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Brazil's Nuclear Submarine: A Broader Approach to the Safeguards Issue

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Abstract

The article discusses the issue of nuclear-propelled submarines as a nuclear non-proliferation question, addresses the issue of safeguards procedures and arrangements, and suggests a broader, political approach to allay international concerns. Such safeguards arrangement would set the precedent for future arrangements, and particularly if integrated into a more comprehensive approach, might strengthen Brazil's hand in nuclear negotiations, including on disarmament.

Keywords: Nuclear submarines, nuclear non-proliferation, nuclear safeguards, Brazil, International Atomic Energy Agency, Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials.

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Introduction

Nuclear propulsion for military use, more frequently in submarines, is considered a loophole in the nuclear non-proliferation regime (Ma & Von Hippel, 2001; Moltz 1998; 2005; 2006; Thielmann and Hoffman 2012); for a different view, see Guimarães 2005). That is is because nuclear propulsion for military craft isa Non-Proscribed Military Activity (NPMA), and the nuclear material used in reactors for that specific purpose is not subject to safeguards. During the negotiations of the Non-Proliferation Treaty - NPT, - it became clear that some prospective members might not join it out of interest in nuclear propulsion for ships and concern about how NPT might impact that. Should safeguards be applied in that case, much of the discretion that is the *raison d'être* of a submarine in the first place would be compromised or forfeited. But even then, in the late 1960s, it was already considered "*a serious loophole in the safeguards prescribed by the Treaty*") (Fischer 1997, 272) because during the unsafeguarded periods of its life-cycle, the nuclear material in the reactor could be diverted for the production of nuclear weapons.

The risk increases with the degree of enrichment of the nuclear material: if the uranium in the reactor is enriched to around 90% ^{235}U (usually called *weapons-grade uranium*[1]), it could be directly used in nuclear weapons; if it is enriched to around 20% or more ^{235}U (usually referred to *highly-enriched uranium* or HEU), it could easily be enriched to weapon-grade uranium. Uranium enriched to less than 20% ^{235}U is usually called *low-enriched uranium* or LEU and, at a level below 10% ^{235}U, it becomes more difficult to substantially enrich to weapons-grade uranium[2] or close to it (Barroso 2009; Bernstein 2008; Bodansky 2004; Heriot 1988; Murray 2001)[3]. Uranium for land-based nuclear reactors is usually enriched to around 3.5%-5% ^{235}U. Therefore, from a nuclear nonproliferation standpoint, risks would be minimized if naval nuclear reactors had LEU, and particularly less than 10% ^{235}U content, as its nuclear fissile material.

As a practical matter, this was not too important until recently, because all countries that produced and operated nuclear submarines were either Nuclear Weapon States — NWS according to NPT (China, France, Russia, United Kingdom, United States) or non-NPT members with nuclear weapons (India), which means that it was taken for granted that they had nuclear material for explosive devices.

But the possibility that Brazil, a NPT Non-Nuclear Weapon State — NNWS, might launch its own nuclear submarine gives the matter heightened importance (Egel et al. 2015; Moore et al. 2016), and puts the issue of applying safeguards to the submarine nuclear fuel cycle in the spotlight. In fact, whatever becomes the accepted practice of safeguards related to Brazil's nuclear submarine is bound to set the precedent in the matter for all other NPT countries in the future (Dawood et al. 2015; Kassenova 2014; Phillipe 2014a; 2014b), and therefore it is poised to become a very important issue for the non-proliferation regime and the international nuclear order. When the time for launching the first Brazilian nuclear submarine approaches, and some of the most important decisions are taken, Brazil must be prepared for renewed international scrutiny and pressure. If the most controversial issues are identified and discussed in advance, concerns can be addressed in time and mistrust (and significant, additional adjustment costs) can be avoided, to everybody's benefit.

The discussion below does not mean or imply any kind of endorsement of the idea that Brazil needs nuclear-propelled submarines, or that they would be in Brazil's best interest. In this article, Brazil's decision to pursue them is just taken for granted, independently of its merits (or lack thereof).

1 Those categories are not absolute; a device with uranium enriched to, say, 88%-^{235}U will be less efficient, will be larger and need more fissile material (and explosives) in order to produce an explosion with a determinate yield than would be the case for a device with, say, 93%-^{235}U (and the same yield); but it would make a significant explosion anyway: the uranium in the bomb dropped in Hiroshima had been enriched to around 80% ^{235}U (Bernstein, 2008).

2 Actually, when uranium is enriched to 5%-^{235}U, around half of the isotopic separation work needed for enriching it to 90%-^{235}U has already been executed. But it would have to go through a centrifuge cascade more than once to reach the weapon-grade quality, and not only it takes time and complex work to adjust the cascade for that run: as for each run it's necessary to stop the centrifuges from spinning and then to restart them, risk of serious damage is severely increased. Therefore, only when the input material is around 20%-^{235}U it's deemed a practical possibility to enrich it to around 90%-^{235}U before detection, at least if facilities are fully safeguarded. For a not too technical treatment of uranium enrichment, see Heriot (1988).

3 Alternatively, the plutonium that accumulates in the reactor as a byproduct of its functioning could in theory also be diverted to nuclear weapons production, but that would be a more challenging endeavor: it would require special facilities for reprocessing the spent fuel; and nuclear explosive devices that use plutonium are much more complex, and require extensive testing to develop (Barroso 2009; Bernstein 2008; Bodansky 2004; Heriot 1988; Mark et al. 2009; Murray, 2001). That said, it's important to keep in mind that more plutonium is produced in reactors that use LEU than in those that use HEU.

Brazil's nuclear submarine

Brazil's nuclear submarine is being built with French assistance, except for the nuclear reactor and associated uranium fuel-cycle technology, which is being developed by the Brazilian Navy. According to open sources, the Brazilian Nuclear Submarine Álvaro Alberto (SN 10), which would be the first of 6 planned nuclear submarines, would run on a 48-50 MWth reactor[4] (NTI 2015a; Padilha 2012), would displace around 6,000 metric tons in a hull around 100 m long and 10 m beam with a crew of 100 personnel (Padilha 2012), and its patrolling time, including transit time, would be 3 months (Brazil 2014; Padilha 2012). Nuclear refueling would take place every 5 years, and would not require cuts in the internal structure. It's maximum operational depth would be around 350 m, and its maximum submerged speed would be 24-26 knots (Izique, 2007; Kassenova, 2014; Padilha 2012).

So, it would be substantially larger than: (i) the French submarines of the non-nuclear *Scorpène* class (66,4 m length, 6,2 m beam, 1,711 t submerged), in which SN-10's design would be based, (ii) the nuclear *Barracuda* class (99,5 m length, 8,8 m beam, 4,765 t surfaced), and (iii) the *Rubis* class (72,10 m length, 7,6 m beam, 2,670 t submerged). Álvaro Alberto will have smaller time between refueling and complex overhaul (RCOH) procedures: 5 years, against 7 years for the *Rubis* and expected 10 years for the *Barracuda* (Defense Industry Daily, 2015; Ewing 2011; Huan and Moulin 2010).

What is not clear is the degree of enrichment of the nuclear fuel for its reactor. The chairman of the Brazilian Navy's Nuclear-Propelled Submarine Development Program, Admiral Gilberto Max Roffé Hirschfeld, insisted, during a hearing at the Brazilian Senate's Foreign Relations and National Defense Committee in 2014, that the nuclear fuel for the submarine's reactor would be enriched to 6-8% (Brazil, 2014). On the other hand, Kassenova (2014), in her systematic review of Brazil's nuclear activities, claims that "*… All indications are that Brazil will power its submarines with fuel produced from uranium enriched to 18–19 percent.*" (p. 29). The latter figures were mentioned by former CNEN's chairman Odair Gonçalves in 2005 (Huntington 2005; Pomper and Huntington, 2005). This is a very important issue.

Uranium enrichment and submarines' reactors requirements

Nuclear reactors for submarine propulsion have different requirements from those on land. First, since refueling is a major operation that may add substantially to the time that the submarine will be out of service[5], time between refueling should be maximized (Ippolito Jr 1990). Second, for tactical reasons (e.g., to evade an area after attacking, or after being detected), submarines may need very sudden power transitions — typically, from 10% to 100% power in 30 seconds to 1 minute

4 It's expected that it will be based on a conventional design, not a plate one, but from the second submarine onwards, it's possible that reactors would have a plate design, and might generate around 75 MWth (Padilha 2012).

5 This is a more significant problem for submarines that require cutting off the internal structure of the submarine and disassembling of the reactor in order to proceed with refueling. When there is a hatch over the reactor compartment, the refueling operation takes less time.

(Fribourg n. d.). This implies difficult choices about material for the production of the nuclear fuel element, due to considerations about temperature, conductivity, structural resistance, and neutron-absorption cross-section of different materials, which may limit the time-between-refueling of the reactor (Ippolito Jr 1990). Third, naval reactors cannot allow the "reactor dead time" that happens after a reactor shutdown (e.g., due to some emergency), when the highly neutron-absorbing ^{135}Xe fission product accumulates, leading to a 24-hour interval for restarting operation, until the ^{135}Xe decays. Therefore, naval reactors need excess reactivity in order to overcome the ^{135}Xe buildup (Ippolito Jr 1990; Ragheb, 2011). Fourth, there are strong incentives for keeping submarine reactors as small and compact as possible:[6] (i) power plants usually account for 20-30% of the total weight of the submarine, so since shielding against radiation accounts for a large part of powerplants' total weight, the smaller the reactor core and the steam generator, the better (Ippolito Jr 1990), (ii) the smaller the submarine, the more maneuverable they are, and particularly in shallow waters.

Ippolito Jr. (1990) simulated the impact of variation in uranium enrichment (7%, 20% and 97.3% ^{235}U) in the performance of nuclear submarines. Assuming a submerged volume displacement of 2670 m^3 — like the French submarine Rubis (the smallest-volume nuclear attack submarine ever deployed) —, a reactor power output of about 50 MWth would be necessary to generate a forward velocity of 29.6-33.2 knots[7]. Considering, for purpose of comparison, 60 days of full power operation (or 240 days at 25%-power operation) each year, his conclusions are: (i) reactors with uranium enriched to 7% have a maximum time-between-refueling of 10 years, because it becomes impossible to maintain excess reactivity by the end of that period, (ii) reactors with 20%-^{235}U fuel can operate 20 years without refueling, but, in that case, its core will be larger than the 7%-^{235}U reactor's, (iii) reactors with 97.3%-^{235}U will attain a 20-year time-between-refueling, and its core will be significantly smaller than the others' — in fact, US submarines of the Virginia class (which use uranium enriched to 93%) are expected to operate without refueling for 33 years, which is longer than the typical 30 years life of US submarines (Ragheb, 2011).

Therefore, on tactical, logistical and economic grounds, there are strong incentives for higher degrees of uranium enrichment to fuel submarines' nuclear reactors. In fact, most operational (as in 2014) submarines' reactors have HEU for fuel: 93%-97,3% ^{235}U for US submarines, 20%-40% ^{235}U in the case of Russia, 93% ^{235}U for UK submarines, and 40% in the case of India. On the other hand, Chinese nuclear submarines use 3%-5% ^{235}U, and French submarines use 7.5% ^{235}U fuel, albeit the recently constructed submarines of the new class Barracuda (the first of which is expected to be commissioned in 2017 or 2018) would use 5%- ^{235}U fuel (Moore et al. 2014).

Of course, the problem here is that HEU can be easily enriched to WGU. More troublesome still, nuclear material with ^{235}U concentration around or above 90% can be directly used as the

6 Shielding against radiation accounts for a large part of submarine nuclear powerplants' weight; therefore,to minimize the shielding and the reactor total weight, it's important to keep the reactor core and the steam generator as compact as possible (Ippolito Jr 1990).

7 Assuming a combined propeller/transmission system efficiency of about 75%. The larger velocity is obtained when the submarine is in favorable conditions and has a drag coefficient of 0.025; the smaller is obtained in not unusual worse conditions, when the drag coefficient increases to 0.035 (Ippolito Jr 1990, 12-13).

fissile material of a nuclear explosive device[8]. Therefore, since uranium enrichment for nuclear reactors dedicated to propulsion is not proscribed by the NPT, it becomes an *entirely legal path for producing fissile material for nuclear explosive devices*[9] — a significant proliferation risk, even if that particular country is not interested in nuclear weapons, because other parties might be bent on putting their hands in that kind of material, maybe even stealing it.

The issue becomes still more complicated because current safeguard arrangements establish special procedures for nuclear reactors for propulsion; specifically, those reactors are *not subject to safeguards while they are actually operational and being used for that purpose*.[10] In consequence, it rests entirely on the timing of inspections on land to certify that nuclear material is not being diverted from the reactor. There is, then, room for concern that in the absence of stringent safeguards arrangements, it might be possible for a country that operates nuclear submarines to divert nuclear material for the production of nuclear explosive devices (Moltz 1998; 2005; 2006; Philippe and Hippel 2016; Thielmann and Hoffman 2012).

Safeguarding submarines' nuclear material

Though there is real ground for those concerns, it is possible to devise safeguards arrangements that would give sufficient assurance that nuclear material is not being diverted, even in the absence of a safeguards agreement based on the Model Additional Protocol, or INFCIRC/540.[11] [12]

The heart of the matter is to dispel the false idea that safeguards would not apply to nuclear material for submarines. The exception only applies *while the nuclear material is actually being used in a nuclear reactor in a submarine*.[13] [14] Philippe (2014 a,b) stresses this point very forcefully. Comparing the dispositions relevant for the matter in INFCIRC/153, Corrected and

8 One might think that this would apply even to LEU nuclear propulsion reactors, since spent, irradiated nuclear fuel generates large quantities of plutonium. But that's an entirely different issue, because: (i) building devices with plutonium as fissile material is a technically challenging endeavour; and (ii) clandestine transportation of the plutonium would be close to impossible without reprocessing, and that would greatly simplify the security challenges.

9 Guimarães (2005) claims that "*... it is not credible that a country procuring a nuclear explosive would choose such an indirect route as the development of a SSN*" (Guimarães 2005: 5), since "*[b]oth de jure and de facto NWS countries obtained SFM through programs specifically directed to that purpose*" (id. p. 4 This conclusion fails to take into account that, when NWS pursued their nuclear weapons, the direct path was not closed to them, either because there was still no NPT or because they were not NPT parties (India). A country that wishes to benefit from technical cooperation in the nuclear field might definitely follow the 'indirect path' as the most practical and economic route.

10 Any broader claim that production of nuclear fuel for submarine propulsion is not subject to safeguards is totally unwarranted.

11 This should not be construed as a statement either in favor or against signing and ratifying an Additional Protocol.

12 The Brazilian-Argentinian Agency for Nuclear-Material Accountancy and Control — ABACC is said to be aware of the matter and discussing the subject (see, for example, Hibbs 2009), but we couldn't find any ABACC's technical document on nuclear submarine-related safeguards; also, we have no knowledge of negotiations on the matter going on between IAEA and ABACC, Brazil, or Argentina.

13 Egel et al. (2015: 247) casts doubt on this interpretation, and argues that IAEA should state its view on the matter. This author doesn't share this doubt at all.

14 It's interesting to notice that this point seems to be completely missed by Kaplow (2015) and his 'canary in the coal mine' approach. For him, the decision to invoke the nuclear propulsion exemption would allow facilities handling that specific material not to be safeguarded, enabling a country to carry on nuclear weapons-related activities. So, in his view, to invoke the nuclear propulsion exemption would set off an alarm, and might put the country's nuclear program under intense scrutiny, which, incidentally, makes the nuclear propulsion exemption an unattractive path to be threaded by any country towards obtaining nuclear weapons. Of course, as soon as one realizes that the exemption only applies to the nuclear material only while it is being used for that role, that position does not hold water.

in INFCIRC/435[15], he shows that when it comes to nuclear propulsion, the language in the Quadripartite Agreement is more specific and detailed, as it makes it very clear that 'special safeguards procedures' (the codeword for non-application of safeguards to nuclear material in NPMA) would apply "*only while the nuclear material is used for nuclear propulsion or in the operation of any vehicle, including submarines and prototypes, or in such other non-proscribed nuclear activity as agreed between the State Party and the Agency*" (IAEA 1994a, §13, [b]; emphasis added). According to Philippe, this not only makes the Brazilian nuclear submarine a little less severe problem than would be the case for an INFCIRC/153, Corrected country, but also helps to make it a model case for safeguards arrangement specific for naval nuclear fuel cycles, including NWS.

In any case, the text in INFCIRC/435 means that safeguards apply to the whole nuclear fuel cycle until it is actually used to propel a submarine. It assumes that (i) Brazil's naval reactor will fit the description in the public literature, (ii) that it will not be very different from the prototype at the Nucleoelectric Energy Generation Laboratory - LABGENE, - and (iii) that the submarine hull will have a hatch over the reactor compartment large enough to facilitate fueling and defueling. These are very reasonable assumptions: the first two for obvious reasons, the third because not having hatches over the reactor compartment makes refueling operations much more complex (e.g., requiring cuts in the internal structure of the submarine), maybe even increasing the time that the submarine will be in the shipyard and decreasing its overall availability (Ippolito Jr 1990) which, in the case of Álvaro Alberto, already is expected to be well below current standards. Since DCNS — the French company that is helping develop Brazil's nuclear submarine — knows how to do it, it is safe to assume that Brazil's nuclear submarine will have such a hatch. Philippe (2014 a;b) proposes a model for safeguarding military naval nuclear fuel sensible enough to take the need to protect information about the submarine performance into account, based on three conditions established in both INFCIRC/153, Corrected and INFCIRC/435:

> "First, any arrangement to remove material from safeguards must be made in agreement with the IAEA and would be submitted to the IAEA board of governors for approval. Second, the state must declare the total nuclear material inventory that is to be taken out of safeguards, including quantities and composition. Finally, safeguards must be re-applied on the nuclear material as soon as it is reintroduced into peaceful activities." (Philippe 2014a).

In fact, the third condition is not entirely consistent with the standard of INFCIRC/435. If safeguards do not apply as long as the nuclear material is not being used for propulsion, it is not unreasonable that, during *regular* maintenance periods, and not only RCOH, inspectors could check the integrity of seals and of the nuclear vessel outer structures. As Philippe (2014b) himself stresses, it is entirely consistent with both INFCIRC/435 and INFCIRC/153, Corrected

15 Argentina's and Brazil's comprehensive safeguards agreement with IAEA is somewhat different from INFCIRC/153 (IAEA 1972). It's an original arrangement: the Quadripartite Agreement between Argentina, Brazil, ABACC and IAEA, documented in INFCIRC 435 (IAEA 1994a).

that the reactor hatch should be sealed in the presence of ABACC and IAEA inspectors to make sure that it will not be opened until refueling or other maintenance operation is held, again in the presence of ABACC and IAEA inspectors[16].

Now, we would be more stringent here: in our understanding, inspectors could be there to monitor the transfer of the fuel, the closure of the *reactor vessel head* and of the reactor compartment hatch, and then seal them, to register reference images for containment verification, to periodically check the integrity of seals and to run the containment integrity verification, including during the submarine's regular maintenance activities[17], and also, to monitor its opening, check the integrity of the seals of reactor's vessel head and of the reactor compartment hatch, and to run the containment verification at the time of RCOH procedures. On the other hand, INFCIRC/435 language forecloses remote-monitoring systems, such as installing remote monitoring-related devices or systems *inside the submarine*, since these would apply while the nuclear material is being used for propelling the submarine, and so are not in accordance to INFCIRC/435. These additional procedures are in order because of the need to assure that there is no diversion of nuclear fuel at a clandestine facility, including in other countries.

Of course, that could raise legitimate secrecy concerns about other, non-nuclear-related features of the submarine's design. These concerns could be addressed by: (i) allowing inspectors' movements inside the submarines to the nuclear reactor compartment and the passages leading to and from it, and (ii) screening the fixtures and fittings in the transit route to the reactor compartment from the inspectors' view.

So, should this concept be enshrined in the submarine-related safeguards arrangement between Brazil, ABACC, IAEA and, presumably, Argentina, it would not only be a major boost in the overall confidence in Brazil's nuclear submarine program; it would also set a major example, including for NWS, and might become *the* precedent for submarine-related safeguards arrangements. Philippe (2014 a,b) also stresses the importance of the Naval Base design, in order to facilitate inspectors' work and minimize its costs. Related to that, it is interesting to call attention to the somewhat recent IAEA's *Safeguards by Design* concept (IAEA, 2013), in which it is recommended that nuclear facilities might be built already incorporating design features that take inspections' needs into account, and gives practical suggestions for that matter. Since some facilities related to the nuclear submarine program still are under construction, there is still time to review blueprints and make some modifications. At the moment of writing (February 2017), three of the most critical facilities that are being built are: the submarine construction shipyard, the submarine maintenance shipyard, and the Radiological Complex, all of them at the Naval Base of Itaguaí (RJ).

16 It should be added that it's also entirely consistent with the understanding in Guimarães (2005): "*The NPT-NNWS is only allowed to withdraw the material strictly necessary to SSN operation. Their fuel cycle facilities and remaining materials shall be kept safeguarded. The withdrawn material shall be submitted to specific safeguards provisions, defined by multilateral agreements between IAEA and interested parties. By some slightly different means, the continuity of safeguard enforcement should be assured.*" (Guimarães 2005, 4).

17 During maintenance, the nuclear material is not being used for propelling the submarine. That wouldn't apply if the submarine is in port but available for short-notice deployment.

Therefore, *as long as the future nuclear submarines are operated by Brazil*, the issue of safeguarding the nuclear material of its reactor would be a matter of:

- applying standard, regular monitoring and verification procedures (including remote techniques):
    - at the nuclear facilities related to the nuclear submarine program
    - during all activities related to the transportation of nuclear material and nuclear fuel (including spent nuclear fuel) between facilities and within them
    - during all activities related to the installation and removal of nuclear fuel into and from the submarines
    - during the transportation, storage or discard of spent nuclear fuel[18]
- adopting the safeguards by design (SBD) concept in the design of
    - Conversion Unit at FCN (*Fábrica de Combustíveis Nucleares*), in Resende (RJ)
    - at the Naval Base of Itaguaí (RJ)
    - submarine building shipyard, under construction
    - submarine maintenance shipyard, under construction
    - Radiological Complex, under construction, more directly involved in nuclear refueling
- installing seals in the submarine nuclear reactor vessel head and in the reactor compartment hatch after fueling and refueling;
- periodically checking the integrity of the seals and of the containing structures.

Challenges and uncertainties

On the other hand, there are some unsettled issues that, due to the sensitivity of the whole matter, might complicate things and raise the tension in the international nuclear order.

Fuel enrichment level

Since France is helping Brazil build its nuclear submarine, one might expect that the nuclear fuel for the Brazilian submarine's reactor would have around 6%-8% ^{235}U (Brazil 2014), in likeness with the French vessels. But the combination of technical hurdles[19] and economic drawbacks might turn out to be too difficult to overcome. Not surprisingly, some officials and authorities, though reaffirming the commitment to LEU fuel, have now and then hinted at the possibility that it might be closer to the 20% ^{235}U threshold (Kassenova 2014; World Nuclear Association 2017). Should things come to that, international concern will probably be significantly raised, and increased pressure for stringent safeguard measures should be expected.

18 We assume that spent fuel from naval reactors would be stored for at least about 10 years at the Radiological Complex in the Naval Base of Itaguaí before being moved.

19 One should keep in mind that, though France is definitely helping Brazil with developing its submarines, R&D of the nuclear reactor is an entirely Brazilian endeavor, without any help whatsoever from France or any other country.

Access to facilities

The issue of inspectors' access to facilities might come to the fore again. Though the incident at the Resende plant back in 2004 is said to have been satisfactorily settled, some uneasiness about it lingers on, and the whole issue might resurface with renewed strength and even acrimony, particularly if the nuclear fuel is made of close to 20%-enriched uranium (Herz and Lage, 2013; Kassenova 2014; Squassoni and Fite 2005). Brazil will have to decide if, - even in light of the impressive IAEA's record in protecting legitimate industrial secrets, and the almost universal practice of granting inspectors full access and view to the cascades at enrichment plants, - it has more to lose by granting inspectors full access, or by increased pressure and even mistrust due to screening and concealment of cascades and centrifuges. Whatever its decision, Brazil would have more to gain by deciding it sooner rather than later, with full appreciation of the possible consequences, and brace for them. But one must be advised that there is little room for wishful thinking on this matter.

Exports

A most difficult issue is that of exports (Nuclear Threat Initiative, 2015b).[20] Navy officers have now and then claimed that, since other countries would be interested in Brazil's nuclear submarine, there might be room for exports[21]. The problem is that, when it comes to safeguards for nuclear activities and material, a country's responsibility and obligations end as soon as the nuclear material is transferred to another country. The Nuclear Suppliers Group's (NSG) guidelines for export of nuclear material— adopted by Brazil — establish that:

> "In this regard suppliers should authorize transfers, pursuant to this paragraph, only when the recipient has brought into force a Comprehensive Safeguards Agreement, and an Additional Protocol based on the Model Additional Protocol or, pending this, is implementing appropriate safeguards agreements in cooperation with the IAEA, including a regional accounting and control arrangement for nuclear materials, as approved by the IAEA Board of Governors." (IAEA, 2016A: § 6 [c]).

Thanks to ABACC, Brazil is temporarily deemed in full compliance with the Nuclear Suppliers Group - NSG's - guidelines, and intends to abide by them (Herz and Lage 2013; Kassenova 2014). But since Brazil strongly resists the Additional Protocol on the grounds that, to Brazil, it increases the burden upon NNWS without significant gains in Article VI-related disarmament measures by

20 For instance, Kaplow (2015) notes that until now, NWS have refrained from exporting nuclear submarines to NNWS, but he also recalls that, when Canada announced its intention to acquire nuclear submarines, back in 1988, both UK and France were competing for supplying them. By the time, there was strong reaction (Kaplow 2015). It should be added that, interestingly enough, criticism seems to have been directed more towards Canada, and not to UK or France.

21 For instance, Fleet Admiral Gilberto Max Hirschfeld, chair of the Nuclear-Propelled Submarine Development Program, stated before the Foreign Affairs and National Defense Committee of Camara dos Deputados (the Brazilian equivalent of the House of Representatives) that "[w]*e intend to be irradiators of this knowledge for export*" and that *"many Navies from other countries have already got in touch to have access to the project*" (Gabino 2014).

NWS, and since Brazil is also not an enthusiast of the state-level approach, it is possible that any prospect of Brazil exporting nuclear submarines, or related technology, might raise concerns that, due to its own approach to more stringent measures, Brazil might have a different understanding of whom it should be able to export to. Brazil might consider addressing these concerns in advance, in order to avoid more serious trouble in the future.

Rescuing a damaged submarine

There might be a tricky issue, one that has not arisen to date because it is a problem that is related only to nuclear reactors for propulsion: what the procedures should be for monitoring and verification for a damaged (or sunk) nuclear submarine. This is an issue that might require some creativity from ABACC and IAEA technical staff.[22] The issue arises because: (i) at that moment, the nuclear material in its reactor definitely is not being used for propulsion, and therefore should be submitted to safeguards as soon as it gets to a shipyard - if it's feasible at all, - (ii) international assistance in rescuing the crew and the remains of the submarine might be needed - even Russia had to rely on British and Norwegian assistance to rescue the remains of the Kursk, in 2000 (Barany 2004). An important issue is that, even if the reactor hatch had been sealed, the seal may have been damaged at any point in the sequence of events that led to damages and/or sinking. The point is how to determine if there was any intentional violation before the accident, and who is responsible for that.

Another problem with international help is that, if Brazil exports a submarine to a third-country, and this country request some other's assistance for rescuing it and its crew, the submarine buyer will have helped to disclose possibly classified information about the Brazilian design to a country without Brazil's authorization. For instance, if repairing work is to be performed by a third-party (possibly a NWS), how to cope with the safeguards issue?

On the other hand, it is possible that the damaged submarine may turn out to reveal a lot about the submarine that is not related to safeguards. Therefore, this is a most sensitive issue that should be addressed head-on in the early stages of the discussion amongst ABACC, IAEA, Brazil and, presumably, Argentina. Actually, this discussion might even serve as the starting point for precautionarily addressing the possibility of such things happening, and how Brazil would handle the issue. Cooperative arrangements - presumably with France, due to its technical assistance to Brazil in submarine non-nuclear matters - to rescue damaged submarines should even be negotiated in advance, with both safety of ship and crew and safeguards in mind. But there is no escaping it: the rescuing of a damaged ship might potentially expose secret information that the application of safeguards normally would not, and the best way to minimize it, and also to minimize potential stress between agencies and countries, is to face it immediately and prepare for that.

22 I couldn't find any discussion of this issue in the open literature.

Some possible initiatives

There are some initiatives that might be considered by Brazil and/or ABACC in order to address possible bones of contention about Brazil's nuclear submarine program in the future. A list of suggestions is put forth below for consideration.[23]

A draft arrangement proposal

Probably, the safest way to advance Brazil's interests on the matter of the nuclear submarine before the world might be a full proposal of a safeguard arrangement by ABACC, addressing the main issues head-on. Particularly, that draft might include a statement of full adoption of IAEA's *safeguard by design* concept (IAEA 2013). As a prelude, Brazil might double-check the plans for the facilities under construction right now, so as to adapt the plans with minimal extra cost, and run a full review of the others, in order to announce any redesign (if practical) or any kind of related construction work in nuclear cycle facilities as part of this confidence-building effort. It could be a major boost in confidence if, from the start, the view was adopted that seals would be applied to the reactor under monitoring, and that refueling operations also would be inspected, without compromising legitimate secrets. It might also preempt initiatives or model safeguards agreement that might be drafted within IAEA only[24], which might make negotiations more difficult for Brazil.

The draft would then be negotiated with IAEA. The sooner the better, because if those arrangements are left to be negotiated too close to the eventual commissioning of the first Brazilian nuclear submarine, tensions would be heightened, and international pressure might lead either to a worse arrangement (from Brazil's standpoint) or to ill-will and uneasiness about Brazil's nuclear submarine program and related activities. As a matter of fact, one might even imagine that it could be in the interest of some NWS to actually postpone the discussion to that very moment, in order to extract more concessions from Brazil due to heightened pressure and intensified worries. Should that be the case, it might be better for Brazil to anticipate that discussion and to press the issue while it is in a better position to shape it by taking the initiative.

Clear and public commitment to an export policy

A clear and public announcement of some policies, in coordination with Argentina, ABACC and IAEA, might help put the negotiations of the safeguards arrangement in a more favorable framing. Particularly, the announcement, before the beginning of the negotiation of the safeguards

23 It's important to emphasize that this is a list of *suggestions*. We resist to call it even "recommendations". One should be aware that those are delicate matters for a delicate and politically sensitive issue, and that it's possible that discussion and debate might greatly improve the approach proposed *for debate* here.

24 Egel et al. (2015), for instance, suggest that IAEA take the initiative in drafting their proposed "Naval-Use Safeguards Agreement Framework (NUSA)", but they think it's a good idea to have ABACC involved in the drafting of Brazil's specific agreement. We suggest the other way around.

arrangement for the submarine, of a comprehensive nuclear submarine-export policy, including a Model Supplier-Recipient Agreement, consistent with NSG Guidelines § 3, 4, 5, 6, 9, 11 and 16 (IAEA 2016a), and with INFCIRC/225/ Rev. 5 (IAEA 2011a), to be adopted as the basic standard for all nuclear submarine exports by Brazil, might help put the negotiations in a more positive mood.

In may still be argued that NSG does not have guidelines for export or transfer of weapons or military platforms or applications. But a nuclear-propelled attack submarine is, all in all, an attack submarine (which in itself is not subject to any multilateral or international export control regime) with a nuclear reactor (which is part of the Trigger List of NSG Guidelines). Therefore, all restrictions that apply to nuclear reactors, source and special fissionable materials and non-nuclear reactor materials, should apply[25]. Furthermore, the aforementioned Model Supplier-Recipient Agreement should include restrictions to retransferring of the submarine, of nuclear materials, or any related technology or equipment.

A more difficult issue is related to RCOH procedures. The most straightforward and safe policy would be to have them performed in Brazil, under the same or even more stringent safeguards arrangement as Brazil would have, under ABACC and IAEA supervision. One proviso of that Model Supplier-Recipient Agreement might be that the recipient country would have to notify both ABACC and IAEA of any impending RCOH. On the other hand, the Brazilian Safeguards Agreement with ABACC and IAEA would require Brazil to notify both agencies of any refueling operation to be performed at its shipyards. In this manner, should ABACC and/or IAEA identify any violation of the seals or of the container's integrity, full responsibility for it would be ascribed to the recipient country; not to Brazil. Remote monitoring devices might be placed at specific points in Itaguaí's submarine maintenance shipyard to help clear that. Otherwise, Brazil's submarine exports might become indirectly and involuntarily involved in clandestine, nuclear proliferation schemes, which would be very detrimental both to nuclear nonproliferation and to disarmament, and heavily damaging to Brazil's international standing.

Addressing major concerns

Fuel

Even if at the moment there is no certainty from a technical standpoint , of which degree of uranium enrichment will be used in the nuclear material for the reactor fuel, being straightforward in the matter would help allay concerns and avoid unpleasant surprises. If it is possible that close-to-20% ^{235}U enrichment will be needed, it might be advisable to take that into consideration when it comes to the commitments mentioned above - and particularly about export policy. On the other hand, if Brazil decides to rule out higher ^{235}U concentrations, authorities should start to make it clear that further research on the reactor is in order, that it might take much

25 Of course, this does not preclude any specific arrangement within NSG for addressing naval-related exports more specifically, as suggested by Egel et al. (2015). But a lot can be accomplished even without that.

longer to launch, and it will be more expensive than current projections would allow one to expect, or that the reactor might have to be larger than is currently being considered - which might also be impractical due to hull and internal space considerations.

The point here is that any of those alternatives implies substantial political costs, either domestic or international. It is about time to acknowledge, and face these costs and take the political responsibility of addressing the consequences.

Changing Brazil's nuclear institutional arrangement

Currently, the same agency - the National Nuclear Energy Commission (CNEN) - is in charge of planning, guidance, oversight, and monitoring of Brazil's nuclear energy policy, and also of regulating, authorizing, and overseeing the production and use of nuclear energy in Brazil. This is definitely in conflict with internationally accepted best practice, and particularly with Article 8, § 2, of the Convention of Nuclear Safety (IAEA 1994b).

It might be a good idea to seize the opportunity to promote a major institutional overhaul in Brazil's nuclear arrangement, splitting CNEN and transferring its oversight and monitoring responsibilities and capabilities to a separate agency, under the Executive branch umbrella, but with full institutional autonomy.

In fact, CNEN itself has been pushing this splitting since at least 2009 (Gandra 2009; Mugnatto 2009), and CNEN's interest has since then been reaffirmed many times (Antunes 2011; Borges 2015; Vieira 2014). There is a draft bill circulating, since 2012, within the Executive Branch, establishing the National Nuclear Safety Agency (*Agência Nacional de Segurança Nuclear*- ANSN), which would take over CNEN's responsibilities on "*regulation, normatization, licensing, control and oversight of facilities and activities involving nuclear materials, strategic elements of interest for nuclear energy and sources of ionizing radiation in the national territory*" (Brazil 2012). That might appear rather straightforward, but it may be more advantageous to make this part of a broader initiative. Yet, public debate on the bill might begin immediately.

A new look at the Additional Protocol

Brazil's current stance on the Additional Protocol, enshrined in its National Defense Strategy (*Estratégia Nacional de Defesa,* END), is that Brazil will not sign it. Brazil claims that NNWS should not be burdened with additional demands until 'significant progress' is made by NWS on their Article VI obligations. That is an understandable and respectable position, and it might even be construed as a sort of leverage in order to push NWS to further commitments (Hibbs 2013).

But this leverage is eroding very fast. As of October 7, 2016, out of 196 countries[26], 149 countries had an Additional Protocol signed, approved, or in force, while only 47 had none - and

26 Including the Holy See, Palestine and Taiwan; also includes non-NPT countries India, Israel and Pakistan; doesn't include North Korea. The European Atomic Energy Community (EAEC or Euratom) also has an Additional Protocol in force, but is not counted here.

the latter numbers are decreasing every year (IAEA 2016b,c). The increasing acceptance of the Additional Protocol significantly weakens that rationale. As more and more countries accept an Additional Protocol, its leverage value against NWS decreases to the point of insignificance; the more NNWS have an Additional Protocol, less credible is Brazil's claim of speaking for them against NWS's imposition of additional burdens. On the other hand, given the impressive record of IAEA when it comes to protecting secrets, it seems that Brazil's concerns about the protection of proprietary technology[27], however legitimate, are somewhat out of place.

Therefore, it is possible that opposing the Additional Protocol actually is becoming a burden in itself, standing in the way of an easier path to Brazil's nuclear submarines (Dawood and Herz 2013; Kassenova 2014). It might be worth for Brazil's political and military leadership to take a fresh look at this matter. An eventual change of mind might significantly contribute to allay concerns about Brazil's nuclear submarine and to put at least some of those concerns to rest.

It is sometimes claimed that an eventual adoption of the Additional Protocol by Brazil and/or Argentina might have some negative impact on ABACC itself, due to eventual inconsistency in some dispositions (Kassenova 2016). In that case, there is no reason why Argentina, Brazil, ABACC, and the IAEA might not draft a particular specific protocol that would both address the Additional Protocol requirements and the ABACC-related concerns of both countries (Argüello 2009). It is important to keep in mind that ABACC has a large experience with short-notice, random inspections (Almeida et al. 2010; Castro et al. 2006; Iskin et al. 2007). Actually, solving these issues might even turn out to be an opportunity for ABACC: due to increasing burden of ever-growing safeguards activities within IAEA without any alleviation to the Agency's quasi-permanent budgetary constraints, it is not too far-fetched to anticipate that ABACC might have its mandate expanded and take on a regional role, instead of remaining limited to Brazil and Argentina (Kassenova 2016).

One might anticipate some resistance within IAEA to that approach, out of concern that this might undermine the Additional Protocol and create a crack in the wall that might be exploited by other countries. But it seems that this concern is not warranted. First, though temporary, an exception for Argentina and Brazil, thanks exactly to ABACC, is already established in other venues - noticeably in the NSG guidelines for nuclear material exports. As already mentioned, there is no sensible reason for not taking it into account here. Second, the increased acceptance of the Additional Protocol cuts both ways: while it weakens Brazil's stance on not accepting additional burdens on NNWS until effective progress in nuclear disarmament by the NWS, it also weakens an eventual case against tailoring it to specific countries out of concern for precedent. Third, IAEA should understand that accepting such an approach would be a major gesture of goodwill and confidence-building by both countries. After all, ABACC was created - and universally praised - *before* the Additional Protocol was drafted. Acknowledging that, and incorporating specific concerns from Brazil and Argentina related to ABACC, would actually be to reward

27 Brazil claims that its centrifuges have an innovative design, and this should be protected for commercial reasons. On the other hand, we have no knowledge at all of any interest whatsoever, by any country or foreign institution, to either buy some of those centrifuges or to have access to that specific technology.

cooperation, not stonewalling. Finally, this adjusted protocol might even be an opportunity for IAEA. If it incorporates agreed safeguards dispositions related to nuclear submarines, this adjusted protocol would be furthering the safeguards approach into a hitherto dubious, ambiguous niche of safeguards issues; it would be advancing the safeguards culture, not weakening it.

Of course, should that reconsideration take place and Brazil come to embrace the Additional Protocol or a specifically-tailored equivalent, it would not necessarily mean abandoning its proactive stance towards nuclear disarmament[28]. Quite on the contrary, this could actually be an opportunity. For instance, Brazil would be in an excellent position to endorse or promote initiatives for total elimination of HEU, including in naval nuclear reactors (Ma and Hippel 2001; Philippe and Hippel 2016; Hippel and Philippe 2016). In fact, naval propulsion, particularly by the US and Russia, is by far the largest source of annual demand for HEU, accounting for more than half of its estimated total yearly use (Hippel and Philippe 2016). The bad example set by those countries and also by the UK could be played as a card for any NNWS intent on being less than transparent in its nuclear endeavors - in fact, this card was actually played by Iran during the UE3+3 negotiations (Philippe and Hippel 2016). Since that is technically feasible, eventual NWS's resistance to those standards might even be construed as hypocritical and penny-picking, and a lack of commitment to non-proliferation and to nuclear security overall. Also, a push for increased naval nuclear fuel cycle transparency, on which NWS's fall very short (Maerli 2002), might also enhance Brazil's proactivity.

Finally, should Argentina eventually sign the Additional Protocol, Brazil's hand might become severely weakened, even for this alternative. Though it seems that Argentina would rather act jointly with Brazil on that matter, the possibility that Argentina might sign the Additional Protocol on its own should not be excluded (Kassenova 2016). Overall, time seems not to be in Brazil's favor in this regard.

Of course, all this discussion should not lead one to forget that the whole issue of safeguards related to the nuclear submarine can be addressed entirely within the framework of INFCIRC/435 and INFCIRC/153, Corrected. Addressing the Additional Protocol issue is a matter related to the broader context of negotiations, and not to the safeguards arrangement for the nuclear submarine itself.

Conclusion

An eventual safeguards arrangement on nuclear material for submarine propulsion between Brazil, ABACC, IAEA and, presumably, Argentina, would set the precedent for future arrangements by NNWS and NWS alike. Contrariwise to the rather defensive thinking in Brazil, that might even be an opportunity for enhancing Brazil's role in non-proliferation and nuclear disarmament issues. It might boost confidence in Brazil's nuclear submarine program and, by implication, in Brazil's nuclear program as a whole, even in the absence of an Additional Protocol. A comprehensive approach, including a fresh look at current nuclear policy in Brazil, might strengthen, not weaken,

28 This should not be construed as a statement either in favor or against Brazil's stance on nuclear disarmament, and also not in favor or against nuclear disarmament.

Brazil's hand in nuclear negotiations, including on disarmament. Such a comprehensive approach is suggested here as a contribution to the debate. Of course, we are looking at issues and decisions with long-term implications, so further debate is much needed.

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