope is limited to the state. The obligation is also limited to the stages of the nuclear fuel cycle that have the technological potential to produce unirradiated direct use material: enrichment, reprocessing or processing of ILW/HLW containing HEU/Pu. Given that these stages of the fuel cycle are the most proliferation-sensitive, the SRA ought to be actively monitoring for these activities even by private entities in the state. In Australia, this is reflected in the requirement in the *Nuclear Non-Proliferation (Safeguards) Act* for the entity to obtain a permit to possess "associated technology" for certain information on enrichment and reprocessing.

## DEFINING "NFC R&D" AND "NOT INVOLVING NUCLEAR MATERIAL"

Article 18.a of the Additional Protocol defines NFC R&D activities as "those activities which are specifically related to any process or system development aspect of any of" seven stages of the nuclear fuel cycle. The definition excludes "theoretical and basic scientific research [and]

industrial radioisotope applications, medical, hydrological and agricultural applications, health and environmental effects and improved maintenance".

Accordingly, NFC R&D is not just any nuclear-related research. The definition is limited to R&D on a step of the fuel cycle (not including mining or ore concentration). Furthermore, the objective of NFC R&D goes beyond contributing to a body of scientific knowledge and instead has potential direct application in a process or system in a nuclear fuel cycle facility. The SRA can use these criteria to sort through the information it collects on R&D projects to determine which projects to declare as NFC R&D (see below).

Where a research stream involves some NFC R&D work with nuclear material and some without nuclear material, the simplest solution may be to declare the whole activity under article 2.a.i or 2.b.i. For NFC R&D work that involves nuclear material, ASNO's practice is to write an entry under article 2.a.(i) or 2.b.(i) with a reference to the relevant batch number, ICR and/or PIL for the nuclear material being used. This is a straightforward way to ensure that the combination of information provided by Australia under the CSA and the AP gives a complete picture of all safeguards-relevant activities. This is particularly important for R&D collaborations where one organisation conducts practical research with nuclear material and the other organisation conducts theoretical research.

## COLLECTING REPORTS FROM PERMIT HOLDERS/LICENSEES WITH KNOWN NFC R&D ACTIVITIES

In order to comply with article 2.a.(i), 2.a.(x) and 2.b.(i), the SRA should ensure it captures as much information as possible on state's research sectors with capacity to perform NFC R&D.

Each NFC R&D activity receives its own entry annually under either the 2.a.(i), 2.a.(x) or 2.b.(i) declaration. By January each year, the SRA should have prepared update entries for each of the entries that were submitted to the IAEA in the previous year. Initially, these updates entries simply contain the same data as the previous year, with only dates and declaration numbers incremented.

Each NFC R&D activity may have several in-state collaborators and several international collaborators. In Australia, ASNO usually tries to identify one in-state organisation as the leader on the project (noting that the leader may change over time).

Each nuclear facility operator (i.e. the Australian Nuclear Science and Technology Organisation in the case of Australia) should have a designate with their own copy of protocol reporter software (currently Protocol Reporter 3, PR3) for writing AP declarations and reference copies of all entries for their organisation. (A nuclear facility will have many different types of entries, including operational activities, buildings, etc so it is worthwhile investing the time to train a designate to use PR3.) The SRA may export the entries in PR3 format, send to the designate and assign the delegate the task of importing the entries to its version of PR3 and updating them before end of March.

For each licensee that has ongoing fuel cycle-related R&D, the SRA can export each entry as a MS Word DOCX, and then task the licensee to edit using tracked changes.

Many universities have licences/permits because nuclear material is stored or used in small quantities by geology, medicine or biochemistry departments (often under the supervision of a centralised health and safety unit), while any NFC R&D is conducted by physics or engineering departments. ASNO's practice has been to issue a permit to possess nuclear material to the university as a whole and add one condition that the university provide annual reporting on NFC R&D where directed by ASNO. ASNO and the university then decide whether ASNO will contact the researchers directly or go through the unit that is responsible for other aspects of the permit, such as accounting for the nuclear material.

For organisations that only occasionally conduct NFC R&D or that are new to NFC R&D (or where finding a point of contact is difficult), the SRA can use the results of the searches described below to write a draft entry and then send to the researchers with questions.

## CONDUCTING OPEN SOURCE SEARCHES

Since the mid-1990s, the growth of online academic databases, the reduced barriers to searching for research publications and the automation of open source information analysis have significantly enhanced the IAEA's capability to verify the absence of undeclared NFC R&D in the public domain. Nevertheless, the imperative for the SRA to declare all NFC R&D remains. The SRA should use its resources to:

- catalogue the relevant information in the public domain on NFC R&D and consolidate it into one entry for each broad "activity",
- check that the information in the public domain accurately and completely reflects the totality of declarable activities in the state,
- add relevant information that it receives from the conduct of regulatory work, such as interviews with researchers, domestic inspections and interactions with other government agencies, and
- cross-reference the NFC R&D activities to any related activities that are declarable under other parts of the AP (e.g. article 2.a.(iii) building descriptions) or under the CSA.

Academic journal databases like Science Direct, the IAEA's International Nuclear Information System (INIS) Repository and arXiv generally allow multicriteria or Boolean searching of a wide variety of scientific journals and books. One of the search criteria could be that at least one author has an institutional or corporate address in "Australia" or containing the word "Australian". The search strings can be based on the text of AP article 18.a, as long as the searches are repeated to look for variations and synonyms. As examples, search strings for potential NFC R&D on enrichment could include specific enrichment technologies or could simply be:

- "Uranium hexafluoride" or UF6
- "Isotope separation"
- "Isotopic separation"
- "Separation of isotopes"
- "Separating isotopes"

- "Uranium enrichment"
- "Enriching uranium"
- Uranium and fractionation

If necessary, the results can be narrowed by adding an additional criterion like "and not (mineral or environmental or bio* or cancer or astro* or galactic or protein* or mine or mining)" to eliminate nuclear-related fields that are generally outside of the definition of NFC R&D. Since the aim is to identify and describe activities, it is not necessary to collect every publication by a particular author on a particular project. Once a representative sample of publications have been collected on, for example, Synroc technology, the results can be narrowed by adding "and not (Synroc)" to the search criteria.

Similar searches can also be conducted through university thesis collections and publication lists in staff profiles for universities with nuclear physics and engineering departments.

Google Scholar searches (restricted to domain ".edu.au") also allow an easy overview of the activities of Australian education institutions. For other R&D institutions, the same search strings can be applied to searching press releases. Finally, a simple Google search (restricted to domain ".au" or restricted to country "Australia") using search strings based on the text of article 18.a helps to cover the possibility of R&D activities in private companies.

For ASNO, the annual process of conducting open source searches requires a team of two, with each member having a background in physics, chemistry or engineering and a working knowledge of each stage of the nuclear fuel cycle. One team member could be relatively new to safeguards and would preferably be in charge of conducting the open source searches and making a short-list of about 100 candidate publications/projects. This exercise provides a useful overview of nuclear-related research across the state.

The second team member should have experience with writing AP declarations and will be in charge of making a final decision whether:

- the publication is part of a previously declared NFC R&D activity and should be included in that entry o declare each publication under an existing entry for a,
- the publication is part of a new NFC R&D activity and should be included in a new entry;
- the publication is not NFC R&D but is relevant to another part of the CSA or AP (e.g. as part of a description of how a building on a site is being used under AP article 2.a.(iii), or
- the publication is not relevant to any part of the CSA or AP.

In ASNO, the team arranges its short-list in an Excel spreadsheet with each year represented on a separate tab. Each row corresponds to an academic publication, press release, news article, webpage, patent, etc. The columns of the spreadsheet detail how each publication was found, the details of the publication, and the decision on whether it is declarable:

- Database searched
- Search string
- Year of publication

- Authors
- Title
- Digital object identifier (DOI) or URL
- Abstract
- Australian organisations (e.g. university departments) named as authors/collaborators
- Locations in Australia where research is taking place
- Overseas organisations named as authors/collaborators
- Whether it will be declared in an AP declaration
- The paragraph number (2.a.(i), 2.a.(x) or 2.b.(i)) and title of the entry that the publication will be declared under
- Follow-up questions to ask the Australian authors/collaborators

Even though individual publications identified may not constitute NFC R&D activities, the short-list should be retained so that it is possible track the progress of an R&D project over time. For example, a series of publications initially on corrosion of alloys in the presence of high temperature steam or CO2 could progress to research on the cladding-coolant for a particular fuel design in a reactor. Similarly, research on radioactive waste conditioning by encapsulation in a medium could progress toward research on processing with separation of elements.

## OUTREACH TO OTHER GOVERNMENT AGENCIES

National research funding bodies (such as the Australian Research Council in Australia) maintain records of applications for funding and grants, often arranged by discipline. The SRA can contact major research funding bodies at least once per year to request a list of grant applications in specific disciplines or with executive summaries/abstracts containing specific search terms.

Export control applications for nuclear-related goods (including dual-use goods and intangible technology) should be reviewed by the SRA, even if the final decision rests with a separate export control regulator. Even if the goods being exported are not declarable under AP article 2.a.(ix), the export could form part of NFC R&D collaborations with organisations overseas. The SRA should assess the relationship between the applicant (sender) and the end user (receiver) and the stated end use of the goods. If necessary, the SRA may follow-up with the applicant to obtain details about any research collaborations, for example, by making this a condition of the export permit.

The patents office can assist with identifying NFC R&D in two ways. First, the patents office and the SRA could arrange for relevant patent applications (e.g. applications that contains a process or technology that purports to relate to enrichment or reprocessing) to be referred to the SRA.[ii] Second, the patents databases are useful resources that the SRA can search regularly for applications containing the search terms described above.

## CONSOLIDATING THE DATA INTO PROTOCOL REPORTER 3

The text of Additional Protocol articles 2.a.(i) and 2.b.(i) requires the state to provide "a general description and information specifying the location". The fields in PR3, along with the guidance in IAEA Services Series 11[iii] help to elaborate on what is meant by "general description" in the context of articles 2.a.(i) and 2.b.(i). Each NFC R&D activity should have:

- Project title
- Project period [approximate start and end dates]
- Fuel cycle stage (i.e. conversion, enrichment, etc)
- Description of the R&D activity
- Relationship of the activity to the state (i.e. whether it is funded, authorised, etc by the state)
- Objectives and intended application of the R&D activity
- Degree to which objectives are met.

The SRA should combine the information received from permit holders/licensees with information from open source searches, interviews with researchers, domestic inspections or notifications from other government agencies to write a short response to each of these fields and then add citations to relevant academic publications.

## CONCLUSION

By performing broad searches annually, using a spreadsheet to track patterns in institutions' publications and patents, and asking targeted questions of researchers, a small team in an SRA can build up a complete picture of existing NFC R&D activities and identify new NFC R&D activities as they emerge. Along the way, the SRA can establish a positive relationship with the research community in the state. This has the obvious benefit of facilitating information gathering for the purposes of CSA and AP implementation and helps ensure relevant research organisations are ready to facilitate any complementary accesses where the IAEA may choose to focus on R&D. In addition, the international safeguards system and the SRA benefit from an active research community, particularly if that community is aware of safeguards. Where possible the SRA should conduct outreach to university students in nuclear physics and engineering disciplines about nuclear safeguards, both to build safeguards culture in the research community and to cultivate professionals with relevant skills who the SRA may one day wish to recruit or who could one day contribute to the member state support program (MSSP), assisting the IAEA with R&D on new tools or techniques for safeguards.

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[i] See s 4 Nuclear Non-Proliferation (Safeguards) Act 1987. With a few exceptions the list of "associated equipment" reflects the NSG and NPT Exporters lists of equipment especially designed and prepared for nuclear use as of 1987, which covers nearly all of the equipment in AP Annexes I and II. The term "associated technology" covers [inter alia] information related to enrichment, reprocessing and heavy water production but does not cover other stages of the nuclear fuel cycle.

[ii] In Australia, the requirement for the Commissioner of Intellectual Property Australia to notify the Director General of ASNO is written into s 147 *Patents Act 1990*.

[iii] IAEA Services Series 11, "Guidelines and Format for Preparation and Submission of Declarations Pursuant to Articles 2 and 3 of the Model Protocol Additional to Safeguards Agreements" (Vienna, 2004).