

# Nuclear Security Science & Policy Institute

A Division of the  
Texas Engineering Experiment Station

NSSPI-12-010

## SAFETY, SAFEGUARDS AND SECURITY IN INDIAN CIVIL NUCLEAR FACILITIES

*Ankush Batra\* and Paul Nelson*

April 5, 2012



*\* Visiting Scholar from the School of Nuclear Energy, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, India. Currently affiliated with PM-Dimensions Pvt. Ltd.*

Comments, criticisms, discussion, questions and suggestions regarding this report are welcome. Respondents are kindly requested to provide same in the form of electronic mail addressed to [three\\_s\\_report@ne.tamu.edu](mailto:three_s_report@ne.tamu.edu).

## EXECUTIVE SUMMARY

There have recently been many calls, especially from within the International Atomic Energy Agency (IAEA), for states interested in civil nuclear energy programs not only to focus upon the “3Ss” of safety, safeguards and security, but to exploit commonalities between these important concerns in order to make this focus practically realizable. Much of the emphasis upon the 3Ss has occurred within the context of states having or considering developing new civil nuclear programs. The study described in this report considers the issue of integrating the 3Ss for the unique case of India, as a state that has long had a civil nuclear energy program, but which has only recently become well integrated within the international market for nuclear materials and technology.

This study begins with a review of calls for achieving synergies between the 3Ss, as arising from the IAEA and elsewhere, along with reasons for India to be interested in such synergies. India plans sharp expansion of its domestic nuclear-power industry, based upon imports of uranium enabled by its 2008 agreement with the Nuclear Suppliers Group, and has an announced intent to export some of its considerably developed pressurized heavy-water reactor technology. If synergies among the 3Ss could increase economy and efficiency for civil nuclear energy, that could be very helpful to India in either domestic expansion or export. The present study identifies, at a very high-level, the opportunities and challenges that exist in this regard for India, especially in view of the foreseeable changes in the nuclear energy enterprise within India. The challenges stem partially from the current administrative organization of the nuclear enterprise within India, but also from generic difficulties inherent in achieving synergies among the 3Ss.

The general understanding of the 3Ss, and the administrative structure supporting efforts in each of these areas individually, is reviewed, for both the IAEA (Section 2) and India (Section 3). There appears to be few fundamental differences in the respective approaches to the 3Ss individually, although there is a paucity of openly available literature from the Indian Department of Atomic Energy (DAE) regarding its efforts in either safeguards or security. In fact, much of the current motion in India toward restructuring the organizational responsibility for regulation of the civil nuclear enterprise seems based on criticism of lack of public communication by the DAE on even nuclear safety, which is viewed globally as the ‘S’ for which transparency is by far the most desirable.

Notwithstanding this criticism, India has a good record in nuclear safety; however, its experience with safeguards is limited to cooperation with the IAEA for the limited number of Indian nuclear facilities procuring internationally supplied fuel or technology. Further, although India has some activity on nuclear security, its key organization in this field, the Global Centre for Nuclear Energy Partnership, is newly announced and as yet scarcely functioning.

Availability of IAEA assistance and guidelines in meeting the challenge of coordinating the 3Ss at the facility design level is reviewed from the open literature. Although a great deal of optimism is expressed in various publications of the IAEA, a substantial review of various possibilities fails to identify concrete instances of application. Within the DAE there appears to be little consideration, at least in the open literature, of synchronizing the Ss. Underneath this lack of initiatives there are real technical challenges associated to achieving significant synergies among the 3Ss at the level of either facility design or system operation. Many of these challenges, along with possible specific measures to address them, are identified. Some of them take the form of tensions among the 3Ss; that is, measures that improve one of the Ss may have the potential for a negative impact upon another.

The following are the key conclusions and recommendations resulting from the study:

- The potential for synergies among the 3Ss to bring significant benefits to the Indian civil nuclear energy program, both domestic and export, has long been recognized by senior officials in the DAE.
  - For one example, in his statement to the 46<sup>th</sup> IAEA General Conference (2002), then DAE Secretary Dr. Anil Kakodkar observed that the IAEA International Project on Innovative

- Nuclear Reactors and Fuel Cycles “is the most appropriate and timely activity to overcome barriers to growth of nuclear power ... (and) ... such technological solutions are the need of the hour and provide superior, cost effective and comprehensive alternatives to the current segmental approach of dealing with technology, safety and safeguards separately.”
- For another, in his paper for the Second International Conference on Asian Nuclear Prospects (ANUP 2010), Dr. S. K. Jain, Chairman and Managing Director of the Nuclear Power Corporation of India, Ltd., noted that “the proliferation risks associated with nuclear power make it inevitable that the cooperation (within the Asian region, on nuclear power) has to be in accordance with the IAEA safeguards mechanism, with monitoring of all nuclear activities.”
  - Both a division of regulatory authority across the 3Ss and what some perceive as an unusually high degree of reliance on opacity in the Indian nuclear program could constitute significant impediments to realization of any possible benefits from synergies among the 3Ss.
  - No instances were found (globally) of significant new advances in realizing synergies that demonstrably offer net cost benefits across the life cycle of civil nuclear facilities, and there are major unresolved technical challenges associated to achieving such benefits.
    - Some of these challenges are analytic, such as developing a methodology for rationally choosing between benefits across the 3Ss (*e.g.*, in facility design), for which benefits currently are denominated in incommensurate terms.
    - For another challenge, technical demonstration of the possibility of dual yet secure use of equipment, especially communications equipment, for control and accounting of nuclear material, could have significant mutual benefits for both safeguards and security.
    - Ultimately it will be necessary to obtain experience with one or more civil nuclear facilities to be constructed (or modified) to obtain tangible experience in the specifics of exploiting synergies and dealing with tensions among the 3Ss in the design and operation of facilities.
    - In order to enable any serious effort to capitalize upon synergies among the 3Ss in the design of nuclear facilities it likely will be necessary to execute a multiyear multistep research program having components of both analytic development and testing of proposed analytic methodologies in the design and construction of actual facilities.
  - The history, capabilities and current intentions of India’s nuclear program place it in a unique position to address these technical challenges, and thereby move toward meaningful design-level and facility-operation synergies among the 3Ss.
    - For one example, the international community could consider attempting to engage the considerable mathematical and computational modeling skill resident in the DAE and associated institutions toward developing methodologies for technologically neutral evaluations of the proliferation resistance afforded by various approaches to safeguards.
    - For another, the international community conceivably could benefit from a better understanding of India’s experience in applying root-cause analysis to improve counter-terrorism efforts.
    - As an ultimate step in a multiyear research and development program as envisioned above, India could contemplate possible advantages in its efforts to sell indigenous nuclear technology on the international market that might stem from offering the “new national reprocessing facility dedicated to reprocessing safeguarded nuclear material under IAEA safeguards” mentioned in the Indo-US 123 Agreement as a test bed for design-level implementation of synergies among the 3Ss.

## TABLE OF CONTENTS

Executive Summary .....	iii
Table of Contents .....	v
Table of Figures .....	vi
List of Tables .....	vii
1 Introduction.....	1
1.1 A Brief Discussion of “3S” Concepts and Synergies .....	1
1.2 Research Objective .....	1
1.3 Statement of Problem .....	2
1.4 Approach to Objective.....	4
1.5 Of Literature Otherwise Not Discussed .....	5
2 IAEA Approach to the 3Ss .....	9
2.1 Overview .....	9
2.2 Definitions .....	10
2.3 Administrative Organization and Activities.....	12
2.3.1 Safety.....	12
2.3.1.1 Nuclear Installation Safety .....	12
2.3.1.2 Radiation, Transport and Waste Safety .....	13
2.3.2 Safeguards .....	14
2.3.3 Security .....	19
3 Indian Approach to the 3Ss .....	23
3.1 Overview .....	23
3.2 Definitions .....	24
3.3 Administrative Organization and Activities.....	25
3.3.1 Safety.....	26
3.3.2 Safeguards .....	29
3.3.3 Security .....	31
4 Opportunities and Challenges for Synergism.....	35
4.1 Potential Synergies, as perceived from the IAEA and India.....	35
4.2 Applicability to India.....	37
4.2.1 Safety and Safeguards.....	38

4.2.2	Safety and Security.....	40
4.2.2.1	Control of sources.....	42
4.2.2.2	Engineering design.....	44
4.2.2.3	Access control.....	47
4.2.2.4	Emergency preparedness and consequence mitigation.....	48
4.2.3	Safeguards and Security .....	49
4.2.4	Safety, Safeguards and Security.....	51
4.2.4.1	Legal and regulatory frameworks.....	52
4.2.4.2	Toward a common measure of risk?.....	55
4.2.5	A Research Program to Enable 3SBD .....	58
4.3	Tensions .....	61
4.3.1	General tensions – an abstract perspective.....	61
4.3.2	India-specific tensions.....	63
4.3.3	A tabular summary of synergies and tensions among the 3Ss.....	68
5	Conclusions and Recommendations.....	71
	Acknowledgments.....	75
	References .....	76

## TABLE OF FIGURES

Figure 1 - A Venn diagram depiction of potential synergies among the 3Ss, with examples. (Courtesy of the IAEA, via blanket permission, from Suzuki et al., 2010) .....	8
Figure 2 - The IAEA Headquarters Complex, in Vienna, Austria. (Source: Wikipedia, by blanket permission) .....	10
Figure 3 – Organizational chart of the IAEA Department of Nuclear Safety and Security (from IAEA, undated s, by blanket permission).....	13
Figure 4 - An emergency Diesel generator (foreground) and associated control system (background). In nuclear power plants such systems typically are used to provide backup electrical power necessary to execute vital safety functions, including core cooling, in event of loss of the offsite power that normally serves. (Photograph courtesy of Diakont Advanced Technologies)Safeguards .....	14
Figure 5 - A floor-mounted VXI Integrated Fuel Monitor CANDU Core Discharge Monitor (VIFC). VIFC is a specialized unattended radiation monitoring system developed to implement safeguards capabilities to	

monitor the core fuel inventory in CANDU reactors, which are very similar to the pressurized heavy water reactors that constitute the bulk of the Indian power reactor fleet. As of 2002 the IAEA reported “the VIFC implementation programme is ... well-matured with 19 systems installed and approximately six new installations scheduled for the next two years. (Photograph courtesy of IAEA, via blanket permission) ..... 15

Figure 6 - Staff at the IAEA's Safeguards Analytical Laboratory (in Seibersdorf, Austria), where samples of nuclear materials from IAEA safeguards inspections are analyzed. (Photo credit, D. Calma/IAEA, used by blanket IAEA permission; from Fischer, 2007)..... 19

Figure 7 - A radiation portal monitor, such as installed at many roadway points of entry into the United States. The devices are used to scan entering vehicles and cargo for radioactive materials. (Photograph courtesy of the Pacific Northwest National Laboratory) ..... 21

Figure 8 - Units 1 and 2 of the Tarapur Atomic Power Station. (Source: Nuclear Power Corporation of India, Limited, by permission ) ..... 25

Figure 9 - Organizational structure of the Department of Atomic Energy (from DAE, 2006, Section “Department of Atomic Energy,” by permission) ..... 27

Figure 10 - Dr. Anil Kakodkar, then Secretary of the Indian Department of Atomic Energy, addressing the IAEA General Conference in 2005. (Photograph courtesy of the Department of Atomic Energy, Government of India)..... 32

Figure 11 - CISF guards at a gated entrance to the Madras Atomic Power Station, which is located at Kalpakkam, about 80 kilometers south of Chennai. (Photograph courtesy of the Department of Atomic Energy, Government of India)..... 33

Figure 12 - Diagrammatic depiction of the complementarity of safety and security (from IAEA, undated a1, by permission) ..... 40

Figure 13 - Dr. S. K. Jain, Chairman and Managing Director of the Nuclear Power Corporation of India, Limited. (Source: Nuclear Power Corporation of India, Limited, by permission)..... 73

**LIST OF TABLES**

Table I - Values of the 3Ts, for each of the 3Ss ..... 62

Table II - Some steps that potentially impact multiple Ss..... 69

**This page is intentionally without content.**



## 1 INTRODUCTION

India has long had a good record in nuclear *safety*, through the activities of the Atomic Energy Regulatory Board (AERB) and the Safety Research Institute (SRI), which is the research arm of the AERB. It has also long (*cf.* AERB, 2001) cooperated with the International Atomic Energy Agency to keep international nuclear materials and technology under the IAEA *safeguards* that are the accepted standard by which the international community receives assurance that such materials and technology provided by countries for peaceful purposes are not diverted by those countries so as possibly to be used for destructive purposes. With the recent announcement of the Global Centre for Nuclear Energy Partnership (Press Information Bureau, 2010), India has taken an initial step toward joining the international nuclear *security* effort to ensure that nuclear materials and technology supplied by or to India or other countries for peaceful purposes are not diverted to other uses by entities acting without proper authorization. (*e.g.*, substate actors such as terrorist groups). In view of many recent suggestions (*cf.* below for instances), it is reasonable to inquire as to possible opportunities for and benefits to India in seeking to capitalize on alleged complementarities (synergies) among these “3Ss.”

### 1.1 A Brief Discussion of “3S” Concepts and Synergies

Recently, there has been a high-level of promotion of the concept of possible synergies between the “3Ss” of Safety, Safeguards and Security for nuclear materials (*e.g.*, Japanese Ministry of Foreign Affairs, 2008). These represent respectively a need to minimize safety risks, proliferation hazards, and security risks in the design and operation of nuclear facilities, in a global environment of potential nuclear power expansion. For the sake of meeting the growing energy need for sustainable development while assuring energy security and alleviating CO<sub>2</sub> emission to the environment, there is a possible global trend to expand or newly embark on the use of nuclear energy for electric power generation in the coming years (World Nuclear Association, 2011). This trend is often referred to as “nuclear renaissance”. Hence, the “3Ss” – safety, security, safeguards – are seen as key enablers for large-scale nuclear energy growth (Bunn, 2008). The trend toward expanding nuclear energy is particularly strong in the Asia Pacific region. In India, the plan is to increase its nuclear generating capacity to “40 GigaWatts-electric (GWe) in 2020 and 60 GWe in 2030, from only 4.1 GWe today” (Arai and Naito, 2009).

### 1.2 Research Objective

It has recently been suggested that a comprehensive design-level approach to the 3Ss highlighted in italics in the preamble to this section (*i.e.*, safety, safeguards and security) offers much opportunity for cost savings and

enhanced efficiency. *The objective of this report is to identify, at a very high-level, the opportunities that exist for India in this regard, especially in view of the foreseeable changes in the nuclear energy enterprise within India, and the challenges that exist, particularly as due to the current administrative organization of that enterprise.*”

See Subsection 1.4 (“Approach to objective”) for an overview of the process taken to achieve this objective, in the form of a very high-level overview of the organizational structure of this report. But prior to that let us first (Subsection 1.3) discuss the current considerations that we believe make this objective worthy of pursuit.

### **1.3 Statement of Problem**

In addition to the motivation from its domestic plans for nuclear energy, India has reasons to consider synergies between the 3Ss because of its announced interest in exporting its pressurized heavy-water reactor technology. Indian Atomic Energy Commission Chairman Srikumar Banerjee (Banerjee, 2010) has stated that Nuclear Power Corporation of India Ltd. is "ready to offer Indian PHWRs (pressurized heavy water reactors) of 220 MWe or 540 MWe for export."

This is a natural direction for India to take, because today there is revival of interest in small and simpler units for generating electricity and this interest is driven both by a desire to reduce capital costs and to provide power away from large grid systems (*e.g.* World Nuclear Association, 2011). However, there is a paucity of experience in either building or operating small nuclear power plants (NPPs). If size be denominated in capacity rather than physical dimension, as appropriate to the concern about capital investment, then India with its fleet of reactors of the capacities in the preceding quotation is practically unique globally in its extent of such experience.

Nonetheless, the international market for nuclear-energy technology is extremely competitive, so that taking advantage of this capability will require holding costs in check, in order to compete favorably with alternative technologies. At the same time it will be important to facilitate customers to meet the expectations of the international community for enhanced attention to the requirements of safeguards and security in nuclear power plants. There is, of course, some tension between these differing objectives. Nonetheless, a comprehensive design-level approach to safety, safeguards and security (the 3Ss) offers a vision of a possibility for cost savings and enhanced efficiency.

Among the 3Ss, design-level opportunities to achieve benefits in cost and other areas have perhaps been most often discussed in the extensive literature on the topic of “Safeguards by Design” (SBD). This subject ties to the preceding suggestion of economic benefits for competitive marketing via the following points from Stein *et al.* (2009): “Opposite to nuclear safety, which is broadly understood and supported by the nuclear industry, safeguards is generally applied after the design and sometimes even after construction has been completed, and it is an unwelcome constraint on the operator. Thus, there is little incentive for facility designers to follow

the developments in the safeguards arena and to analyze what impact they may have on their design concepts. ... However, designers are certainly interested in offering such services so that the owner can operate the facility in the most effective and efficient manner and this may turn into a marketing asset in favor of their design. If SBD can help (by) providing more attractive conditions for both safeguards authorities and operators, the designers will be willing to contribute to the safeguards culture and to work towards synergetic solutions.”

It therefore appears worthwhile to provide here a brief overview of SBD:

Safeguards by Design is defined as “the integration of international and national safeguards, physical security and non-proliferation features as full and equal partners in the design process of a nuclear energy system or facility” (Bjornard *et al.*, 2008, p. 1). According to this reference, the objective of safeguards by design is “to achieve facilities that are intrinsically more robust while being less expensive to safeguard and protect,” and the SBD process has been developed so as to facilitate a number of desirable aims. These aims are listed below (quotations from Bjornard *et al.*, 2008), along with our assessments of what is either desired or needed within the specific Indian framework:

- SBD1. SBD “provides improved safeguards, security, and stronger proliferation barriers, while reducing the life cycle costs to the operator and regulatory agencies.” This precisely encapsulates a possible key motivation for India to achieve synergies between the 3Ss.
- SBD2. The SBD process developed “can be translated to any international context as a model for nuclear facility design.” It certainly is to be hoped this is true, but ultimately that can only be demonstrated by specific successful instances of such translation. However, SBD does at least provide a potentially useful starting point that possibly can be adapted to the specific circumstances of various nations, including India.
- SBD3. SBD “fosters a culture change to ensure the treatment of ‘nuclear security’ considerations as “full and equal” partners in the design process.” At this point that particular aim perhaps is more of a wishful intent, or reasonable hypothesis, than a proven fact.
- SBD4. SBD “provides a useful tool for the project manager responsible for the design, construction, and start-up of nuclear facilities.” India has a significant pool of personnel with project management experience in the civil nuclear area. This particular aim may be better suited to the many states having no prior experience with nuclear energy but currently considering initiating civil nuclear energy programs.
- SBD5. SBD “addresses the key integration activities necessary to efficiently incorporate International Atomic Energy Agency safeguards into the design of nuclear facilities.” This particular aim

seems virtually synonymous with the term “Safeguards by Design,” but it serves the useful purpose of emphasizing that the IAEA is a crucial, perhaps even the crucial, “customer” for any product intended to facilitate safeguards.

## **1.4 Approach to Objective**

In order to accomplish the objective of Subsection 1.2, the subsequent sections of this report will be structured as follows.

- O1. An overview of the IAEA is presented, with some brief discussion of relevant history. This is followed by a discussion of the definitions used by the IAEA for each of the 3Ss, then by a description of the administrative structure of the IAEA for responding to the needs of member states regarding individually each of safety, safeguards and security. (Section 2)
- O2. The overall Indian nuclear enterprise is described, again with some brief history. This is followed by a discussion of the definitions used by the Indian Department of Atomic Energy (DAE) from each of these 3Ss. Following there is a description, to the extent possible based on open-literature sources, of the way India has organized that enterprise to deal with each of safety, safeguards and security. (Section 3)
- O3. Section 4, which is the core of this report, is a high-level critical analysis of the prospects for synergies between and among the 3Ss, from both a general perspective, and for the specific case of India. More specifically:
  - Subsection 4.1 contains a review of the open literature from the IAEA and India on synergies between the 3Ss. We particularly find a paucity of such literature originating from within the Indian nuclear establishment.
  - Therefore Subsection 4.2 consists of a critical review of specific instances of concrete synergies between various of the 3Ss that have been suggested in the literature, with some specific reference as to their potential for the specific case of India. This review then leads into:
  - A discussion in Subsection 4.3 of some possible tensions between and among the 3Ss, both generically and for the specific case of India. (By “tensions” are intended considerations that might make it difficult to achieve synergies between two or more of the 3Ss, without possibly in some way compromising vital aspects of one of safety, security or safeguards.)
- O4. The more salient conclusions and recommendations drawn from these considerations are then briefly summarized in a concluding Section 5.

## 1.5 Of Literature Otherwise Not Discussed

Per the outline of the preceding subsection, much of the pertinent literature emanating from the IAEA or the Indian DAE will be reviewed in Subsection 4.1 below. The present subsection serves to provide an opportunity to review other pertinent literature that otherwise would not be discussed.

Hashim *et al.* (2011) emphasize how an integrated safety, safeguards and security system plays a major role in any nuclear power program. “[This report also] stated there are many benefits to having an integrated [3S] system such as spending less time & resources on reporting, providing synergy and better efficiency in terms of taking corrective action as well as it would be the first step into creating one department that can be both specialized and capable of multi-tasking.” This work was carried out in the context of the GNEII program described by Williams *et al.* (2011), and therefore presumably is aimed primarily at states that are relative newcomers to the benefits of civil nuclear energy.

Kovacic *et al.* (2009) capture what perhaps is the essence of the commonality between the 3Ss, and therefore the potential for synergism between them that many envision: “Safety, security, and safeguards are all ‘preventive’ concepts. Therefore, there are definite commonalities for developing their legal, regulatory, and operational aspects and for how states can organize themselves to achieve them.” The discussion of the present work somewhat loosely follows the morphology suggested by the last sentence of this quotation, in that it is loosely organized about the interaction of the 3Ss with the legal, regulatory (or, more expansively, administrative) and operational aspects of civil nuclear energy, but also attempts to contemplate actions at the level of facility design that would enable achievement of synergies among the 3Ss.

Kovacic *et al.* (2009) also emphasize the unique role of safeguards among the 3Ss, which in turn plays a role in delimiting the scope of the present paper. Specifically, these authors note (*ibid.*, section on “Integration of Safety, Security and Safeguards”) “the term ‘safeguards’ in some newcomer states has a very negative connotation.” Although India is very far from being a “newcomer state” as regards nuclear energy, for certain well-known reasons that do not require further elucidation here the negative connotation accorded in some states to the term “safeguards” arguably reaches its zenith in the case of India. (Here we intend *international* safeguards; domestic safeguards are regarded quite otherwise in India.) A major consequence of this has been a reluctance of India to engage in bilateral or regional agreements on the topic of nuclear energy generally, especially as intended to buttress the nuclear nonproliferation regime. This reluctance has historically not encompassed the International Atomic Energy Agency (IAEA), within which India has tended to be very active. For this reason the scope of the present work is limited to the IAEA (Section 2) and Indian (Section 3) approaches to the 3Ss, with emphasis upon the challenges India faces in integrating them, and the role the IAEA might offer in meeting these challenges.

Arai and Naito (2009) discussed the importance of the 3Ss, especially in light of the impending nuclear renaissance in the Asia Pacific region. The importance of the 3Ss was emphasized, especially in establishing necessary national infrastructure for states expanding or newly embarking on the use of nuclear energy. (In particular the key position of the 3Ss in the IAEA Milestones Document (IAEA, 2007), which was designed to provide guidance to such states, was strongly noted by Arai and Naito.) Some more-or-less specific forms of possible synergy between and among the 3Ss also were identified. These authors emphasized a Japanese initiative to assist other states in the Asia Pacific region to establish suitable 3S-based infrastructures, particularly in the context of Japan's key role in the International Initiative on 3S-Based Nuclear Energy Infrastructure that emerged from the 2008 G8 Hokkaido Toyako Summit (Japanese Ministry of Foreign Affairs, 2008).

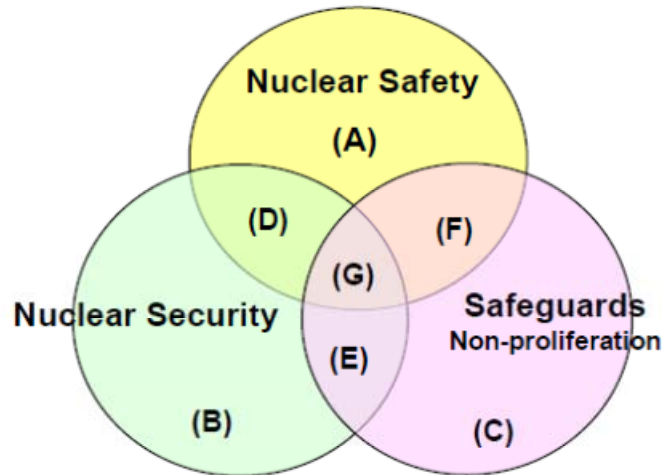
Khalil et al. (2009) contemplate an "integrated consideration" of, on the one hand proliferation resistance and physical protection, and on the other hand safety and reliability, "to facilitate the optimization of their effects and the minimization of potential conflicts" within the context of the Generation IV International Forum. (This forum consists of 13 members – India is not a member – "working together ... to lay the groundwork for the fourth generation of nuclear energy systems" (GIF, undated). See GIF (2008) for the basis for nuclear safety considerations within the context of this international organization.) In the terminology of the present report, Khalil *et al.* (2009) look at a relatively high level, but with consideration of some specific examples, first at potential synergies *and tensions* between safety and security, and then between safeguards and the combination of safety and security. Further, some attention is given to economic considerations as a backdrop to all of these considerations, especially as motivation to operators impacts both potential synergies and possible tensions among the 3Ss.

As further suggestions of synergies among the 3Ss, Khalil *et al.* (2009) also suggest that "passive systems and structures that eliminate requirements for external power sources and frequent operator surveillance may be synergistic for both safety and security, if designed for both functions. Likewise, it is important to know where nuclear materials are and how their protection against hazards and threats is organized from both PR&PP (proliferation resistance and physical protection) and S&R (safety and reliability) standpoints." (Parenthetical explanations added.) See more on p. 2448 of Khalil (2009). The first of these points indeed is a potential synergism between safety and security attack by attempted sabotage; on the other hand, the second is a potential synergy between safety and security attack by attempted theft. We shall again have occasional need to distinguish by intended consequence between these two different types of security attacks. See Subsections 2.2 and 3.2 for definitions of "nuclear security" that underlie this comment, and subsection 4.2.1 for a discussion somewhat related to the second of these perceived synergies, but denominated as a

synergy between safety and the material control and accounting function attendant to safeguards rather than between safety and security.

Stein *et al.* (2009) begin with a review of SBD, the goal of which they regard as “through early and continuous interaction, to integrate international safeguards into the complete design process of the facility and to provide designers with sufficient guidance to facilitate Safeguardability of new nuclear installations which allows for efficient and effective application of safeguards measures (systems and processes) with reduced impact on the facility operation.” (Re SBD, see the further quotation from this work in Subsection 1.3 above.) They then use this as a springboard from which to introduce the concept of “Safety, Security, and Safeguards By Design (3SBD)” through which they envision the possibility of “broad cost savings for multiple stakeholders” that could “thus be a competitive advantage for the designer.” Opportunities for, and challenges to, 3SBD are reviewed, and it is suggested that “the backbone of a 3SBD will be a multi-customer approach to the various instrumentation types used at a nuclear facility to maximize the synergies between different users.” Some of the concepts mentioned that could be instances of this approach include: an on-line sensor network designed for a multi-customer approach; “video surveillance (that) has different clients that can share the same instrumentation if ... placed in the appropriate locations so that it supports the field of view needed by each user”; and “the underlying data management and processing infrastructure ... especially the use of standard communications protocols (with separate authentication and encryption schemes for each user) ... .”

Suzuki *et al.* (2010) describe efforts by the Japan Atomic Energy Agency to conduct “detailed analyses of the R&D programs and cultures of each of the ‘S’ areas to identify overlaps where synergism and efficiencies might be realized, to determine where there are gaps in the development of a mature 3S culture, and to coordinate efforts with other Japanese and international organizations.” The results are summarized in the Venn diagram of Figure 1, in the form of instances of activities that fall into each of the seven nonempty intersections thus created. The authors discuss issues that “challenge promotion of the 3S initiative,” with particular focus on the different cultures between the 3Ss as regards assessment of the associated risk. Suzuki *et al.* (2010) further suggest that “one of the most promising synergies resulting from the integrated 3S consideration is the adoption of a 3S by Design (3SBD) approach for new nuclear facilities,” again somewhat in analogy to the SBD approach outlined above. Some emphasis is devoted to an effort to develop notionally a risk-informed approach for safeguards and security, similar to that more-or-less familiar within the field of safety, toward “harmonization of the risk notions embedded in each of the ‘S’ areas.” Further toward that end an overview of current risk assessment methodologies is provided.



- (A) Emergency core cooling system for nuclear power plant, (B) Barrier at the facility entrance, (C) Authenticated apparatus**
- (D) Double-entry doors to keep negative pressure and prevent radioactive release**
- (E) Management of nuclear material using containment and surveillance and remote monitoring camera**
- (F) Management of nuclear material for criticality and accounting control**
- (G) Possible monitoring camera for multipurpose use, such as joint use of equipment**

Figure 1 - A Venn diagram depiction of potential synergies among the 3Ss, with examples. (Courtesy of the IAEA, via blanket permission, from Suzuki et al., 2010)

Suzuki, Burr and Howell (2011) extend this discussion by providing a review of several approaches, principally for safeguards, capable of providing estimates of frequency of occurrence of threats and associated measures of consequence, presumably as inputs to some measure of risk. Among the approaches considered, some emphasis seems to be given to the Markov model of Yue, Cheng and Bari (2008) as a means of estimating both frequency of occurrence of attempts at diversion and the magnitude of associated errors in measurements. This approach is illustrated in application to a hypothetical reprocessing facility.



## 2 IAEA APPROACH TO THE 3Ss

In this section there is a description of the working approach of the IAEA toward safety, safeguards and security in NPPs and fuel-cycle facilities. There are three subsections. The first consists of a brief history of the IAEA, and how it interacts with the international community so as to bring the benefits of nuclear energy to mankind, while reducing the risks associated with that technology. The second subsection consists of the definitions given by the IAEA, and therefore suggests how IAEA views each of the 3Ss. The third subsection treats the administrative organization of the IAEA, specifically the suborganizations within the IAEA responsible for each of the 3Ss, and how that suborganization fits within the hierarchical organization of the IAEA itself (IAEA, undated b). In this last subsection there is a subsection for each of safety, safeguards and security.

### 2.1 Overview

The current edition of Wikipedia (2011) succinctly describes the history of, legal basis for, and mission of, the IAEA in a manner that very nicely suits current purposes: “The IAEA was established as an autonomous organization on 29 July 1957. Though established independently of the United Nations through its own international treaty, the IAEA Statute (IAEA, undated c), the IAEA reports to both the UN General Assembly and Security Council. ... The IAEA serves as an intergovernmental forum for scientific and technical cooperation in the peaceful use of nuclear technology and nuclear power worldwide. The programs of the IAEA encourage the development of the peaceful applications of nuclear technology, provide international safeguards against misuse of nuclear technology and nuclear materials, and promote nuclear safety (including radiation protection) and nuclear security standards and their implementation.”

An alternate brief history, as excerpted from Fischer (1997) and quoted on the current IAEA website (IAEA, undated d), is: “The IAEA was created in 1957 in response to the deep fears and expectations resulting from the discovery of nuclear energy. Its fortunes are uniquely geared to this controversial technology that can be used either as a weapon or as a practical and useful tool. The Agency's genesis was US President Eisenhower's Atoms for Peace (Eisenhower, Dwight D., 1953) address to the General Assembly of the United Nations on 8 December 1953. These ideas helped to shape the IAEA Statute (IAEA, undated c), which 81 nations unanimously approved in October 1956. The Statute outlines the three pillars of the Agency's work - nuclear verification and security, safety and technology transfer.” (See Chernus (2002) for a fascinating description of the interactions within the US Government that ultimately led to the Atoms for Peace speech. In the present context it is also an interesting historical footnote that the presiding officer (General Assembly President) on the occasion of this speech was Mrs. Vijaya Lakshmi Pandit, of India.)

Both of these brief histories emphasize the longstanding importance of the 3Ss to the mission of the IAEA. (Provided, in the second, one understands “verification” as referring to safeguards.) Both Scheinman (1987) and the official history by Fischer (1997) provide extremely detailed historical overviews of the IAEA.



Figure 2 - The IAEA Headquarters Complex, in Vienna, Austria. (Source: Wikipedia, by blanket permission)

## 2.2 Definitions

IAEA (2006) has given definitions of nuclear safety, safeguards and security that tend to be internationally accepted, although (as emphasized by Kovacic, *et al.*, 2009, esp. for safeguards) there are sometimes differences of terminology or of language that can cause difficulties:

- **Nuclear safety:** “The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.”
- **Nuclear safeguards:** “The means applied to verify a State’s compliance with its undertaking to accept an IAEA safeguards agreement on all nuclear material in all its peaceful nuclear activities

and to verify that such material is not diverted to nuclear weapons or other nuclear explosive devices.”

- **Nuclear security:** “The prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear or other radioactive substances or their associated facilities.”

The IAEA safety glossary (IAEA, undated) notes:

*“Safety is primarily concerned with maintaining control over sources, whereas (radiation) protection is primarily concerned with controlling exposure to radiation and its effects. Clearly the two are closely connected: radiation protection (or radiological protection) is very much simpler if the source in question is under control, so safety necessarily contributes towards protection.”*

(See also SAPIERR II, 2008, p.12)

Past these bare definitions, IAEA (2006) contains extensive discussion intended to clarify the relationship between the terms thus defined and kindred terms that often are encountered in discussions of nuclear technology. As above, “nuclear safety” sometimes is taken as directed toward maintaining control over sources of nuclear radiation, whereas the term “radiation protection” is applied to efforts to control exposure to radiation and its effects. The definition give above is more comprehensive, in that it is inclusive of both of these types of efforts to minimize adverse consequences of exposure to nuclear radiation.

Similarly, nuclear security “... includes ‘physical protection’ as that term can be understood from consideration of the Physical Protection Objectives and Fundamental Principles, the CPPNM (Convention on Physical Protection of Nuclear Materials) and the Amendment to the CPPNM.” (IAEA, undated e, p. 3, parenthetical explanation added). Finally, “nuclear security” is sometime used, especially in the United States, in a more comprehensive sense to include threats involving misuse by either host state or substate actors, and thus also encompassing what the IAEA would term as “nuclear security.”

The documents mentioned here are widely considered as the international pillars of nuclear security. They are somewhat different and complementary. The Physical Protection Objectives and Fundamental Principles are formulated as the “recommendations level document for the physical protection of nuclear materials and nuclear facilities” INFCIRC/225 (IAEA, 2011g). These recommendations are nonetheless sometimes given a basis in national law by incorporation into international supply agreements. By contrast the CPPNM and Amendment thereunto, as embodied respectively in INFCIRC/274 (IAEA, 1980a) and IAEA (2005c) are or respectively are intended as binding international agreements. The CPPNM entered into force on February 8, 1987, and as of June 30, 2008 had been agreed to by 136 states. As of March 16, 2012 the Amendment had been ratified by 54 states (IAEA, 2012).

## 2.3 Administrative Organization and Activities

The IAEA website (IAEA, undated f) succinctly captures the IAEA mission as follows: “The IAEA's mission is guided by the interests and needs of Member States, strategic plans and the vision embodied in the IAEA Statute (IAEA, undated c). Three main pillars - or areas of work - underpin the IAEA's mission: Safety and Security; Science and Technology; and Safeguards and Verification.”

Thus all three of the Ss feature prominently in the mission of the IAEA. The following three subsections are devoted to brief descriptions of the suborganizations of the IAEA that focus upon respectively safety, safeguards and security, and of the principal activities of those suborganizations in support of the relevant interests and needs of Member States. The highest level suborganizations within the IAEA are termed as “departments.” Departments are organized into divisions, and divisions in turn into sections. See IAEA (2010) for an organization chart down to the section level.

### 2.3.1 Safety

The IAEA (2011) considers that “national governments are responsible for regulations that govern how safety at nuclear facilities is maintained,” while “nuclear facility operators are ultimately responsible for the safety of their facility.” “The IAEA, through the Department of Nuclear Safety and Security, works to provide a strong, sustainable and visible global nuclear safety and security framework ... ; but it does not have the mandate to enforce the application of safety standards within a country.”

The indicated framework has a variety of elements: These include (Taniguchi, 2009) “... high quality safety standards, security guidelines (and) various peer reviews, advisory services and training events based on these standards and guidelines.” See IAEA (undated i) for a (much) more comprehensive list of items falling within this safety-related framework, with many useful links.

Within the IAEA responsibility for activities related to nuclear safety reside within the Department of Nuclear Safety and Security (see Figure 3). More specifically, within that department these responsibilities belong to the Divisions of Nuclear Installation Safety, and of Radiation, Transport and Waste Safety.

#### 2.3.1.1 Nuclear Installation Safety

The objectives of this division are as follows: (IAEA, undated g)

- “To enhance the global nuclear safety regime and to ensure appropriate levels of safety throughout the total lifetime of all types of nuclear installations in Member States by ensuring the availability of a consistent, needs-based and up to date set of safety standards, and assistance in their applications”

- “To enable Member States seeking to embark on nuclear power production programmes to develop appropriate safety infrastructures through the availability of Agency guidance, assistance and networking.”
- “To enable Member States to build improved competence frameworks for the safety of nuclear installations and to enhance their capabilities for capacity building as the foundation for strong safety infrastructure.”

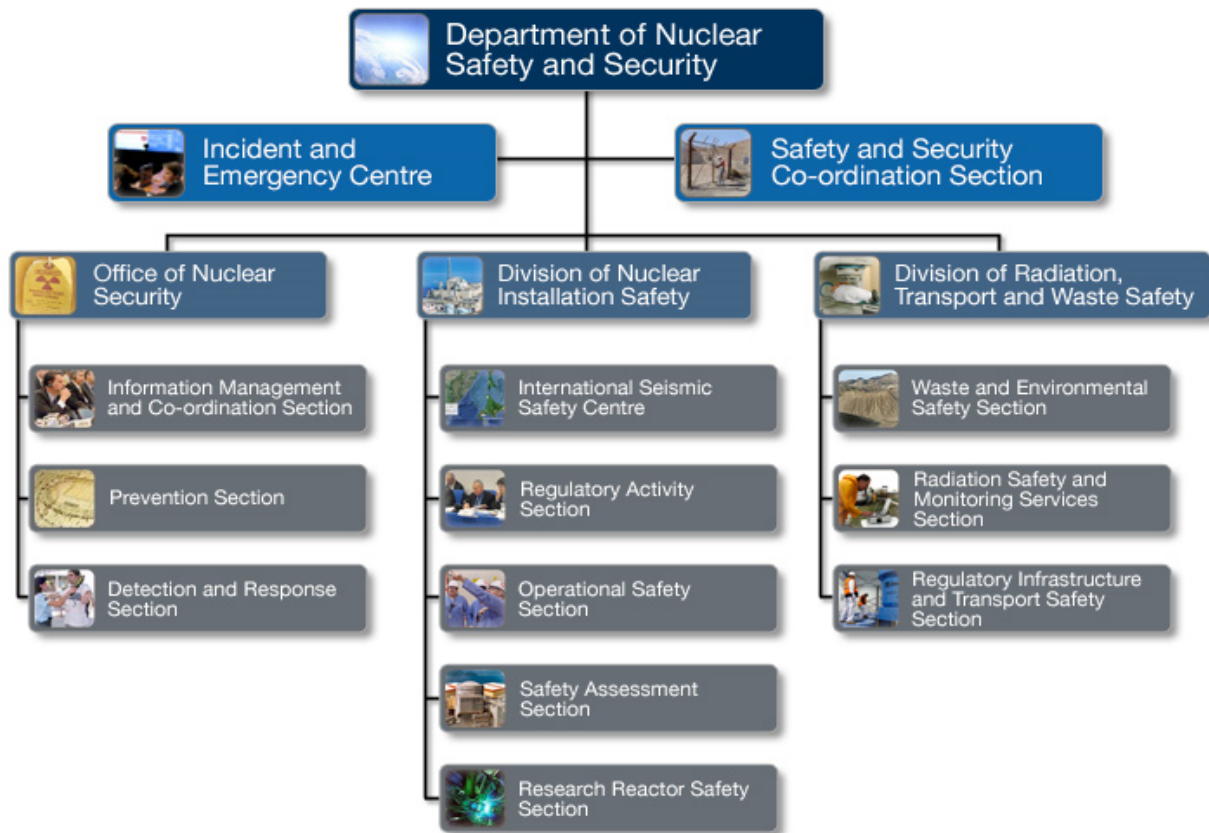


Figure 3 – Organizational chart of the IAEA Department of Nuclear Safety and Security (from IAEA, undated s, by blanket permission)

### 2.3.1.2 Radiation, Transport and Waste Safety

“The Division of Radiation, Transport and Waste Safety ... develops and maintains standards for radiation protection, radioactive waste safety and safety in the transport of radioactive material that enable the beneficial uses of radiation to be exploited while ensuring appropriate protection of workers, the public and

patients. It also assists Member States in the implementation of these standards and provides related services” (IAEA, undated h).



Figure 4 - An emergency Diesel generator (foreground) and associated control system (background). In nuclear power plants such systems typically are used to provide backup electrical power necessary to execute vital safety functions, including core cooling, in event of loss of the offsite power that normally serves. (Photograph courtesy of Diakont Advanced Technologies)Safeguards

### 2.3.2 Safeguards

The IAEA meets its safeguards responsibilities through its Department of Safeguards (IAEA, undated j). The mission statement of that department reads as follows: “As the verification arm of the IAEA, the Department of Safeguards primary role is to deter the proliferation of nuclear weapons by detecting early the misuse of nuclear material or technology, and by providing credible assurances that States are honouring their safeguards obligations. The Department also contributes to nuclear arms control and disarmament, by

responding to requests for verification and other technical assistance associated with related agreements and arrangements” (IAEA, undated k).

States may come by the “safeguards obligations” mentioned in the preceding paragraph via a variety of bilateral or multilateral agreements. The best known of these undoubtedly is the Nuclear Non-proliferation Treaty (IAEA, 1970), but there are a number of other agreements that states have entered into (*cf.* IAEA undated n for an extensive list of such treaties). Such treaties commonly contain clauses that authorize the IAEA to enter into agreements with the various States Party to verify independently that the states are meeting their respective obligations. In order to be able to meet this requirement for independent



**Figure 5 - A floor-mounted VFI Integrated Fuel Monitor (VIFC). VIFC is a specialized unattended radiation monitoring system developed to implement safeguards capabilities to monitor the core fuel inventory in CANDU reactors, which are very similar to the pressurized heavy water reactors that constitute the bulk of the Indian power reactor fleet. As of 2002 the IAEA reported “the VIFC implementation programme is ... well-matured with 19 systems installed and approximately six new installations scheduled for the next two years. (Photograph courtesy of IAEA, via blanket permission)**

verification the IAEA, through its Department of Safeguards, has developed “the safeguards system (that) comprises an extensive set of technical measures by which the IAEA Secretariat independently verifies the correctness and the completeness of the declarations made by States about their nuclear material and activities” (IAEA, undated o).

The material of this paragraph, on the basic elements of safeguards procedures, is adapted from IAEA (undated x), especially the section entitled “How Are Safeguards Agreements Implemented?”. All otherwise unattributed quotes are from that reference. A summary view of these procedures from the IAEA perspective is that the agency carries out an initial facility design review and verification, and subsequently carries out on-site inspections to verify reports of material flows that are provided to the IAEA, by the facility operator, through the State System of Accounting and Control (SSAC) of the host state. “These data provide the basis for the IAEA's own independent

verification activities, which include on-site inspections involving activities such as record checking and the taking of measurements.” Details of these activities depend upon “the design and type of nuclear facility and the type and quantities of material being handled there.” The backbone of the system, both for SSACs and IAEA verification, is material accountancy. But “special measures - the use of seals on containers or doors, and surveillance by cameras and other devices - are used to monitor access to and use of the nuclear material, and provide complementary measures to material accountancy.”

The SSACs mentioned in the preceding paragraph offer opportunities for taking advantage of potential synergies among the 3Ss, so are of some note in the present context. But there are nontrivial challenges to

realizing these opportunities, as will be detailed, especially for the particular case of India, in Section 4 below. Here we limit ourselves to two particular relevant questions regarding SSACs: What are the objectives of an SSAC? What is, if any, the legal basis for the requirement that a state have an SSAC? According to IAEA (1980, p. 2): “A system of accounting for and control of nuclear material may have ... a national objective, to account for and control nuclear material in the State and to contribute to the detection of possible losses, or unauthorized use or removal of nuclear material (and) an international objective, to provide the essential basis for the application of IAEA safeguards pursuant to the provisions of an Agreement between the State and the IAEA.” The former objective is related to nuclear security, and the latter to safeguards. The cited reference continues to say: “These two objectives are different in nature, and the organization and functions of a system of accounting for and control of nuclear material having only one of these objectives will differ in many respects from those of a system having only the other. Nevertheless, there are many elements of each system which would contribute to the attainment of both objectives.” The latter quotation captures both the potential for tension among the 3Ss, and the hope for beneficial aspects of synergistic effects. Presumably because of this dilemma, IAEA (1980, p. 2) further notes that “it is for each State to decide whether or not it wishes to establish one combined system or independent systems to pursue these different objectives.”

As regards the legal basis for a requirement that states have SSACS, IAEA (1980, pp. 1-2) states: “The objectives of IAEA safeguards are set out in the IAEA Statute (IAEA, 1956) and in documents INFCIRC/153 (Corrected) (IAEA, 1972) and INFCIRC/66/Rev.2 (IAEA, 1968). Document INFCIRC/153 (IAEA, 1972) provides the basis for Safeguards Agreements between the IAEA and States pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and INFCIRC/66/Rev.2 provides the basis for other Agency Safeguards Agreements. A Safeguards Agreement conforming to INFCIRC/153 (Corrected)” requires a SSAC. “Safeguards Agreements conforming to INFCIRC/66/Rev.2 do not explicitly call for States to” have SSACs, “but the fact that the document calls for agreement between the IAEA and the State on a ‘system of records’ and a ‘system of reports’ implies the need for a system. The establishment of a State System of Accounting for and Control of Nuclear Material (SSAC) can serve a useful purpose in all IAEA Safeguards Agreements, whether or not such a system is explicitly required.” (IAEA (1975) also is a useful basic reference regarding SSACs.)

Material accountancy, either for national or international purposes, typically is applied as described in the form of the following adaptation from IAEA (2008b), especially Section 5.5. If conservation of mass is applied to material of a specific isotopic composition, within a specified “material balance area” (MBA) and over a specified “material balance period” (MBP) then necessarily

$$AE = AB + AX - AY,$$



where: AE = actual amount of material in the MBA at the end of the MBP; AB = actual amount of material in the MBA at beginning of the MBP; AX = actual additions to material within the MBA during the MBP; and AY = actual removal of material from the MBA during the MBP.

Now suppose estimates of these four quantities are available, say respectively PE = ending physical inventory, PB = beginning physical inventory, X = estimated additions to inventory and Y = estimated removals from inventory. Then the amount of material that is unaccounted for by these estimates is

$$\text{MUF} = \text{PB} + \text{X} - \text{Y} - \text{PE}.$$

These estimates might come from simply counting items, or from measurements of the amount of mass of some isotope, or from computational modeling of the process presumed to occur within the MBA, which process could destroy some amount of certain isotopes and create amounts of others. “For item facilities, normally zero MUF is expected. For bulk handling MBAs a non-zero MUF is expected because of measurement (or computational) uncertainties and the nature of the process. MUF is not in itself an indication that diversion has occurred, but does constitute an estimate of the quantity that might have been available for diversion.” (From IAEA, 2008b, p. 10, parenthetical clarification added; see this reference for more such details on material accounting and its control.)

Hough *et al.* (1975) state that “... every safeguards agreement concluded in connection with NPT ... (includes) ... a definition of the objective of safeguards as ‘timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection’.” In this context “significant quantity” typically is on the order of ten kilograms.<sup>†</sup> But various, depending on the nature of the facility and even the particular MBA, of the numbers on the right could be much larger than this.

This difficulty of determining MUF with satisfactory accuracy, as a small difference of much larger numbers, is the central technical challenge to safeguards – especially as material conceivably could be accumulated in significant quantities over several MBPs. See IAEA (2003) for a detailed overview, from the perspective of the IAEA, of the status of safeguards technology circa 2003. See Rundquist and Watkins (1984) for a more-or-less detailed overview, from the IAEA perspective, of the efforts (circa that date) by member states to provide improved technology; Sacchetti (2009) provides a more recent, but less detailed, perspective on the past evolution and projected future development of safeguards technology. See Conlin *et al.* (2011), Lee,

---

<sup>†</sup> IAEA (1993) considers a significant quantity of plutonium as eight kilograms, and of uranium-235 in highly enriched uranium as twenty five kilograms.

Kim, Shin and Kim (2011) and Goddard, Charlton, Gariazzo and Peerani (2011) for examples of currently ongoing research intended to supply methodologies to improve the accuracy of estimates of MUF, in various types of situations.

For safeguards verification at declared nuclear facilities material accountancy is the traditionally key technical measure, although surveillance has played an increasingly important role in recent years. On the other hand, implementation of the measurements necessary to material accounting can interfere with achievement of optimal operation of a NPP or other facility. For that reason some states have entered “Additional Protocol” (IAEA, 1997a) agreements with the IAEA that permit “IAEA not only to verify the non-diversion of declared nuclear material but also to provide assurances as to the absence of undeclared nuclear material and activities (anywhere) in a State” (IAEA, undated z). The ability to look essentially anywhere for possible weapons-related activities can provide confidence that materials are not being improperly diverted, without the necessity for highly accurate material-balance measurements. This approach also permits conclusions to be drawn based on merely qualitative measurements (*e.g.*, environmental swipes); however it is at best of limited value in assuring no such diversion for states permitted to have nuclear weapons and related facilities. See IAEA (1995) for much more on the history of safeguards.

The Department of Safeguards is organized administratively to meet these responsibilities as follows: “The Department consists of six Divisions: three operational, one that is responsible for concepts and planning, one that covers information management, and another that provides technical support; as well as an Office of Analytical Services. ... Each of the three Operations Divisions is responsible for the implementation of safeguards in a different geographical area. **Division of Operations A** is responsible for inspections in Australasia and East Asia; **Division of Operations B** is responsible for the Middle East, South Asia, Africa, some non-EU European states, and the Americas; and **Division of Operations C** is responsible for Europe, the Russian Federation and Central Asia.” (IAEA, undated l).

Thus the Operations Divisions are responsible for obtaining data, perhaps by emplacing equipment, that are intended to verify that nuclear material is being used in the declared manner, typically to produce energy. The other divisions provide a variety of support services, such as data analysis, computational technology and improved measurement equipment.

The IAEA also publishes series of booklets on safeguards with the name *International Nuclear Verification Series (NVS)* with the objective of explaining IAEA safeguards, especially the new developments in safeguards, particularly for facility operators and government officers involved with these topics. IAEA booklet International Nuclear Verification Series No. 1 (IAEA, 2003) comprises a relatively recent discussion of safe-



Figure 6 - Staff at the IAEA's Safeguards Analytical Laboratory (in Seibersdorf, Austria), where samples of nuclear materials from IAEA safeguards inspections are analyzed. (Photo credit, D. Calma/IAEA, used by blanket IAEA permission; from Fischer, 2007)

guards techniques and equipment, as used for both nuclear material accountancy and containment and surveillance measures, and for the new safeguards measure of environmental sampling and IAEA (undated q) is a list (with links) of other recent IAEA publications relevant to safeguards.

### 2.3.3 Security

Within the IAEA the Office of Nuclear Security “plays a leading role in the planning, implementation, and evaluation of the IAEA’s activities in the area of nuclear security” (IAEA, undated r). This office functions as a division within the Department of Nuclear Safety and Security. (See the organization chart as shown in Figure 3). It was formerly the Office of Physical Protection and Material Security (IAEA, undated r) within the Department of Safeguards (Flory, 2010). This original administrative setup reflected a time “when the principal concern was the theft of nuclear material” (Flory, 2010) in amounts of significant quantities.

The renaming and move to Nuclear Safety (in 2002; *cf.* Cavina, 2009, Slide 2) reflected recognition by the IAEA Board of Governors of a need to address an expanded range of security-related threats, including

sabotage of facilities to create deliberate releases of radioactive materials, and trafficking in smaller quantities of radioactive materials for possible use in radioactive dispersal devices. The term “office” (rather than “division”) reflects the financial support for this expanded role through “a voluntary funding mechanism, the Nuclear Security Fund (NSF), to which Member States were called upon to contribute” (IAEA, undated t).

Activities within the Office of Nuclear Security reflect the recognition of this expanded range of threats. The office “... provides advisory services to States to establish the necessary infrastructure to protect nuclear and other radioactive materials from theft and diversion, protect nuclear installations and transport against sabotage and other malicious acts, and to combat illicit trafficking in nuclear and other radioactive materials” (IAEA, undated u). In this respect the functions of the IAEA relative to nuclear security are more nearly similar to those for nuclear safety than for safeguards. That is, there are no legal, regulatory or operational responsibilities of the IAEA, beyond those of serving as a source of advice and information to member states.

Also, (IAEA, 2006a)“... after the September 11, 2001, terrorist attacks on New York and Washington DC, the IAEA launched a three year plan for enhanced antiterrorism activities known as the *IAEA Nuclear Security Plan of Activities*. ... A new IAEA Nuclear Security Plan for 2006–2009 (built) upon the accomplishments of the first Plan and on strengthened international instruments and agreements. This nuclear security plan mainly (focused) on the following three areas which build upon and expand a number of existing IAEA activities.

- **Prevention** activities aim to protect nuclear and other radioactive material and related facilities and transports from malicious acts.
- **Detection and response** activities aim to strengthen the capabilities of States to uncover illegal acts and possession of nuclear and radioactive material, and to effectively respond to malicious acts or threats, such as a possible dispersal of radioactivity.
- **Needs assessment, analysis and coordination** underpin the entire Plan and support its implementation. These include evaluation missions, cooperation with bilateral and multilateral support programmes, and information collection and evaluation.”

Current IAEA nuclear security activities are being carried out under IAEA Nuclear Security Plan (2010-2013), which is the third plan (IAEA, undated u). This plan builds on existing international legal instruments and agreements to help interested states strengthen their nuclear security to combat the risk of nuclear terrorism. The activities delineated in the preceding bulleted list align with the three sections that collectively comprise



Figure 7 - A radiation portal monitor, such as installed at many roadway points of entry into the United States. The devices are used to scan entering vehicles and cargo for radioactive materials. (Photograph courtesy of the Pacific Northwest National Laboratory)

the Office of Nuclear Security. These are the Sections of Prevention, of Detection and Response, and of Information Management and Co-ordination (IAEA, undated s). See Kenn and Verlini (2009) for the views of a former Director of the Office regarding evolutions in nuclear security.

The IAEA Office of Nuclear Security issues a series of publications under the name *IAEA Nuclear Security Series* that comprises of Nuclear Security Fundamentals, Recommendations, Implementing Guides and Technical Guidance. See IAEA (undated v) for a comprehensive current list of the publications in this series.

One of the emphases of this office seems to have been the need for human resource development programs in nuclear security. In this regard one of the reports (IAEA, undated w) in the series mentioned in the preceding paragraph consists of guidance as to the development of educational programs in nuclear security that could be used by all states. In broad outline this report describes two possible approaches to educational programs related to nuclear security: A Master of Science in Nuclear Security; and a certificate program in nuclear security. The latter would represent something of a specialization in nuclear security, within some

broader Master of Science program (*e.g.*, nuclear engineering). It is not clear, from either the US or the Indian perspectives, that employment opportunities in the field of nuclear security would support an M.S. program entirely directed toward nuclear security; but it appears, at least from the US perspective, that a small number of such certificate programs might be quite viable.

This emphasis on education also seems supportive of a parallel emphasis on inculcating a culture of nuclear security. See IAEA (2008c) for an implementing guide in the *IAEA Nuclear Security Series* mentioned above that discusses development of a culture of nuclear security.

### 3 INDIAN APPROACH TO THE 3Ss

In this section there is a description of the working approach of India, largely through the Department of Atomic Energy (DAE) and its integrated group of organizations, toward safety, safeguards and security in NPPs and fuel-cycle facilities. The first of the three subsections consists of a brief history of the DAE and its associated organizations, and how it interacts with established international standards and entities so as to bring the benefits of nuclear energy to mankind, while reducing the risks associated with that technology. The second subsection is concerned with the definitions of the individual Ss, as given by the DAE, and therefore suggests how DAE views each of the 3Ss. The third subsection concerns the administrative organization of the DAE, specifically the organization(s) within India, largely within the DAE, that is (are) responsible for each of the 3Ss, and how that organization interacts with or fits within the hierarchical organization of the DAE itself. In this latter subsection there is a subsection for each of safety, safeguards and security.

#### 3.1 Overview

The initial enabling legislation for nuclear energy in India was the Atomic Energy Act of 1948, which was enacted into law within a year of India achieving independence (GOI, 1998). (“GOI” denotes “Government of India.”) The Atomic Energy Commission was established “immediately after the passage of” this act (Singh, 1965). “On 2 August 1954, the President of India issued an order creating the Department of Atomic Energy with effect from 3 August 1954. The order stipulated that all business of the government of India relating to atomic energy ... shall be transacted in the Department of Atomic Energy (and) ... mentioned that the Department of Atomic Energy shall be allocated to the charge of the prime minister” (Parthasarathy, 2008).

In 1958 “the Indian cabinet approved the setting up of an Atomic Energy Commission ... (that) replaced the one set up in 1948” (Parthasarathy, 2008). Organization charts promulgated by the DAE (e.g., DAE, 2003, p. 4) sometimes portray the AEC as situated *above* the DAE. But the resolution under which the AEC currently operates states “the Secretary to the Government of India in the Department of Atomic Energy is *ex-officio* Chairman of the Commission” (GOI, 2010, Clause 3(b)). Further, that resolution also (GOI, 2010, Clause 6(b)) states that “the Chairman shall have the power to overrule the other members of the Commission ... .” These two facts at best raise questions about the effectiveness of any independent oversight the AEC might actually provide to the DAE and its various constituent bodies. These questions have emerged as significant points in current discussions regarding administrative organization for regulation of nuclear safety (see subsection 3.3.1).

The Act of 1948 ultimately was superseded by the Atomic Energy Act of 1962 (GOI, 1962), as subsequently amended several times. This act, perhaps especially Sections 14 and 20, continued the spirit of the 1948 act in very strongly reserving to the central government all prerogatives in India that in any way relate to nuclear technology. There is interesting history on the concerns underlying this legal position as seen from the following quotation (Parthasarathy, 2008, p. 103)

*In 1947, there were rumours to the effect that the Travancore Durbar (that was the way the administrative set-up in the former princely State of Travancore was then referred to) had entered into an agreement with the British government for the disposal of monazite and thorium nitrate. The beach sands in that part of India contain the world's richest deposit of thorium. The news disturbed Nehru. He was then President of the Indian Science Congress. Many scientists were equally concerned about the development. They passed a special resolution asserting that the State should own and control all these minerals and foreign exploitation of these resources should be prohibited.*

Subsequent governments have established a variety of governmental organizations to exercise those prerogatives. The organizations having specific responsibilities for safety, safeguards and security, along with their activities in support of these responsibilities, are the respective subject of the following sections.

## 3.2 Definitions

The Atomic Energy Regulatory Board (AERB) has long been the duly constituted nuclear regulatory authority for India. (See subsection 3.3.1 below for more historical detail.) The AERB Safety Glossary (AERB, 2005) makes the following definitions and comments:

- **Nuclear safety:** “The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of site personnel, the public and the environment from undue radiation hazards.”
- **Nuclear security:** “All preventive measures taken to minimize the residual risk of unauthorised transfer of nuclear material and/or sabotage, which could lead to release of radioactivity and/or adverse impact on the safety of the plant, plant personnel, public and environment.”

We were unable to find any definition given by DAE or any of its associated organizations for “nuclear safeguards.” Further, India is not a party to the Nuclear Non-Proliferation Treaty (NPT), which is the principal international agreement under which need for safeguards is presumed to arise. However, India is party to an agreement with the IAEA for some of its civil nuclear facilities to be under safeguards. Specifically, the World Nuclear Association (2011) states that: “Under plans for the India-specific safeguards to be administered by the IAEA in relation to the Civil-military separation plan, eight further reactors will be safeguarded (beyond Tarapur 1&2, Rajasthan 1&2, and Kudankulam 1&2): Rajasthan 3&4 from 2010, Rajasthan 5&6 from 2008, Kakrapar 1&2 by 2012 and Narora 1&2 by 2014.”





Figure 8 - Units 1 and 2 of the Tarapur Atomic Power Station. (Source: Nuclear Power Corporation of India, Limited, by permission )

### 3.3 Administrative Organization and Activities

In India functions related to nuclear safety and nuclear security are carried out at all facilities at which significant amounts of fissile materials are handled or generated, and functions related to nuclear safeguards at all such facilities that have been declared as civil in nature (GOI, 2006). Therefore the responsibility for these functions necessarily in large part falls on the various organizations under the DAE that have responsibility for operating such facilities.

Most power reactors, whether civil or strategic, are operated by the Nuclear Power Corporation of India, Limited (NPCIL). NPCIL was formed in the year 1987, “with the objective of operating atomic power stations and implementing the atomic power projects for generation of

#### TAPS 1&2

The Tarapur Atomic Power Station (TAPS) is located in the Thane district of Maharashtra State, approximately 100 kilometers north of Mumbai. Its units 1 and 2 began operation on October 28, 1969, and are the oldest commercially operating nuclear power stations in India. They also provide a microcosm of the nuclear-based discord between India and the “developed” international community.

These boiling water reactors were supplied by the US General Electric Corporation, with the Bechtel Corporation serving as architect-engineer. GE reportedly declined participation in plant operation, because of concerns about liability. It did continue to supply fuel, under the terms of the then operative 123 agreement between the IAEA, India and the United States, and the plants remained under IAEA safeguards under that same agreement.

The Nuclear Nonproliferation Act of 1978 prohibited any US entity from providing any nuclear materials or technology to India. When India responded by indications of withdrawing the TAPS plants from IAEA safeguards, if required to fuel them indigenously, there ensued nearly three decades of the US brokering fuel supplies from other states. There was tension between this effort and concurrent efforts to grow the Nuclear Suppliers Group (NSG), whose members normally would have been precluded from providing such fuel supplies. NSG exceptions for preexisting commitments and for furtherance of safety in operating nuclear plants were useful in resolving these tensions. Circa 2006 a high DAE official described TAPS 1 & 2 as India’s most economical source of electricity, largely because of the very favorable economic terms provided by the United States in the 1960’s.

electricity in pursuance of the schemes and programmes of the Government of India under the Atomic Energy Act, 1962” (NPCIL, undated) A separate organization, the BHAVINI was established in the year 2003 (MTAR, undated), to operate the fast reactors ultimately planned to emerge under the three-stage Bhabha Plan (cf. Jain, undated). The principal organizations that operate facilities at the front end of the fuel cycle are the Atomic Minerals Directorate for Research and Exploration (AMD), Hyderabad; Uranium Corporation of India Ltd. (UCIL), Jaduguda (Jharkhand); Nuclear Fuel Complex (NFC), Hyderabad; and Heavy Water Board (HWB), Mumbai. The operations under the Front-End Fuel Cycle range from mining, milling and processing of ore to fabrication of fuel. In addition, heavy water production is also an ancillary programme to the DAE's PHWR program (GOI, undated a). Mining and milling operations for uranium are carried out at several locations, foremost Jaduguda (in Jharkand state); and fuel fabrication at NFC (in Andhra Pradesh state). Refining and Conversion facilities are located at the DAE Nuclear Fuel Complex at Hyderabad (World Nuclear Association, 2011a). The Back-End of the Nuclear Fuel Cycle comprises fuel reprocessing and nuclear waste management. Along the back end of the fuel cycle the BARC and IGCAR (GOI, undated a) are responsible for reprocessing, so as to recover the fissile materials Pu-239 and U-233 that are bred respectively from the fertile materials U-238 and Th-232. The nuclear waste management related activities for immobilization of waste have been operating at Tarapur, Trombay and Kalpakkam (GOI, undated a). There are also three nuclear enrichment facilities in India, namely Boron Enrichment Plant at Kalpakkam, Rattihali Enrichment Facility near Mysore and Uranium Enrichment Plant at Trombay (NTI, 2011). See Figure 9 for a diagrammatic representation of some of the considerable array of institutional enterprises that operate under the umbrella of the DAE.

### 3.3.1 Safety

Four of the 32 sections of the Atomic Energy Act of 1962 dealt with various aspects of nuclear safety (Parthasarathy, 2008, p. 108). This author indicates that “during the earlier years, DAE itself enforced the provisions of the Act” (*ibid.*). As regards safety issues much of this seems to have been carried out through a Safety Review Committee (DAE-SRC) consisting of experts drawn from within the DAE itself (Parthasarathy, 2008, p. 109).

In 1983 the Atomic Energy Regulatory Board was formed to carry out these functions (*ibid.*, p. 110). “AERB’s functions included enforcement of provisions of radiological protection in the radiation installations outside the DAE” (*ibid.*). “As per the recommendation of a Committee set up on 21 March 1987 DAE-SRC became a part of AERB as AERB-SRC and later as Safety Review Committee for Operating Plants (AERB-SARCOP). The functions and responsibilities of AERB were subsequently broadened considerably” (*ibid.*, p. 110). See the cited work for (many) more details of the history of how India organized itself to deal with nuclear safety.

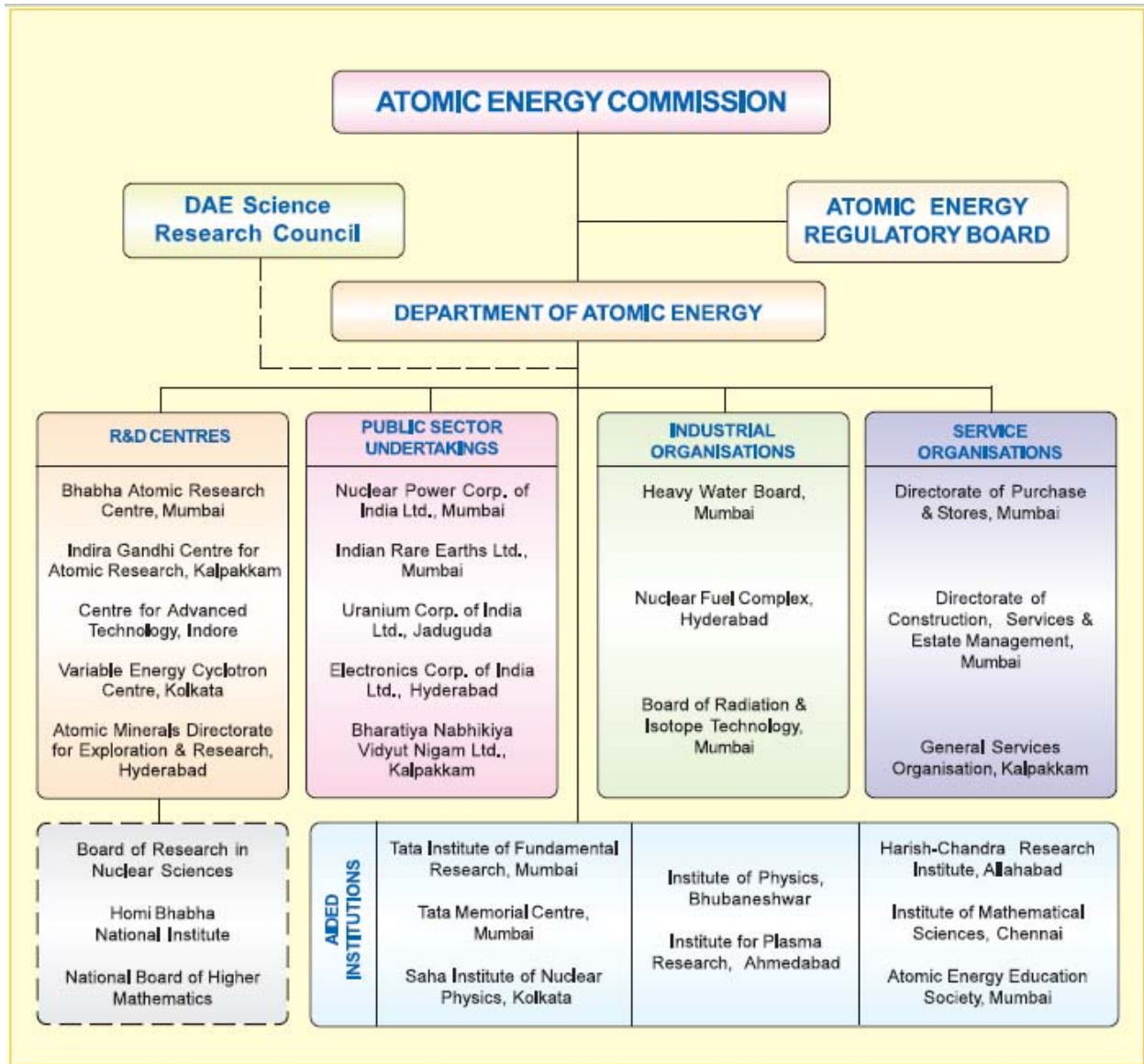


Figure 9 - Organizational structure of the Department of Atomic Energy (from DAE, 2006, Section “Department of Atomic Energy,” by permission)

Many of the organizations operating installations that are regulated by the AERB (*cf.* the preceding preface to this subsection) are themselves under the DAE. The AERB traditionally has been officially portrayed as an independent body. For example, “in all the nuclear installations ... an independent body, the Atomic Energy Regulatory Board (AERB) monitors safety” (DAE, 2006, Section “Safety and the Environment”). See also the organization chart in Figure 9 (from DAE, 2006, Section “Department of Atomic Energy”).

In fact the original intent apparently was “to enable AERB to function effectively and exercise its authority in an independent manner ... (by having it) ... constituted by and reporting to the Atomic Energy Commission” (Parthasarathy, 2008, p. 109). However, the fact that the Chair of the AEC is also the Secretary of the DAE seems at a minimum to create a perception that this independence may be less than full. (Note that Figure 9 shows the AERB at a position above DAE, but below the AEC, which in fact makes its position relative to the dual-capacity Chair AEC and Secretary DAE quite ambiguous.) An example of such perceptions: “The fact that India's Atomic Energy Regulatory Board (AERB) remains a dependent creature of the Department of Atomic Energy (DAE) is an indictment of official attitudes to nuclear safety” (Editor, Frontline, 1999). Different individuals presumably well-positioned to know have strong and diametrically opposed opinions regarding the actual degree of independence of the AERB (*cf.* Parthasarathy, 2008, p. 114 and Gopalakrishnan, 2011).

Ideally there should be considerable transparency in the matter of safety for protecting environment and people. Some view this transparency as missing in the Indian nuclear power program, due to the partial dependence of AERB. For example, Dr. A. Gopalakrishnan, former Chairman of the AERB, recently has been quoted (Newslick, 2011) to the following effect: “I think people like us have to really get after the AERB to make sure that they operate independently. There are various signals of when somebody starts operating independently. You can see minutes of their safety meetings, reviews etc. on their websites or we will insist they should put it there. Basically, transparency.”

In the aftermath of the Fukushima incident (March 2011), many people are questioning the future of nuclear power or, at the very least, asking how much negative influence it will have on future plans. The Indian public is deeply upset and shocked at the disaster. This incident and earlier tensions of questions on independence of the AERB give more emphasis on transparency issues as a public concern. This incident has provided a likelihood of some changes in the present nuclear regulatory framework, to ensure the regulatory authority works as a separate independent body.

World Nuclear News (2011) recently reported a bill calling for restructuring of the current regulatory body and its power was introduced to the Indian Parliament. According to that report “a new Council of Nuclear Safety (CNS) would oversee and review policies on radiation safety, nuclear safety and other connected matters. Chaired by the prime minister, the CNS would be made up of various government ministers, with the cabinet secretary and head of the Indian Atomic Energy Commission (AEC) as *ex-officio* members, plus government-nominated ‘eminent experts.’ The second major body to be established would be called the Nuclear Safety Regulatory Authority (NSRA) and would be responsible for ensuring radiation safety and nuclear safety in all civilian sector nuclear activities.”

As per the wordings of the bill presented in Lok Sabha (PRS, 2011), the NSRA would be “autonomous in the exercise of its powers and functions.” Clause 18 of the bill provides that NSRA would subsume and supersede the existing Indian nuclear regulator, the Atomic Energy Regulatory Board (AERB), and AERB's current chair and members would take on the corresponding roles in the NSRA until new officers are appointed. The proposed bill (Chapter VI) also provides for the government to set up other regulatory bodies to take responsibility for the purpose of national defense and security.

In respect to the preceding discussion of transparency, the bill (PRS 2011, at Clause 20(2)(c)) states that the NSRA shall “ensure transparency by systematic public outreach on matters relating to nuclear safety without disclosing sensitive information and compromising confidentiality of commercially sensitive information of technology holders.” One of the more controversial aspects of the current bill seems (*e.g.*, The Telegraph, 2011) to be Clause 20 which in its entirety states that “The Authority (*i.e.*, the NSRA), while discharging its powers and functions, shall not act against the interest of the sovereignty and integrity of India, the security of the State, friendly relations with foreign States, public order, decency or morality.” At this writing the form in which this pending legislation will pass, if at all, is uncertain.

### *3.3.2 Safeguards*

India's position toward safeguards is complex, and not always well understood by the international community (or within India). It essentially is accepting of safeguards on imported materials or technology, or materials derived therefrom (as a form of a “principle of pursuit”), but resistant to safeguards on indigenous materials, as processed via Indian technology. (For example: “India has never been and will never be a source of proliferation. ... We have repeatedly said that every cooperation project in nuclear power would be open to international safeguards,” Singh, 2005.) In this regard safeguards on specific facilities have long been in place in India. (See Kumar, 2007, for historical notes on installing safeguards on some of the earlier Indian reactors, which have continually remained under safeguards to this day.)

This position was consistent with the facility-specific (INFCIRC-26 and -66) safeguards agreements in effect preceding the NPT, but not with the comprehensive (INFCIRC-153) safeguards that came about in the early 1970's, hard on the heels of the NPT. As a consequence India never agreed to comprehensive safeguards, and subsequent events later in the 70's led to India's effective exclusion from the international market for nuclear materials and technology for failure to accept comprehensive safeguards. It is fair to say that India chafed under those restrictions, and thus tended to view the entire topic of “safeguards” with considerable suspicion. For example, immediately following the quotation in the preceding paragraph, Singh (2005) says “however, such cooperation, today, remains hostage to restrictive denial regimes.”

We think it is accurate to state that India's position effectively now prevails, as during the period 2005-2009 India and the international community essentially agreed that at this time it was better for India to be a singular exception within the nuclear nonproliferation regime than a member of a small number of exceptions outside that regime. (Or, in the words of Talbott (2004, p. 231), to be an NPT outlier rather than outlaw.) In October 2009, India's safeguards agreement with the IAEA became operational, with the government confirming that 14 reactors will be put under the India Specific Safeguards Agreement by 2014. This agreement (INFCIRC-754; *cf.* IAEA, 2009) was based on the IAEA's facility-specific safeguards (INFCIRC-66 Rev.2, IAEA, 1968, but contains a number of "India-specific" modifications. Kinney et al. (2011) gives an overview of the implementation of INFCIRC-754, as seen from the perspective of the IAEA.

The fact that India's safeguards agreement with the agency is based on INFCIRC-66 (Rev. 2) raises another issue that has the potential to affect Indian implementation of synergies among the 3Ss, especially between safeguards and security. Pursuant to the earlier discussion in subsection 2.3.2, this has the consequence that any requirement for India to establish a SSAC is rather more implicit than explicit. Regardless of the legalities of this issue, either the absence of an Indian SSAC or the lack of its involvement in safeguards (but see the following paragraph, regarding the latter possibility) necessarily will limit the potential for Indian realization of any synergies between safeguards and security.

Even if India has not formally established an SSAC having the corresponding international objectives, as outlined in subsection 2.3.2, it presumably has some entity that assumes the national accounting and control objectives delineated in that same prior subsection. There is a shortage of material in the open literature that provides any suggestions as to how India is organized to meet those presumed national objectives. The most extensive discussion we find occurs in Eldridge (2005), and appears to be a second-person summary (presumably by the Rapporteur) of remarks by K. Raghuraman. (Raghuraman is identified in Eldridge (2005, p. 57) as affiliated with the International Studies Division of the DAE.) These remarks indicate that the NUMAC (Nuclear Material Accounting and Control) cell of the DAE "is primarily responsible for nuclear material control and accounting activities in India and for meeting India's international safeguards obligations." The subsequent discussion, which is approximately two pages in length, mentions "an Inventory Information and Control and Data Management Section and a control laboratory," by way of control and accounting. Past the quotation earlier in this paragraph, there is no further mention of safeguards. There is the following particularly intriguing passage: "Indian authorities have undertaken 'root cause analysis' to improve counter-terrorism efforts by developing a better understanding of why terrorism occurs."

This historic change in the position of India vis-à-vis safeguards during the past few years presumably has led to the intent to export Indian indigenous PHWR technology that already was mentioned in the Introduction.

In consonance with that intent, it would appear to be in India's self-interest to direct some of its significant capability in nuclear science toward improvements in safeguards technology. More particularly, either the concept of safeguards by design (Cooley, *et al.*, 2009), or that of economies through synergies between the 3Ss that is espoused here, would appear to offer India some additional competitive advantages in marketing its PHWR technology abroad. If India is pursuing such possibilities, it is difficult to discern that from outside the official Indian nuclear complex. Dighe *et al.* (2010) is a noteworthy exception to the general lack of work within the DAE complex that is even nominally directed toward improvements in safeguards technology.

Perhaps the one exception to that trend has been Indian participation in the IAEA International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), which does have a safeguards component. In that context, already in 2002 Secretary Kakodkar stated (Kakodkar, 2002) that INPRO "is the most appropriate and timely activity to overcome barriers to growth of nuclear power ... (and) ... such technological solutions are the need of the hour and provide superior, cost effective and comprehensive alternatives to the current segmental approach of dealing with technology, safety and safeguards separately." This comment is prescient of the current interest in the 3Ss, and it is to be hoped that India has or soon will follow it with commensurate action. However, the absence of the word "safeguards" from the mission description of the recently announced Global Centre for Nuclear Energy Partnership (GOI, undated) does not give rise to great optimism in that regard. (Although "proliferation resistance" is mentioned, in the mission statement for the "School of Advanced Nuclear Energy Systems Studies" subentity.)

As already suggested, India's expanded international safeguards agreement, as of late 2008, not only opened the closed doors of getting support (*e.g.* fuel, other technologies etc) from international communities, but it also gives a platform to India to sell its PHWR technology in the international market. This strongly urges the consideration of "Safeguards by Design," which may offer much opportunity for cost savings and enhanced efficiency (see Subsection 1.3 for the details). The SBD approach not only offers support for taking advantage of possible synergies between the 3Ss, but it also may attract possible importers (*i.e.* countries looking for small and medium power reactors) who have interest in PHWR technology.

### 3.3.3 Security

The Central Industrial Security Force (CISF) "is currently providing security cover to *nuclear installations*, space establishments, airports" (GOI, undated b, emphasis added). The CISF is a paramilitary force that comes under the aegis of the Ministry of Home Affairs (GOI, undated c). Thus nuclear security is one aspect of nuclear-related affairs within India that appears not to be an exclusive monopoly of the DAE.



Figure 10 - Dr. Anil Kakodkar, then Secretary of the Indian Department of Atomic Energy, addressing the IAEA General Conference in 2005. (Photograph courtesy of the Department of Atomic Energy, Government of India)

At the same time one suspects that the DAE of necessity is involved in any aspect of nuclear security that involves aspects of nuclear science and technology. From outside the Indian nuclear establishment it is difficult to know exactly where the line is drawn, but recent press reports (Times of India, 2011) indicate significant efforts toward high-level coordination. Certainly anyone who has visited a nuclear installation in India will be well aware that physical protection, at least at the outer perimeter, appears to be under the tight control of the CISF.

Regardless of issues of internal responsibility, there are many indications (e.g., Kakodkar, 2002) that India long has taken seriously external threats to its nuclear installations, and that this resolve was only strengthened by the 11/26/08 terrorist attacks in Mumbai. For example, India acceded to the International Convention on Physical Protection in 2002 (*ibid.*) and has long supported the IAEA Nuclear security fund through in-kind contributions. One of the schools proposed for the planned Global Centre for Nuclear Energy Partnership (GOI, undated) is to be devoted to “nuclear security studies.” For the 2010 “Common Wealth Games held at New Delhi ... a large number of personnel from various security agencies in the country were trained (by DAE) on detection of any radiation sources and mitigation of any radiation emergency” (Banerjee, 2010a).



BARC very recently hosted an India-IAEA workshop (Anonymous, 2011) on “Protection against Sabotage and Vital Area Identification.”



Figure 11 - CISF guards at a gated entrance to the Madras Atomic Power Station, which is located at Kalpakkam, about 80 kilometers south of Chennai. (Photograph courtesy of the Department of Atomic Energy, Government of India)

India is beset by pockets of unrest associated with different groups seeking some form of greater national autonomy, or simply desiring to create instability for a variety of political reasons. In view of this it is a bit remarkable that so little attention seems to have been given to threats to nuclear security that potentially could arise from such sources (see Kakatkar-Kulkarni, 2010 for an exception from a Track II source), especially given the attention that has been given by the IAEA to the so-called “insider threat” (e.g., IAEA, 2008). This could be simply because India regards secrecy as an unusually vital element of its countermeasures to any such threats, but it is very difficult from the outside to distinguish that from a possibly unrealistic faith that threats of this type will never materialize.

In the references cited thus far in the present subsection there is a notable shortage of works identifiable as emanating from the DAE. This may be because of the aforementioned penchant for secrecy. (See subsection 4.3 for further discussion of this tendency.) Regardless of the reason, this makes anything that is so identifiable all the more valuable by way of perhaps understanding the position of the DAE. One such

source is Raghuraman (2005). At the vantage point of 2011 the sections of this work on “Material Protection, Control and Accountancy,” on “Partnership with the IAEA” and on “Roadmap for the Future” make for interesting reading, if for no other reason than as a reminder of early hopes that remain unfulfilled. Somewhat in that same vein, the previously cited work by Eldridge (2005) contains a summary of remarks by Raghuraman, on the topic of nuclear security.

## 4 OPPORTUNITIES AND CHALLENGES FOR SYNERGISM

This section is the core of the report. It is directed to the reality of the potential for synergies between the 3Ss, especially for the case of India. It consists of three subsections. The first subsection is a review of the literature emanating from the IAEA and from India on the topic of potential synergies. It is concluded that although during the past few years a substantial literature has originated within the IAEA on the potential for such synergies, little or nothing new seems as yet to have emerged by way of illustration of concrete examples of such synergism. An open-literature review of publications emanating from within India shows very little by way of even consideration of such possible synergies.

In view of these somewhat negative results, Subsection 4.2 comprises an assessment, for possible applicability in the Indian context, of concrete instances of the potential synergies that were discussed in the literature previously reviewed in Subsections 4.1 and 1.5. The results of this assessment are not encouraging for possible synergies. In view of this observation, Subsection 4.3 is directed toward a general discussion of possible tensions among the 3Ss, both globally and specific to India, that might have a tendency to prevent realization of possible synergies.

### 4.1 Potential Synergies, as perceived from the IAEA and India

This subsection is a review of the literature, as emanating from either the IAEA or within India, on the subject of possible synergies between and among the 3Ss. Similar literature from elsewhere already has been reviewed in Subsection 1.5,

Some interface between the 3Ss seems obvious from their respective definitions given above, whether one employs the IAEA definitions of Section 2 or the (not too dissimilar) DAE definitions of Section 3. An integrated approach to nuclear safety, safeguards and security has been identified by the IAEA (2008a) as having a “mutually reinforcing effect” that “could create potential synergies and efficiencies.” While such general sweeping statements have an important role, if this vision is in any substantial measure to be realized, then at some point it is necessary to get past generalities and platitudes, and identify specific activities that could somehow possibly benefit from potential synergies between the 3Ss.

IAEA (2006a) already listed a number of such possible activities, as follows:

- “The IAEA undertakes joint safety and security missions to evaluate national laws and regulations for the control of sources.” Note however (IAEA, 2006b, p. 19), the observation that “laws and regulations applying to other aspects of nuclear security, *e.g.*, in the criminal code or related to combating illicit trafficking, do, however, still need separate examination.”

- “The legislative assistance programme takes a comprehensive approach which recognizes the importance of the interface between security, safety and safeguards.”
- “Engineering safety design reduces the vulnerability of vital areas in nuclear facilities to sabotage.” (Here there would appear to be a special opportunity for 3SBD, as previously discussed in the literature review of Subsection 1.5.)
- “National systems for accounting and control of nuclear material deter and/or allow early discovery of theft”; and
- “Physical protection measures and measures to detect illicit trafficking contribute to non-proliferation objectives.”

The safety literature published by IAEA is replete with suggestions of more-or-less specific synergies with security. For example (IAEA, undated p): “The IAEA safety standards concern the security of facilities and activities to the extent that they apply to measures that contribute to both safety and security, such as:

- Appropriate provisions in the design and construction of nuclear installations and other facilities.
- Controls on access to nuclear installations and other facilities to prevent the loss of, and the unauthorized removal, possession, transfer and use of, radioactive material.
- Arrangements for mitigating the consequences of accidents and failures, which also facilitate measures for dealing with breaches in security that give rise to radiation risks.
- Measures for the security of the management of radioactive sources and radioactive material.”

Finally, a strong synergy between safeguards and security has been described (IAEA, 2006b, p. 20) as follows: “Similarly, security and safeguards objectives are jointly attained by measures to enhance the control of and accounting for nuclear material. Training in implementing state systems of accounting for and control of nuclear material has been set in both a safeguards and security framework. The safeguards system in general, with its focus on deterring and detecting the diversion of nuclear material makes a key contribution to the overall nuclear security architecture and, in turn, security requirements such as early detection of theft, detection of illicit trafficking, nuclear forensics and physical protection of nuclear material, make a substantial contribution to non-proliferation objectives.”

By contrast to the voluminous literature on commonalities between the 3Ss that has been published by the IAEA, and is scarcely touched on by the above discussion, a search of the DAE website on “safety & security

& safeguards” turned up a total of seven hits.<sup>‡</sup> Of these, five dealt with various discussions that arose in the context of the deliberation leading to the signing of the Indo-US nuclear agreement in late 2008; one was the historical (Kumar, 2007) paper already touched on in subsection 3.3.2; and one was the presentation by Kakodkar (2002) that also was discussed in that same preceding subsection. As already mentioned in that earlier discussion, the remarks by Secretary Kakodkar quoted there seem remarkably supportive of the general concept that the 3Ss can offer mutual support to each other.

A fair summary of the above literature review is that there is relatively little, from either the IAEA or India, in the way of specific suggestions of possible synergies among the 3Ss, especially of a nature that would permit of implementation at the facility level. There are multiple possible reasons for this paucity. In the case of the IAEA the lack of suggestions concretely applicable at the level of individual facilities could simply stem from the fact that the IAEA itself has no responsibility for such facilities. In the case of India it could be that there is considerable consideration of the benefit of such synergies, just not in the open literature. This is consistent with widespread perceptions of the lack of transparency of the DAE, even on the matter of nuclear safety (*cf.* subsection 3.3.1 and subsection 4.3.2 below).

There is however yet another possibility: It might be that the potential for synergies among the 3Ss is, at least in the case of India (as, *e.g.*, opposed to a state newly starting a civil nuclear program) merely a superficial illusion, without real substance. Based on the information developed thus far, we simply cannot distinguish between the likelihood of this possibility, versus that of the possibilities indicated in the preceding paragraph. As the literature does not resolve this question for us, we now attempt to develop our own assessment of the potential, in the Indian context, for actions along the lines of the more-or-less specific synergies suggested in the literature in the present subsection, and in Subsection 1.5.<sup>§</sup>

## 4.2 Applicability to India

It is convenient to organize this evaluation, of the potential applicability to India of various more-or-less specific synergies among the 3Ss, into subsections, according to which of the 3Ss are perceived as linked, relative to a given topic.

---

<sup>‡</sup> Comparable number, in parentheses, for other similar organizations are: AERB (6); IAEA (846); NPCIL (6), US DOE (158) and US NRC (3895).

<sup>§</sup> Number of hits is, for a variety of reasons, at best a very crude metric for determining relative level of activity on any particular subject.

### 4.2.1 Safety and Safeguards

There seems to be relatively little in the literature reviewed above (Subsections 1.5 and 4.1) that deals with specific (facility-level) synergies between safety and safeguards. We conjecture this is in some part because these two particular Ss have long been subjects of concern, both at the IAEA and for states having long-existing civil nuclear programs. Consequently any potential synergies between them are likely to have been identified long ago, and corresponding efficiencies already to have been implemented for some time.

As an example, the only specific instance of a synergy between safety and safeguards that seems to have been mentioned in the literature reviewed in this report is the suggestion of Suzuki et al. (2010; *cf.* Subsection 1.5) that “management of nuclear material for criticality and accounting control” comprises a commonality. In some measure this in fact represents a long-recognized and commonly known point of contact between these particular Ss. In the US the Nuclear Regulatory Commission treats its official responsibility for safety and safeguards of nuclear materials through its Office of Nuclear Material *Safety and Safeguards* (*cf.* US NRC, 2011). For an example in the IAEA context, IAEA (1997) notes that: “activities may be required for long term, quality assured, records and availability of the FA (fuel assembly) data to characterize the spent fuel in storage. *This data (sic) is required for safety and safeguards reasons.*” (Parenthetical explanations and italicized emphasis added.) More generally, criticality safety and SSACs require much the same data (i.e., isotopic content and physical location) regarding spent fuel.

However, even in issues related to the “back end” of the nuclear fuel cycle there can be tensions between safety and safeguards. For example, IAEA (2010a, p. 3) notes that the “generally accepted principle relating to the long term safety of radioactive waste/spent fuel present in a geological repository” is to rely on passive isolation systems and therefore “post-closure safety being provided by means of engineered and geological barriers,” whereas under “the legal basis of the application of IAEA safeguards” there is some requirement for an active role because “there remains an obligation to establish and implement a safeguards regime that is capable of detecting the possible diversion of nuclear material for use in nuclear weapons production.” This source of tension has been recognized for some time (*e.g.*, Linsley and Fattah, 1994).

Khalil, *et al.* (2009, p. 2450) state that “the IAEA convened a workshop in October 2008 to examine facility design and plant operation features that facilitate the implementation of IAEA safeguards.” These authors further indicate that the report of this workshop notes that: “The IAEA should prepare high-level functional safeguards guidelines that designers could reference during the development process.” The hope underlying

Khalil *et al.* (2009) seems to be that this could lead to a technology-neutral approach\*\* to evaluating the effectiveness of various approaches to safeguards, similarly to the alleged approach by the US NRC to “begin the development of a technology neutral licensing approach for safety assessment.” Of course this would also necessitate development of a methodology for evaluation in the safeguards setting of some quantity analogous to the “total public safety risk” (Khalil et al., 2009, p. 2451) that provides the technology-neutral common medium of currency that is employed in the context of safety. Suzuki *et al.* (2009) and Suzuki, Burr and Howell (2010) seem to represent an admirable initial attempt in this direction, but it would seem there is much further work to be done.

The work discussed in the preceding paragraph largely arose in the context of the Generation IV International Forum (GIF, undated). While India is not, as already noted (Subsection 1.5), a member of this organization, it has expressed interest in exporting nuclear technologies for civil use that are unusual (PHWRs) or even unique (thorium cycle). For that reason it is arguably in the best interests of India to actively participate in furthering the development of technologically neutral methods for the evaluation of the effectiveness of safeguards approaches in preventing proliferation.

We are unaware of any efforts within India to engage in this direction, or even in the direction of synergies between safety and safeguards via “management of nuclear material for criticality and accounting control,” as discussed at the beginning of the present subsection. Given the maturity of India’s nuclear energy program, and the technical capabilities of the professional staff of the DAE, it would be surprising if some application had not been made of the latter within the entity responsible for India’s domestic equivalent of an SSAC. (Which presumably is, per the discussion of subsection 3.3.2, the “NUMAC cell of the DAE.”) However we are unable to find any verification of that on the DAE website. More precisely, a search of that site on the string “safety & safeguards” returned fifteen hits, seven of which were (of course) those previously discussed in the preceding Subsection 4.1, in response to the search string “safety & safeguards & security.” By way of normalization, similar searches on the websites of other organizations returned the parenthetically indicated number of hits: AERB (8); IAEA (860); NPCIL (14); US DOE (323) and US NRC (7252).

None of the fifteen documents thus fetched, beyond those previously discussed in Subsection 4.1, seem to have any relevance to the present discussion. In particular, none of them suggested existence of any activity

---

\*\* “Technological neutrality” generically means not limited to or favoring any particular technology for accomplishing the purpose, where in the present context the purpose generally is to use nuclear energy to produce electricity. For example, safety regulations written in a manner to presume use of some particular technology (e.g., light-water reactors), by prescribing approaches to safety that are meaningful only for that technology, would *not* be technologically neutral.

within India that might be categorized as taking advantage of commonalities between nuclear safety and nuclear safeguards. The extent to which that is due to no advantage being taken of such synergies, as opposed simply to such matters not being considered appropriate for general release, is a matter that cannot be determined here.

#### 4.2.2 Safety and Security

See Figure 12 for a depiction via Venn diagram of what seems to be the broad IAEA view of the potential for synergies between safety and security. This view seems consistent with the observation of Taniguichi (2009) that: “The IAEA’s first key area of focus is with the safety and security of existing nuclear facilities and activities. As [we] know, a serious safety or security event in one corner of the world can have lasting implications in another and diminish the confidence and support needed to introduce a new nuclear program or expand an existing one.”

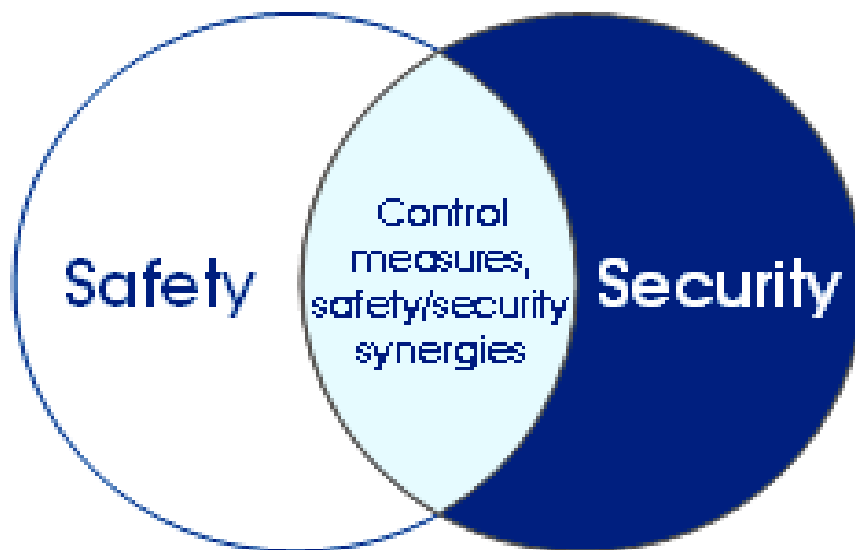


Figure 12 - Diagrammatic depiction of the complementarity of safety and security (from IAEA, undated a1, by permission)

At the same time it also is well recognized that there exist tensions between safety and security that create obstacles and challenges to realizing any pertinent synergies. The following observation from IAEA (undated a1) comprises an excellent example: “Safety matters are intrinsic to activities, and transparent and probabilistic safety analysis is used. Security matters concern malicious actions and are confidential, and threat based judgment is used.”

Although in this quotation the difference is ascribed to security versus safety, it would apply equally well if “safeguards” were substituted for “security.” As this thread therefore represents an issue that runs through



all of the 3Ss, we set it aside for the moment, to be picked up again in subsection 4.2.4, especially subsubsection 4.2.4.2.

The “Safety and Security Co-ordination Section” within the IAEA Department of Nuclear Safety and Security (see IAEA, undated b1) reports directly to the Deputy Director General for that department. This section existed prior to responsibility for security moving into this department (see subsubsection 2.3.3), in order to coordinate activities of the two safety-related divisions within the department (see Figure 3). It appears that this move much enhanced the role of that section, which perhaps underlines complexities in coordinating safety and security. With the forewarning of the existence of tensions comprised by this and the preceding two paragraphs, in the remainder of this preface to subsubsection 4.2.2 we focus upon identifying concrete instances of potential synergies.

As already mentioned in Subsection 4.1, there is considerable literature from the IAEA that brings attention to more-or-less specific potential synergies between safety and security. Most of these potential synergies seem to lie within the realm of one of the following four topics: Legal and administrative frameworks for the *control of sources* (e.g., IAEA, 2006a, 2006b and undated p; Arai and Naito, 2009, p. 8); *engineering design* (IAEA, 2006a and undated p; Arai and Naito, 2009, p. 8; Hashim *et al.*, 2011); *access control* (IAEA, undated p; double-door example of Suzuki *et al.*, 2010); and *emergency preparedness and consequence mitigation* (IAEA, undated p; Hashim *et al.*, 2011).

Before launching into a discussion of these individual topics, with special reference to the Indian context, it is useful to summarize aspects of jurisdictional responsibility for nuclear safety and security within the Indian framework, because the dividing lines between these responsibilities can themselves lead to tensions between different organizational cultures and thereby adversely impact efforts to take advantage of synergies between safety and security. At the operational level nuclear safety and nuclear security presumably are primarily the responsibility of various operational elements of the DAE, as discussed in Subsection 3.3. (See especially Figure 9.) However the physical protection of facilities seems to be under the jurisdiction of the CISF, as discussed in subsubsection 3.3.3. Further, as regards control of and accounting for nuclear materials, the NUMAC cell of the DAE seems to have overall responsibility. (*cf.* subsubsection 3.3.2). As discussed in subsubsection 3.3.1, the AERB has had regulatory responsibility for nuclear safety since its formation in 1983. Only in 2010 did AERB expand “the scope of its regulatory inspections to include security of nuclear facilities in addition to the existing one which covers nuclear, radiation and industrial safety” (AERB, 2011, p. 5). (Although this seems at some variance with the suggestion, in a document date 2007, that “for details on physical protection and nuclear security aspects, AERB manual on Nuclear Security of Nuclear Power Plant should be referred” (AERB, 2007, p. 21). We were unable to identify the referred manual on the AERB website.) The National Disaster Management Authority (NDMA), which was created in 2005 (NDMA,

undated), has responsibility to “lay down guidelines to be followed by the different Ministries or Departments of the Government of India for the Purpose of integrating the measures for prevention of disaster or the mitigation of its effects in their development plans and projects” (NDMA, undated a).

#### 4.2.2.1 Control of sources

Radioactive sources are a safety concern because they can be, if not handled with knowledgeable care, extremely hazardous. This is emphasized by the observation, attributed to M. Shashidhar Reddy, Vice-Chairman of the (Indian) National Disaster Management Authority (Jog, 2011), that while “33 out of some 150 deaths recorded worldwide owing to radiological and nuclear accidents are because of nuclear accidents ... (31 from Chernobyl) ... the rest were because of radiological accidents.” Radiological sources are a security concern because such sources could be used within radiological dispersal devices (*i.e.*, so-called “dirty bombs”; *cf.*, *e.g.*, Argonne National Laboratory, 2005, and references cited therein).

The IAEA has been extremely active in providing resources to member states to combat both the safety and security threats posed by the widely distributed radioactive sources that find multiple beneficial applications in education, industry, and medicine. See, for example, IAEA (2006c). (Those proceedings contain a paper by Ghosh (2006) that gives an excellent overview of how India is organized to provide radioactive sources to meet the needs listed above, along with the corollary safety and security demands.)

The focal point of this IAEA effort seems to be the (voluntary) *Code of Conduct on the Safety and Security of Radioactive Sources* (IAEA 2004). (This particular IAEA effort is coordinated through the Division of Radiation, Transport and Waste Safety of the Department of Nuclear Safety and Security.) As of September 2011 the IAEA (2011a) lists India as one of 105 states that have made some type of political commitment to this Code of Conduct, and one of only 46 that had as of that time responded to all of four indicated related action items. One of those was designation of a contact point for the IAEA’s “Supplementary Guidance on the Import and Export of Radioactive Sources” (IAEA 2005), which for India was, as of June 2011 (IAEA, 2011b), Mr. S.A. Hussain, Head, Radiological Safety Division, AERB. While this in itself suggests an emphasis on safety, news items such as Jog (2011) and the previously cited Times of India (2011) suggest there exists a significantly coordinated effort on nuclear security within the GOI.

In the present context it is appropriate to note that this IAEA-led effort on the safety and security of radioactive sources significantly predates the current (circa 2008) interest in the “3Ss” as such. Witness the document “Key IAEA Publications Related to Safety and Security of Radioactive Sources” (IAEA, 2005a), which lists IAEA publications on this topic dating back to the late 1980s.

The use of sources within India is mandated to occur within the framework of the relevant regulations issued by the AERB. What seem to be the currently relevant regulations in regard to safety of sources apparently

were published in 2001 (AERB, 2001a). The corresponding regulations related to security seem to be significantly more recent (AERB, 2011).

While India thus currently appears to be solidly, if perhaps somewhat belatedly, in line with the international effort to promote the level of attention given security of sources to that accorded safety, it should not thereby be inferred that all is necessarily well within India, in regard to either safety or security (protection and control) of radioactive sources. One of the better publicized recent incidents to the contrary was the early 2010 “Mayapuri incident” in which “radioactive Cobalt 60 from a Delhi University lab found its way to the Mayapuri scrap yard, killing one person and exposing seven others to radiation” (Times of India, 2011a). (This incident led the AERB to suspend all authority of Delhi University to use radioactive sources of any kind (Indian Express, 2010), and to charges filed against six faculty members (Times of India, 2011a).) It would appear difficult, without undertaking more effort than reasonably warranted for present purposes, to determine whether this incident is an extreme within a growing trend in India regarding so-called “orphan sources,” or simply an unfortunate isolated event.

The former is suggested by recent press reports, in both India (Parthasarathy, 2009) and the United States (Bloomberg News, 2008) to the effect that a large and growing fraction of incidents of radioactively contaminated scrap metal imported into the United States arises from India. (Parthasarathy (2009) cites the statistic that of “123 shipments of (radioactively?) contaminated goods (that) have been denied entry to US ports since screening began in 2003, ... 67 originated in India.” Bloomberg News (2008) quotes similar figures. We have been unable to verify these data from a primary source.) A 2009 series of articles on radioactive contamination of a variety of consumer products, by Isaac Wolf and by Dale McFeatters, of the Scripps-Howard News Service, heightened the awareness of Americans to this alleged problem. At least one of these articles mentioned India several times as a source of radioactively contaminated materials imported to the United States, but the focal point was on alleged deficiencies in US regulation. (Individual articles in this series may be accessible from the archives of newspapers in which they were published. See Wolf (2009) for a Scripps-Howard rebuttal to an official response from the US Nuclear Regulatory Commission (US NRC, 2010) to this series of articles.) See IAEA (2011c) for several anecdotal reports, from concerned professionals, of radioactive metallic imports to other countries from India. See Mahaprashasta (2010) for a popular medium report suggesting that some such material tends to arise as radioactively contaminated material imported to India, which is then re-exported following merger with other materials via melting. See Singh and Agarwal (2011) for a more-or-less official Indian government (DAE) perspective, including the economics as seen from the perspective of an Indian dealer in scrap metal.

On the other hand, the mentioned press reports provide no quantitative information regarding the magnitude of the associated radioactivity. (Although Parthasarathy (2009) observes that: “The health consequences

from these products were negligible, as the radiation levels were low.”) Such indications are important to perspective in a field where perfection (zero radiation dose) is unattainable, but conservatism is both universal and widely varying in magnitude. Nonetheless, they are not as important as nuclear professionals might like, because public fears about matters involving radioactivity are not always rational. (Recognition of this presumably was the basis for the further note of Parthasarathy (2009): “But the presence of even low radiation levels is not desirable.”) The most recent detailed data we could find (Dicus, 1999) shows only one of a total of ten “radioactively contaminated products imported into the USA” between 1984 and 1998 originated in India. (Compare to four of thirty incidents of “accidental meltings of radioactive materials in the USA” over that same period arising from the single US State of Kentucky.)

In summary, maintenance of proper control over radioactive sources has for some time, even well prior to the current explicit interest in synergy among the 3Ss, been recognized as a commonality between nuclear safety and nuclear security. While issues in this area are by no means completely resolved, the international community is actively engaged, principally through the IAEA, and India appears to be fully active in that effort.

For completeness we mention the recent IAEA document “Nuclear Security Recommendations on Radioactive Material and Associated Facilities” (IAEA 2011d). This is a “recommendations level publication for the nuclear security of radioactive material, associated facilities and associated activities,” and as such includes consideration of radioactive sources, but is a bit broader in overall scope. This document contains (pp. 11-12) a subsection on “Interfaces with the safety system,” quite appropriately under the broader heading (p. 10) “Risk Based Nuclear Security Systems and Measures.” Notwithstanding this title, a key recommendation under that heading is that “the *regulatory body* should establish regulations based on a prescriptive approach, a performance based approach or a combined approach.” This allowance for a prescriptive approach, as opposed to a risk-based (or performance-based) approach, presumably reflects the difficulty of finding a performance measure for security systems, especially one that is commensurate with corresponding measures for safety systems. This is somewhat of a recurrent theme for the safety-security interface, as will become clear in the following subsection. This also presumably is in no small measure responsible for the broad homilist nature of the recommendations relative to the interface between safety and security (*e.g.*, p. 11, “the State should ensure that a balance is maintained between safety and security.”)

#### 4.2.2.2 Engineering design

We found a significant body of IAEA-related work on high-level considerations that surely have a place in engineering design work at what these days seems often termed the “safety-security interface.” A few examples:

- International Nuclear Safety Group (2010) lists (pp. 15-16) some concrete instances of synergies (*e.g.*, implications for security of the single-failure criterion for safety; passive or robust systems for safety also promote security) and “antagonisms” (*e.g.*, delay barriers for security could prevent or inhibit access by emergency responders; “designs to channel attackers into a field of fire could limit” access for safety purposes).
- The IAEA Safety Standards (IAEA, 2006c, p. 4) deal with design issues at the safety-security interface thusly: “Safety measures and security measures have in common the aim of protecting human life and health and the environment. The safety principles concern the security of facilities and activities to the extent that they apply to measures that contribute to both safety and security, such as:
  - Appropriate provisions in the *design* and construction of nuclear installations and other facilities;
  - ...
 Safety measures and security measures must be *designed* and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.” (Italicized emphases added.) This statement of principle appears difficult either to take exception with, or to apply, at the design level, in any meaningful way to any situation involving real tension between safety and security.
- Koenick (2011, Slide 11) suggests that the obvious necessity for some type of safety-security interface raises the corollary question of whether a state would prefer “a single or two different regulators for safety and security” and “the advantages and disadvantages of each options.” From a designer’s viewpoint one obviously would be preferable, because that would provide some reasonable expectation that tensions between safety and security would be resolved at the regulatory level.
- IAEA (2007a) appears to be mostly directed at evaluation of the capability of engineered safety features of existing facilities, especially reactors, to deal with acts of sabotage; however, many of the considerations discussed seem readily adaptable to issues associated to design of new facilities.

These worthy efforts notwithstanding, the current state of affairs regarding the ability to employ presumed synergies between safety and security at the level of engineering design seems to fall far short of the vision of Stein *et al.* (2010), as quoted in Subsection 1.3. While that discussion was directed toward SBD, we feel the following gist applies equally well to practical design-level realization of any synergies among the 3Ss: “...designers are certainly interested in offering such services so that the owner can operate the facility in the most effective and efficient manner and this may turn into a marketing asset in favor of their design. If SBD can help providing more attractive conditions for both safeguards authorities and operators, the designers will be willing to contribute to the safeguards culture and to work towards synergetic solutions.”

From that perspective what is missing at the moment for engineering design considerations at the safety-security interface seems to be any practical experience in implementing synergies and dealing with tensions between safety and security, or even existence of high-level guidelines to assist designers in achieving market value and operators in envisioning efficiencies through realizing such synergies. This lack is hardly surprising, in view of the fact that such guidelines and experience are only now beginning to come into existence for SBD, which as a concept has been around significantly longer than has 3SBD.

Sevini *et al.* (2010) describe a new IAEA task (circa late 2008) on “Guidance for Designers and Operators and Measures to Facilitate the Implementation of Safeguards at Future Nuclear Cycle Facilities.” This could serve as a prototype for a similar IAEA task directed toward development of high-level guidelines – but not so high as those already extant, as surveyed above – for designers and operators to take advantage of synergies and deal with tensions between safety and security at future nuclear cycle facilities. (This task conceivably could be expanded beyond safety and security, to include all of the 3Ss, but there may be advantages to initially keeping it simpler, and later expanding to include safeguards.)

Similarly, Okko (2010) seems to represent an initial effort to develop practical design-level experience with SBD as applied in the context of construction of a specific facility. The experience documented in this reference is extremely interesting and relevant. For example, “strong national contribution is needed to facilitate the early communication and exchange of information between the IAEA and the other stakeholders to enable the design of facilities that can be efficiently safeguarded.” Also, “submitting binding, official and complete Design Information documents before the design is finalised is not possible – and by that time many of the details that make or break the cost-efficiency of the facility safeguards are already fixed. This problem can be avoided by changing attitudes and developing a ‘new’ open-minded safeguards culture instead of the current protocol and declaration based approaches.”

In view of its role as one of the leaders in the global nuclear renaissance, India could perform the international community a service by offering one of its soon-to-be constructed civil facilities as the object of a similar study to obtain similar tangible experience in the specifics of exploiting synergies between safety and security at the design level. To the extent that this experience reveals economies of cost, it also could be beneficial to India. The facility itself need not be of a particularly complex nature (*e.g.*, a nuclear power plant). In the SBD instance of Okko *et al.* (2010) cited above, the example was “enlargement of the Olkiluoto (Finland) spent fuel storage building.”

It presumably would be necessary to carry out any such effort within the existing Indian framework relative to the interplay between safety and security considerations in the design of nuclear facilities. AERB (2007) and AERB (2009) are important regulatory documents that outline significant portions of that framework. However, it likely will be difficult to extract significant information relevant to security from such open

sources, for the understandable reasons well-described in the following somewhat generic extract from AERB (2009, p. i): “This safety code does not address all requirements for ensuring physical security of the plant or consequences arising from breach of provisions of physical security. As details of this aspect are restricted, they would be dealt with by appropriate authority.”

In this context even a conceptual design at roughly the level of a “safeguards approach” (e.g., IAEA, 1998) could have some value. Although such a study need not be at the level of a NPP, IAEA (2011e) would seem already to provide an adequate open-literature basis for a study at this level.

#### 4.2.2.3 Access control

International Nuclear Safety Group (2010) emphasizes the relevancy of “access and control measures” in the context of “the interface between safety and security at nuclear power plants.” For example, such controls “can prevent unexpected radiation exposure” (thus improving safety) and “advance security through reducing risks of theft” (Paragraph 66, p. 18).

But this reference also observes that “access controls can create conflicts between safety and security” (Paragraph 67, p. 18). As an example of such conflicts the following is provided: “Rapid access is necessary for safety purposes to respond to events in a timely manner and rapid egress may be necessary to protect the health of workers. But the provision of means for rapid access or egress can create a vulnerability that could be exploited by a terrorist adversary.” (Paragraph 67, p. 18; see also Paragraph 4, p. 2.) Likewise (Paragraph 57, p. 15) “the introduction of delay barriers for security purposes might, for example, prevent access by the fire brigade or off-site firefighters, or might block evacuation routes.”

Somewhat more general concerns regarding tensions between safety and security are mentioned in IAEA (2011d). Specifically, at Paragraph 3.28 (p. 120 this report admonishes to the following effect: “The *competent authorities* working with the *operator* should ensure to the extent possible that security measures during a response to a *nuclear security event* do not adversely affect the safety of the personnel.” (Italics in original.)

Paragraph 70 (p. 18) of International Nuclear Safety Group (2010) expresses a point regarding the need for quantitative measures of safety and security that seems so salient that we quote here that paragraph in its entirety:

*It may also be found to be necessary to establish performance indicators for safety and security. It is necessary that the management of the operating organization be capable of measuring the status of safety or security of a nuclear power plant and to define progress or slippage in the achievement of either objective.*

Although this need is difficult to gainsay, identifying metrics of this form that are readily measurable does not appear to be straightforward. The following observation might make it somewhat easier. The specific concrete instances of alleged tensions cited above do not actually seem to be tied to safety versus security.

Rather they seem more to be tied to the need to limit access under some circumstances, versus the need to facilitate either ingress or egress under other circumstances. But one might wish to limit access for reasons of either safety or security, and likewise to facilitate ingress or egress because of an event having its root cause lying in either ingress or egress. Therefore what really seems needed is some relative measure of the value of limiting access prior to an incident related to either safety or security, versus the value of facilitating post-event egress by those seeking to flee and post-event ingress by those needing to respond.

The latter consideration brings us to the fourth and final of the topics that our literature review uncovered as the subject of some prior discussion in the literature.

#### 4.2.2.4 Emergency preparedness and consequence mitigation

The challenges in this area are very similar, regardless of whether the initiating event was accidental (safety) or deliberate (security). This is well exemplified by IAEA (2005b): “Early in the course of an event, it is usually unknown whether the cause is accidental, due to negligence or deliberate. The principal aim is to mitigate the event and its radiological consequences; a secondary aim is to address non-radiological issues, in part through consistent and authoritative provision of information to the public. Coherent initial assessment and crisis and consequence management are needed, which can only be achieved through coordinated and effective preparedness involving all relevant authorities and response organizations.”

Of course there are different tendencies between safety-related and security-related events. For example the former are more likely to be centered on some type of nuclear facility. Nonetheless, every event is unique, and even safety-related events can affect widespread areas, as unfortunately seen in the March 2011 event at Fukushima Daiichi. An observation emerging from an IAEA fact-finding team mission (IAEA, 2011f) related to this event was that “the Japanese accident demonstrates the value of hardened *on-site* (emphasis added) Emergency Response Centres with adequate provisions for handling all necessary emergency roles, including communications.” For the aforementioned reason, the “on-site” portion of this recommendation would be less relevant for security-related incidents than to safety-driven events.

The similarities seen between safety and security in responding to potentially dangerous events also is attested by the fact that the IAEA’s Incident and Emergency Center (IEC) is administratively located within in the Department of Nuclear Safety and Security (IAEA, undated h). This center “serves as the Agency’s focal point for responding to nuclear or radiological incidents and emergencies and for strengthening Member States’ emergency preparedness and response” (*ibid.*). See IAEA (undated y) for more information on the IEC.

Emergency response and consequence management, along with safety, play a significant role in the IAEA’s proposed educational program in nuclear security (IAEA, undated w). Independent reviews of education and



training needs in regard to preparedness for emergency response is mentioned by Delattre (2011) as a service provided by the IAEA to member states.

Within India the lead responsibility for responding to nuclear or radiological incidents seems (NDMA, 2009, p. xxxi) to be assigned between the DAE and NDMA as follows: “Detailed plant-specific emergency response plans are in place at all the nuclear facilities and are functional for the entire lifetime of the facility. Barring off-site emergencies, all other emergency plans are the responsibility of the facility operator. The most critical type of emergency of a nuclear plant is an off-site emergency where members of the public may get affected. To cope with such an off-site emergency, detailed response plans are required to be put in place by the collector of the concerned district in coordination with the plant authorities. The Atomic Energy Regulatory Board does not permit the operation of a new or existing power plant or radiation facility unless preparedness plans are in place for the postulated emergency scenarios. It is also mandatory for the power plant operators to periodically conduct on-site and off-site emergency exercises.” The regulatory requirements of the AERB for on-site and off-site emergency preparedness plans are contained respectively in AERB (1999) and AERB (1999a). See Sundararajan (1991) for a report on a DAE-organized emergency preparedness exercise.

For present purposes, the essential result is that within the field of emergency preparedness we find neither specific opportunities for synergism between safety and security nor concrete instances of tensions between those two Ss. Notwithstanding this apparent absence of realizations, the US NRC recently issued a rule (US NRC, 2009) that appears to be directed – without explicitly saying so – toward assuring any type of modification to plant equipment or operating procedures motivated by security considerations not have any adverse impact on safety. US NRC (2009a) provides some minimal guidance as to issues of concern, and a process deemed adequate to provide the required assurance. But the approach of that document definitely is consistent with the following statement contained therein: “Each licensee is responsible for balancing the needs of both safety and security to ensure that all program goals, requirements, and procedures are met.”

### *4.2.3 Safeguards and Security*

The overwhelming majority of the suggested synergies between safeguards and security seem to lie in the area of control of and accountancy for fissile materials. For a few examples: as already mentioned in the preface to Subsection 4.1, IAEA (2006a) notes, in the context of a discussion of synergies among the 3Ss, that “national systems for accounting and control of nuclear material deter and/or allow early discovery of theft”; likewise, in the context of a discussion of synergies involving security, IAEA (2006b) notes that “security and safeguards objectives are jointly attained by measures to enhance the control of and accounting for nuclear material”; Arai and Naita (2009, p. 8) observe that “security and safeguards objectives are jointly attained by measures to enhance the control of and accounting for nuclear material”; Figure 1 of Suzuki *et al.* (2010),

which is reproduced as Figure 1 of this report, displays “management of nuclear material using containment and surveillance and remote monitoring camera” within the intersection of safeguards and security in a Venn diagram illustrating synergies between the 3Ss; and Hashim *et al.* (2011, Table 2) indicate “establishment of accounting areas” and (definition of the) “surveillance system” as among the main common areas of security and safeguards.

It certainly is true that the issue of material protection, control and accountability is basic to both safeguards and security, and thus indeed offers much commonality – from a technical perspective – between these particular two Ss. Indeed at a sufficiently abstract level these particular two Ss are all but identical. For each there is a class of potential threatening parties that conceivably would try to divert sensitive materials from their authorized uses, and there is an inspectorate whose job is to detect if and when attempts at such diversion are attempted, and thereby deter such attempts, or permit timely intervention to occur should such attempts in fact occur.

Because of this abstract similarity, any technology useful for material protection, control and accountability in the context of either safeguards or security almost certainly is capable of being used for the other. See Abousahl *et al.* (2010) for an extensive discussion of technologies that are available to assist in attaining the objectives of either safeguards or security.

This element of similarity notwithstanding, at the operational level there is a significantly confounding factor that seemingly will tend to make it very difficult to use the technical similarities of means to achieve cost savings at the operational level in accomplishing the desired ends for both safeguards and security. That factor is that for security it is the host state that effectively comprises the inspectorate, but for safeguards it is that very same host state that constitutes the presumed threatening party, while the cognizant operations division of the IAEA Department of Safeguards constitutes the inspectorate. (Abousahl *et al.* (2010) refer somewhat obliquely to this in noting that “at political level, security and safeguards remain in separate hands.”)

Under these circumstances, the relevant question is whether the savings from sharing, between the safeguards and security functions for any type of facility, the infrastructure necessary to material control and accounting, will be sufficient to offset the costs attendant to ensuring that sharing does not provide the host state the means to contravene the verification function of safeguards. Stein (2009, p. 2265) framed this issue as follows:

*One major concern is the authentication of data that is necessary to qualify data to be used for safeguards conclusions. Essentially, the IAEA has to assume that its instrumentation resides in a hostile environment where an adversary*

*with state-level resources has constant access to the equipment to try and break its security. Tamper indication features and authentication are thus critical for safeguards conclusions to be independent and reliable.*

In the second paragraph following this problem description, the same authors suggest a *possible* technological solution, as follows:

*... modern technology can support broadening the data sharing between multiple stakeholders. As long as the authentication of data takes place in a secure environment, there is now the processing speed available to generate parallel data streams on a single instrument in accordance with different sets of user requirements. Each party could even apply its own data encryption scheme to ensure that only authorized users have access.*

Such technological solutions, which could be considered an instance of achieving synergy between some of the Ss via engineering design, certainly seem promising. At the same time, because of the absolutely crucial need for authentication of data related to safeguards, any such approach would require extensive and rigorous testing and validation, and likely also would need to be associated with some continuous improvement process.

If a facility is subject to such testing, there is always the possibility that validation would fail, so that if safeguards were required for the facility they would need to be provided by some alternative means, presumably the traditional *ad hoc* approach. For that reason the international community as a whole should, presumably through the IAEA, bear the bulk of the expenses for such tests, rather than the host state for that facility. Any state offering a suitable facility for such tests would thereby provide a noteworthy service to the international community. Of course the potential for that host state to thereby gain some commercial advantage, through acquiring an intimate understanding of technological measures offering a significant reduction in life-cycle costs for security and safeguards measures, could offer considerable incentive to any state offering nuclear technology on the international market.

#### **4.2.4 Safety, Safeguards and Security**

Most of the suggested concrete synergies that run across all of the 3Ss seem to fall within one of the two following topics:

- Formulation of a suitable state-level legal and regulatory framework for development of civil nuclear energy.
- “Harmonization” of the notion of “risk” across the 3Ss.

These two topics are the respective subjects of the two subsubsubsections in this subsubsection.

#### 4.2.4.1 Legal and regulatory frameworks

A number of prior works have identified development of consistent and comprehensive state-level legal and regulatory frameworks as one challenging thread that runs through all of the 3Ss. For one example, IAEA (2006a) mentions that the IAEA “legislative assistance programme takes a comprehensive approach which recognizes the importance of the interface between security, safety and safeguards.” For another, see the quotation, in Subsection 1.5, from Kovacic *et al.* (2009) regarding the “definite commonalities for developing ... legal, regulatory, and operational aspects “of the 3Ss; IAEA (undated c1, p. 15) summarizes the challenge as “the need to develop a comprehensive legal framework covering all aspects of nuclear law, which includes safety, security and nuclear liability and other legislative, regulatory and commercial aspects.” Hammoud (2008) emphasized that this challenge is particularly acute, in light of such considerations as:

- Number and complexity of international instruments in the area of safety, security and safeguards;
- Lack of national legal and technical expertise;
- Shortage in available outside legal expertise;
- Number of States that have expressed interest in launching a National Nuclear Power Programme is increasing;
- Current resources will not be sufficient to cover the increased demand for legislative assistance.

Challenges also arise in developing a legal framework for nuclear power that does not inhibit taking advantage of synergies in the 3Ss, and at the same time does not create gaps that are inadequately attended. Hammoud (2008) states this as follows: “The ‘3S’ concept recognizes the interface and interrelations between nuclear safety, security and safeguards as well as liability for nuclear damage. One of the aims is to avoid inconsistent, incompatible or incomplete pieces of legislation in Member states” (of the IAEA). The “number and complexity of international instruments in the area of safety, security and safeguards” also is cited as a confounding factor in such considerations. The latter may in fact be less true for India than for most states having advanced nuclear programs, precisely because Indian policy effectively has been to minimize the number of such instruments to which it has commitments.

This is only one aspect of the unique path India has trod to reach the current point in its nuclear history. Another such aspect is that India has an extensive and again unique history relative to nuclear energy that is embodied in a significant legal history that is nearly as old as independent India itself. By contrast most of the effort of activities such as the Legislative Assistance Program of the IAEA is (understandably) directed toward states that have little or no prior history of activities related to civil nuclear energy, and therefore have experienced little or no motivation to develop a legal or regulatory framework to govern and guide such activities. Indeed India’s nuclear history seems sufficiently unusual so that it is unclear there is any meaningful lesson in the legal or regulatory frame that India could infer from the historical experience of any

other state. For that reason we will, with one exception, forgo here any further discussion of legal and regulatory frameworks in India for dealing with the interfaces between the 3Ss.

The singular exception is the potential impact, upon achievement of synergies among the 3Ss, of current plans (see subsection 3.3.1) for reorganization of the nuclear regulatory function within India. Such reorganizations are sufficiently rare so that we would be indeed remiss not to discuss, at least briefly, the potential that the proposed reorganization has for an impact upon the interaction among the 3Ss.

First, in any state it is more-or-less obviously true that the most desirable regulatory arrangement, as seen from the perspective of attaining synergistic effect among the 3Ss, would be to have the same regulatory body responsible for nuclear safety, nuclear safeguards and nuclear security. Some of the difficulties associated with the understandable historically based different cultural tendencies across the 3Ss have been previously discussed in Subsection 1.5 (second-to-last paragraph), in the preface to subsection 4.2.2 (third paragraph) and in subsection 4.2.2.2. However having regulatory responsibility for all of the 3Ss under the cognizance of a single overall umbrella organization arguably should in some part ameliorate such difficulties. In particular, such an arrangement should at least help to assure some level of consistency in allocating resources among the 3Ss, or at least motivate attempts to achieve some level of such consistency (see the following subsection). It at least will assure existence of some entity having a singular responsibility and motivation to seek synergies among the 3Ss, and provide some organizational encouragement, and therefore presumably tendency, toward a common culture across the 3Ss.

Unfortunately for the prospect, within India, of attaining synergies and developing a common culture across the 3Ss, it does not appear to be the case that either the current assignment of nuclear regulatory responsibilities within India, or the tendency toward reorganizing those responsibilities, has a single entity with regulatory authority across the 3Ss.

The history of the nuclear regulatory function in India, along with the status as of this writing of a move toward legal reorganization of that function, already were summarized in subsection 3.3.1. From that discussion, it appears that at present in India the AERB has regulatory authority for safety (subsection 3.3.1), and it very newly has such authority for security (see the preface to subsection 4.2.2). However, we find no indication that it has any such responsibility for safeguards.

Further, the currently pending Nuclear Safety Regulatory Authority Bill 2011 (PRS, 2011) seems unlikely to change this divided authority. To the contrary, neither of the words “safeguard” or “safeguards” appears in that pending legislation. By contrast, “security” appears 23 times, some of them admittedly with a more generic meaning than commonly used in this report; and the word “safety” appears 127 times. This seems rather strongly to suggest that the entities to replace the AERB are likely to have, like the AERB itself, a

strong responsibility for regulation of nuclear safety, a significant responsibility for regulation of nuclear security and little or no regulatory responsibility for nuclear safeguards.

Bajaj (2010) has emphasized the challenges that nuclear energy regulation in the Indian context poses for the AERB. Many of these challenges will remain to any successor to the AERB. These challenges have been formidable, even though historically they have largely been limited to the safety context. Both any effort to better coordinate all of the 3Ss, and any move toward greater appearance of independence for Indian nuclear regulatory authority, are likely only to make those challenges even more formidable for the Indian nuclear complex as a whole. On the other hand, the juxtaposition of these considerations provides the Indian nuclear enterprise with an unusual opportunity to explore novel approaches to the 3Ss. For example, perhaps the potential benefits of interaction among the 3Ss could be better realized if the regulatory authority were accorded responsibilities beyond regulatory aspects of safety. Examples of such responsibilities that were previously discussed include regulatory and research responsibility in safeguards and security. Because India in particular relies very heavily on secrecy regarding its security and safeguards measures, this “transparency” issue especially has a great impact there on prospect of integrating the 3Ss, as will be further emphasized in the following Subsection 4.3.

It is not the purpose here to suggest that achieving synergies across nuclear safety, safeguards and security should be the overriding consideration in organizing the responsibility for nuclear regulation, in either India or any other state. To the contrary, a strong case also can be made that having regulatory responsibility for all of the 3Ss reside in any single agency has the impact of diluting responsibility, and possibly therefore effectiveness, for the stewardship of any single one of the Ss. Necessarily any decision about how to organize these regulatory responsibilities involves some balance between these considerations, and the balance to be realized likely will be the product of cultural, historical, political and technical considerations.

In the case of India, the motivation for regulatory reorganization seems rooted in the March 2011 nuclear accident at the Fukushima-Daiichi nuclear-power-plant site in Japan. This event has increased everywhere, including India, the emphasis upon public acceptance, and therefore transparency, as a necessary accompaniment to nuclear safety. At the same time this mandate for increased transparency in the arena of nuclear safety seems likely to conflict with the traditional reliance upon secrecy – the polar opposite of transparency – in the arena of nuclear security (see subsection 4.2.2), which the AERB has responsibility for, and its successor organizations seem likely to inherit. At this writing it seems highly likely (see subsection 3.3.1 for more details) that the AERB will be replaced as the regulatory body responsible for nuclear safety and for nuclear security by an entity or collection of entities having a mandate for greater transparency. This factor alone seemingly will hold many challenges for the AERB, or any successor.

Difficult though that challenge will be, it will be treated within the confines of the AERB or its successor. The challenge of achieving synergies at the interface of safeguards with either of safety or security likely will be even greater, because the respective regulatory authorities will be divided between DAE (NPCIL) and the AERB. In fact in this respect the reorganization to give a greater degree of independence to the AERB successor likely will make more difficult the challenge of achieving synergies involving safeguards. This could, in turn, have an adverse impact on India's objective of exporting its PHWR technology. See subsection 4.2.5 for further discussion of this issue.

#### 4.2.4.2 Toward a common measure of risk?

Stein *et al.* (2009, p. 2264) observe that “a quantitative analysis showing that the overall cost for designers and operators is reduced will provide sufficient incentive to pursue SBD.” We suggest this observation is equally cogent if “SBD” is replaced by “3SBD.”

A difficult obstacle to conducting such quantitative analyses, on a common basis over all of the 3Ss, lies underneath the following observation from IAEA (undated a1). “Safety matters are intrinsic to activities, and transparent and probabilistic safety analysis is used. Security matters concern malicious actions and are confidential, and threat based judgment is used.” (As previously noted in subsection 4.2.2, this observation would apply equally well if “safeguards” were substituted for “security,” so that it relates to all of the 3Ss.)

There are really two distinct but related points underlying this line of thought. The first is, simply put, the utility of various actions (countermeasures) traditionally tend to be measured in incommensurate terms between the 3Ss, with safety relying on quantitative probabilistic safety analyses, safeguards relying on the traditional empirical “trust but verify approach,” and security dependent upon evaluations of vulnerability to various sorts of attacks of a defense system directed at some “design basis threat” that is qualitatively selected via some type of expert judgment. The issue then is how to identify some common unit of measurement that can be quantitatively predicted (and therefore is useful at the design stage), so as to lead to a rational basis for decisions regarding the appropriate use of limited resources so as to attain benefits distributed in some type of level manner across the 3Ss.

The second issue thus raised is the different cultures, between safety and security, regarding the appropriate balance between transparency and secrecy. As suggested in the above quotation, extreme transparency is considered the ideal for safety. However, the highly technical nature of probabilistic safety analysis tends to lessen this transparency, at least to the general public. In respect to the balance between secrecy and transparency, safeguards occupy a position intermediate between safety and security, but overall are perhaps a

bit closer to security. (Although allowance must be made for complexities arising from the respective targets of secrecy and transparency; see subsection 4.3.1.)

Prior exploratory work in this direction, by Suzuki and others, was previously noted in the last couple of paragraphs of Subsection 1.5. Here we focus on a more detailed discussion of the two obstacles to achieving this vision that already were noted in the preceding paragraph; the problem of denominating a common measure of (dis)utility across the 3Ss; and the difficulty of predicting the frequency of occurrences of incidents related to safeguards and security.

These two obstacles can be discussed in a more-or-less common framework by employing the risk equation that is widely used in physical protection (*e.g.*, Garcia, 2008, pp. 292-293). The variant of that equation that is most useful here is

$$R_i = f_i P_i C_i,$$

where:

$R_i$  = risk (rate) from incidents of type  $i$ ;

$f_i$  = expected frequency at which incidents of type  $i$  occur;

$P_i$  = probability that an incident of type  $i$  will, given that one occurs, overcome any countermeasures in place to prevent occurrence from proceeding to the adverse conclusion that otherwise certainly would occur; and

$C_i$  = consequences of an adverse conclusion of an incident of type  $i$ .

In the risk equation the factor  $f_i$  has dimensions of (probability) per unit time, and the factor  $P_i$  is a (dimensionless) probability, so that the risk rate is the rate at which the expected adverse consequences from incidents of type  $i$  accumulate. In particular the units of  $R_i$  are those of a time rate of the consequences  $C_i$ .

Therefore, in order to measure the risk rates from different types of events in commensurate quantities, so that they can meaningfully be compared, it is (necessary and) sufficient to measure the corresponding consequences commensurately, and in a form such that the corresponding values reasonably can be estimated. This is rather more easily said than done. Let us take, for example, safety-related incidents, which widely are considered the easier type of incident for which to estimate the consequences. The tool most commonly used to provide such estimates is probabilistic risk assessment (PRA).

The US Nuclear Regulatory Commission recognizes (US NRC, 2011a) three types of PRA analyses as providing “insights into the strengths and weaknesses of the design and operation of a nuclear power plant.” Each of these types of PRA has a different type of associated consequence (all quotations *ibid*):



- for a so-called Level 1 PRA the relevant consequence is taken as “damage to the nuclear reactor core”; whereas
- in a Level 2 PRA the adverse consequence of interest is “release (of) radioactivity from the nuclear power plant”; and
- a Level 3 PRA “starts with the Level 2 radioactivity release accidents, (and) estimates the consequences in terms of injury to the public and damage to the environment.”

For a Level 3 analysis the public consequences might, for example, be denominated as “long-term cancers resulting from the radiation doses to the population around the plant.” Or the environmental consequences might be described in terms of “land contamination (presumably to some specified level) resulting from radioactive material released in the accident.”

Here the consequence pertinent to a Level 1 PRA clearly does not extend, in terms of the type of incident, beyond something potentially untoward in a nuclear reactor. The consequences associated to a Level 2 or Level 3 PRA are somewhat more generally applicable, but are still limited in that they envision a release of radioactivity as the ultimate adverse conclusion of the event.

Consequences at least of the Level 3 variety probably are adequate for most incidents of the type commonly associated to nuclear safety, and even to many of the types of incidents associated to nuclear security (*e.g.*, sabotage of any type of nuclear facility at which radiologically hazardous materials are present, or employment of a radiological dispersal device – see subsubsection 4.2.2.1). On the other hand, for security incidents of the theft variety, or for incidents involving violations of safeguards agreements, the only readily foreseeable adverse conclusion is possession of potential destructive materials (*e.g.*, weapons usable) by some unauthorized and therefore presumably potentially hostile party or parties. However, it is very far from clear how to denominate that potential in the same terms as used for any of Level 1, 2 or 3 probabilistic risk analyses, especially at the design stage. Neither the intent nor the capability of the acquiring party is known nor is knowable at that point.

Suppose nonetheless, for the sake of further discussion, this problem of “harmonization of measure of consequence” were somehow resolved. For example this could be accomplished by some sort of standard conversion of acquisition of weapons-usable materials into probability of usage, and thence to associated costs as denominated in monetary terms, and likewise by some accepted conversion of Level 3 consequences into monetary terms.

Under such an admittedly miraculous consensus, there still remains the challenge of ascertaining, for the various types of incidents, values for the other two terms on the right-hand side of the risk equation,  $f_i$  and  $P_i$ . The latter, the probability of ultimately reaching an adverse conclusion, given that an incident occurs, is

associated to by far the most widely accepted methodologies for estimation. For safety-related incident this is done by estimating the reliability of the relevant safety-related subsystems and components; generating such estimates is at the heart of the methodology underlying probabilistic risk analysis. For incidents related to safeguards and security the methodology is slightly less straightforward, but there exists generally accepted methodologies based on computer simulations, with occasional validation by analog simulations of various kinds, from table-top exercises to full-out live exercises.

For the factor  $f_i$ , the frequency of occurrence of various types of incidents, the situation is much the same for safety-related incidents. There is by now extensive data available to allow reasonable statistical estimation of the frequency of occurrence of the more common types of accidental initiating events. However, the initiating events for incidents related to neither safeguards nor security are accidental in nature; rather they require decision and conscious deliberate action by some adversary. Further, any given type of deliberately initiated incident necessarily is selected from a number of possible alternative possibilities, on the basis of a number of considerations, among them presumably some judgment as to the relative value to the adversary of different adverse conclusions, and some consideration of what is known (or thought to be known) by the adversary regarding the effectiveness of countermeasures that might have been instituted. In such a situation it is a very difficult challenge to come up with any meaningful methodology for estimating the probability of any particular type of incident, or “probability of attack” as it commonly is known in the field of security.

Thus both the difficulty of estimating frequency of a particular type of incident related to safeguards or security, and the problem of harmonizing the consequences of incidents related to safeguards and security-theft, work against any harmonization of the notion of risk across the 3Ss. In turn these factors tend to serve as a significant impediment to the inculcation of a common culture across the 3Ss. These factors are in fact, very largely directly responsible for the different tendencies across the 3Ss that are summarized in the quotation from IAEA (undated a1) in the second paragraph of this subsubsection.

At the same time, this situation offers a challenge that could bring a very large reward to developers of analytical methodologies who were successful in reaching a resolution. Given the very strong history of India in being at the forefront of development of statistical methodology, and the possible reward in the form of enhancing the economic competitiveness of any nuclear technology India should choose to offer for export, it certainly seems a challenge worthy of a significant attempt at resolution.

#### *4.2.5 A Research Program to Enable 3SBD*

In the Introduction (Subsection 1.2) the objective of this report was described as “to identify ... the opportunities that exist for India in (adopting a comprehensive design-level approach to the 3Ss) ... and the (associated) challenges that exist.” As much of such opportunities relate to the potential for India to export

its nuclear-energy technology, it is appropriate to recall here the underlying reasoning, and especially what Indian authorities have stated regarding that intent to export.

The activities related to potential synergies among the 3Ss that were listed from IAEA (2006a) in the preface to Subsection 4.1 could all be a possible help for India's well-known (*cf.* Subsection 1.3) interest in exporting its PHWR technology. Following the Nuclear Suppliers Group agreement that was achieved in September 2008, the scope for supply of both reactors and fuel from suppliers in other countries opened up. The opportunities for synergism cited above could serve to enhance the economic competitiveness of India as an exporter of its nuclear technology. For example, if India should also consider "Safeguards by Design" for export versions of its pressurized heavy-water reactors, that could provide economic benefits to potential international customers in meeting their safeguards obligations, and also be beneficial from the safety point of view.

The potential benefits from this synergy could be received through a strengthening of the global economic competitiveness of the indigenous PHWR technology that India intends to offer for export (Banerjee, 2010). The opportunity also could be impacted by the apparently already announced intent of the GOI (World Nuclear Association, 2011) to reformulate the relationship between the regulatory and development/operational arms of its civil nuclear enterprise. Additional benefits could well accrue via greater efficiency and effectiveness of the safety, safeguards and security measures that will be required for the significant expansion India currently plans for its domestic civil nuclear power programs, which presumably will involve both indigenous and imported technology. (See Subsection 1.3 for more details.)

Many of both the opportunities and challenges associated to such export plans have been implicitly delineated in the preceding subsections of this subsection. The objective in this subsection is to make those opportunities and challenges more explicit, and to suggest ways in which the Indian nuclear establishment might contemplate engaging in order to begin overcoming some of the challenges and thereby move toward realizing the opportunities.

What is needed in order to realize a comprehensive design-level approach to the 3Ss is conceptually fairly simple, although in many points it will be very difficult to achieve. The need is for some uniform way of ascertaining and comparing the benefits to any or all of safety, safeguards and security of measures intended to provide such benefits. Here "uniform" means not only that the benefits should be measured so as to make comparison possible across the 3Ss, but also that the comparison should be possible over the entire range of nuclear technologies and facilities and nuclear or radiological materials, and over the entire life cycle of such facilities and materials. Implicit in that is some mechanism for certifying methodologies for estimating these benefits, and implicit in that is some technology-neutral approach to providing, testing and validating metrics

for benefits so that both respectively the general public and providers of nuclear technology can have reasonable assurance in the reliability and stability of process.

Reaching this point will be a journey of many years. Nonetheless the earlier parts of this subsection suggest some significant preliminary steps toward ultimately realizing this vision that the Indian nuclear establishment might even now benefit from, particularly in terms of realizing its ambition to export its nuclear power technology.

- A worthwhile research objective would be development of a metric for consequences that harmonizes the notions currently employed on the one hand for incidents related to either safety or security attack by sabotage, and on the other hand safeguards or security attack by theft. (See subsubsection 4.2.4.2 for more detail.)
  - At some point the metric developed under such a research program should be extended so as to permit a meaningful comparison of the benefits of post-incident response countermeasures such as consequence management, as enabled by a high degree of emergency preparedness, versus pre-incident “preventive” countermeasures. (For further discussion of such issues see subsubsection 4.2.2.4.)
  - The results of the research described in the preceding subitem should implicitly enable an evaluation of the pre-incident preventive benefits of limiting access to areas having a high concentration of nuclear or radiological materials, versus the post-incident response benefits of a high-level of access (by authorized responders) to those same areas. (See subsubsection 4.2.2.3)
- A second worthwhile research objective would be development of a technology-neutral methodology for estimating the frequency of occurrence of incidents (attacks) related to safeguards and security. (Again see subsubsection 4.2.4.2 for details.)
- Ideally the results from the programs outlined in the two preceding listed items would provide a proposed technology-neutral methodology for evaluation of countermeasures over the 3Ss collectively. Application of these results then might be attempted, in order to select the most beneficial overall design, from a perspective integrated over all of the 3Ss, for some testbed facility. Ideally such a test facility for the concept of 3SBD would occupy a role in some relatively unusual fuel cycle (*e.g.*, fast sodium-cooled reactor). In some ways the “new national reprocessing facility dedicated to reprocessing safeguarded nuclear material under IAEA safeguards” (*cf.* Clause 6.iii of US Department of State (2007)) would be an ideal ultimate testbed facility, but may well be too complex for an initial effort. (See subsubsection 4.2.1 for further discussion of technology-neutral approaches to safeguards.)

- A significant part of any potential synergism between the 3Ss appears to be cost saving via sharing of communication resources between safeguards and security, as needed to meet the respective material control and accounting requirements of those two functions. The design of the test facility envisioned above should attempt to validate the possibility of using technological means to ensure the integrity and authentication of these two separate data streams, even though they employ the same communications facilities, thereby reducing associated cost. (See subsection 4.2.3.)
- The potential for similar savings via sharing of resources between safeguards and criticality safety should be studied. This likely could be particularly important for any facility serving to provide temporary storage for materials (*e.g.*, spent fuel) subject to further processing once radioactively decayed to a sufficient level. (See subsection 4.2.1.) In fact such a facility might serve as an excellent testbed for the 3SBD concept. (*Cf.* the preceding major item.)
- In considering all of these possible endeavors, Indian authorities might also wish to contemplate any potential advantages from having regulatory responsibility for safeguards (domestic or international) under the same regulatory authority responsible for nuclear safety and security.

## 4.3 Tensions

In this subsection we seek a deeper understanding of tensions that might work against a full realization of synergies among the 3Ss. More specifically, in the first subsection we consider an abstract framework for systematically understanding the generic roots of tensions among the 3ss. In the second subsection we explore more India-specific tensions, mostly from outside the 3Ss, that might tend to work against India itself achieving even the maximum synergistic benefit currently available in principle from the 3Ss.

### 4.3.1 General tensions – an abstract perspective

As a specific possible organizing principle for an abstract perspective we seek to understand the various potential tensions as arising from differences among the 3Ss along dimensions defined by the 3Ts: *threat*, *timeliness* and *transparency*. (The authors were introduced to the concept of these 3Ts by Mr. Mark Soo Hoo, of the Sandia National Laboratories – Albuquerque.)

As we perceive matters, in the international norm the values of the 3Ts vary among the 3Ss as delineated in Table 1. Here *threat* varies in value from *passive* (nature, in the case S = safety) to **active** (the host state, for S = safeguards, or some subnational entity, for S = security). Likewise *timeliness* varies in value from **sooner** (immediate, for safety, or a security attack taking the form of sabotage) to *later* (weeks to years, for safeguards, or a security attack taking the form of material theft). Similarly *transparency* varies from *open* (for S = safety) to

**closed** (for S = security), with the value taken as **intermediate** for safeguards. (Here the color code **green** corresponds to the less acute value of the associated tension, and **red** to the more acute (problematic) value.)

Many workers have discussed various elements of the tensions indicated in Table 1. For example, Flory (2010) says: “It is true that in Nuclear Safety, transparency is an obligation, while in Nuclear Security, it is often an offence. But today’s thoughts about ‘society’s chosen level of protection’ embedded in precautionary approaches clearly ask for some level of information of the public.”

**Table I - Values of the 3Ts, for each of the 3Ss**

	<b>Safety</b>	<b>Safeguards</b>	<b>Security</b>
<b>Threat</b>	<i>passive</i>	<b>active</b>	<b>active</b>
<b>Timeliness</b>	<b>sooner</b>	<i>later</i>	<b>sooner</b> (sabotage) or <i>later</i> (material theft)
<b>Transparency</b>	<i>open</i>	<b>intermediate</b>	<b>closed</b>

In this subsection we attempt to delineate the different tensions, between the 3Ss, that underlie the items in the program laid out in subsection 4.2.5, to the extent of determining which of the distinct T values for the associated Ss these tensions are most reasonably associated to. (If this sounds somewhat nonsensical, the first couple of examples following should serve to clarify.)

The tension associated to identification of a commensurate metric for consequences is associated to the differences between, on the one hand, safety and security attack by sabotage, and on the other hand safeguards and security attack by theft. The tension for which each of these two groupings has a common value is timeliness. (The timeliness values “**sooner**” and “*later*,” respectively, corresponding respectively to the need for short-term intervention to prevent realization of the consequences, or the ability to defer for some period of time prior to likely occurrence of any related consequences). Likewise the tension along which the two security subcases separate is timeliness. Either of these observations suggests that differences in timeliness underline this particular tension. A little thought suggests this is correct, or perhaps even more accurately it is differences in expected time of consequence that drives both the different degrees of difficulty in ascertaining a quantitative metric for consequences and the value of the timeliness attribute.

The difficulty of developing a technologically neutral methodology for estimating the frequency of occurrence of incidents (attacks) related to safeguards and security, as compared to safety-related incidents, more-or-less obviously is associated to difference in the nature of the perceived threat.

The challenge of sharing resources across the material control and accounting requirements of the safeguards and the security functions, while maintaining the data integrity necessary to each of those functions, clearly is most closely associated to the transparency T. However the cause of that tension is not fully captured by the evaluation scheme used in Table 1 for the transparency attribute. The ultimate difference is not so much the *degree* of transparency, which is what is captured in Table 1, but rather is the *identity* of the parties to whom the process should and should not be made transparent. For safeguards it is necessary that the international community have enough knowledge about the process to ensure a high degree of confidence in its effectiveness, while at the same time the host state not have sufficient information to contravene the process. This can be a difficult balance. By contrast, for security it is paramount that the host state have full and complete material control and accounting information for sensitive materials, but it is conceivable that the host state would have legitimate reasons (*e.g.*, intellectual property) for desiring that information otherwise to be very closely held. The simple linear two-value (open to closed) evaluation scheme used in Table 1 for the transparency attribute fails adequately to capture that nuance.

On balance, the 3T scheme, as embodied in Table 1, for classifying tensions among the 3Ss is promising, but perhaps needs further development. Such development might take either or both of two forms: First, it could consist of an improved and more nuanced evaluation scale for the transparency attribute, as exemplified by the preceding discussion of the failure of the current evaluation scheme to capture adequately the transparency-related difficulty in achieving cost savings by sharing equipment across the material control and accounting functions of safeguards and security. Second, it might also be helpful to add additional attributes to the Ss (*e.g.*, consequence), or even to subdivide the Ss (*e.g.*, security-sabotage and security-theft).

#### **4.3.2 India-specific tensions**

The preceding subsection comprised an attempt to develop an abstract view of tensions among the 3Ss, based upon a tentative classification and evaluation of attributes representing sources of such tensions, as represented in Table 1. While the evaluation scheme in that table arguably represents a reasonable, if somewhat crude, effort to reflect a consensus evaluation within the international community, India itself is not particularly representative of the international norm regarding the 3Ss. In the present subsection we seek a deeper but India-specific understating of that fact.

The first question is, in what sense does India represent an unusual case relative to the 3Ss. We address that question by first recalling that in subsection 3.3.2 then (2002) DAE Secretary Kakodkar was quoted as speaking very approvingly of potential synergies between safety and safeguards, in the context of the IAEA INPRO project. In view of that extremely farsighted observation, and in further view of India's new need (since 2009) for additional safeguarding of its domestic reactors and of its increasing concerns about nuclear security, it is somewhat surprising to observers from outside the DAE that India has not pursued activities

designed to exploit the potential synergies between safeguards and security, as delineated in the second-from-last paragraph of Subsection 4.1. In view of India's expressed interest (Banerjee, 2010) in exporting its indigenous PHWR technology, as previously discussed in Subsection 1.3, from the vantage point of a similar observer this lack of follow up surpasses surprising and becomes remarkable. In view of India's current candidacy (*e.g.*, Dikshit, 2011) for membership in the Nuclear Suppliers Group, this omission rises to the level of astonishing. At the very minimum an effort to direct some of India's considerable expertise in nuclear technology toward exploitation of the synergies between requirements for security and for safeguards should have served, and perhaps still could serve, to alleviate some of the concerns that might be held by some of the NSG members most hesitant toward Indian membership.

What could be responsible for the obviously different perspective that prevails within the DAE? The hypothesis proposed here is that India has, possibly for reasons embedded in unique aspects of its nuclear history and natural resources, developed a nuclear program that puts an exceptionally high premium on secrecy, and that therefore minimizes the value of transparency, perhaps even feels uncomfortable with the concept of transparency.

To develop this hypothesis, first we seek to establish – with preference toward analysis and commentary from within India – that India's nuclear program does place an uncommonly high premium on secrecy. Second, we explore some of the possible reasons behind this world view.

If there indeed is an unusually high level of secrecy in the Indian nuclear program, as compared to other nuclear programs around the globe, how would that likely be manifested in a manner that could be readily observed? Table 1 suggests that most such programs would place a lesser value on secrecy for safety issues, a somewhat higher value for safeguards, and the highest value for security. This suggests that an exceptional reliance on secrecy is most likely to reveal itself relative to safety. Is there evidence of this? Subsubsection 3.3.1 already contained some indications of this, but our task here requires a deeper discussion.

In fact the charge that India's nuclear safety program is unduly secretive has long been made by Indian critics (*e.g.*, Gopalakrishnan, 1999; Gopi Rethinaraj, 1999; Ramana, 2009), some but not all of whom correctly can be portrayed as activists opposed to civil nuclear energy. Somewhat typical is the allegation by the newspaper *Daily News and Analysis* (DNA, 2011) of “using the Official Secrets Act as a crutch to deny the public the reasonable information and data that relate to the potential adverse impact of nuclear activities.” To the extent that such allegations are true, they suggest that historically the Indian philosophical inclination toward transparency within nuclear safety has been rather less toward the openness indicated as ideal in Table 1, and more toward the position of closure (secrecy) indicated in that table for security. From without the Indian nuclear establishment, it is difficult to know the extent to which that might have been a consequence of efforts to make use of synergies between safety and security, along with perhaps the always strong tendency



within India to rely on secrecy (i.e., lack of transparency) as a pillar of security. In the latter regard, Ramana (2009) refers to “the adoption, deliberately or through the vicissitudes of history and circumstances, of ‘opacity’ as the basis of nuclear strategy.”

The tendency toward secrecy in matters of nuclear safety has been challenged in Indian courts, typically not very successfully. As detailed in Ramana (2009; esp. pp. 53-55; the further quotes in this paragraph are from that source), when news emerged of a 1995 AERB report detailing many safety issues in DAE, two NGOS petitioned the Bombay High Court to make that report public. “On the basis of the affidavits submitted by the nuclear establishment, the Bombay High Court dismissed the petition ... .” In 2004 the Supreme Court dismissed a subsequent appeal. The basis of the court decisions seems largely to have been acceptance of DAE contention that release of the AERB report would facilitate “calculation of the country’s nuclear programme potential.” Ramana argues (p. 55) that to the contrary “the nuclear program *potential* depends essentially on just the broad design features of the reactors ... (which) ... are publicly available at a number of places including the Internet sites of the DAE ... .” See Nelson, Woddi and Charlton (2007) and Woddi, Charlton and Nelson (2009) for efforts that provide a certain amount of support to the latter contention. The chief source of uncertainty in the potential for India’s PHWRs not under safeguards (i.e., not declared “civil”) seems to be how rapidly the refueling machines for Indian PHWRs can be made to extract used fuel; it would certainly seem possible to redact material dealing with that issue while retaining the essence of any safety-related information.

The discussions of the two preceding paragraphs predate the March 2011 Fukushima Daiichi incident in Japan. But, as already mentioned in subsection 3.3.1, that incident has aroused substantial public concern about nuclear safety, and much of that concern has been directed toward perceived excesses of secrecy – or at least failure to communicate adequately - within the Indian nuclear establishment. For just one example, DNA (2011a) recently opined as follows:

*India has been accepted as a nuclear power, and the government has begun to move full steam ahead to generate power from the atom to meet growing energy needs, the Department of Atomic Energy and the Nuclear Power Corporation of India are running into a rising wall of public opposition. To be sure, the near-disaster at Fukushima, Japan, earlier this year has had a major role to play in turning people against nuclear energy. But the biggest share of the blame must lie at the doorstep of the DAE and the NPCIL. The scientists running these organisations may be the best in the business, but they are novices when it comes to the art of communication. And that is putting it mildly.*

For another, in early December 2011 the Supreme Court of India heard a petition, from two NGOs and several prominent individuals, “asking to direct that an independent expert body conduct a thorough safety re-assessment of the country's existing and proposed nuclear facilities” (The Hindu Business Line, 2011).

The Court's decision substantially deferred to the government, but asked the petitioners to submit details of the nuclear regulatory models employed in other countries (The Economic Times, 2011).

Recall that here our objective is not to criticize perceived excess secrecy by Indian nuclear authorities. To the contrary, nuclear fuel-cycle facilities can be an attractive target to those malefactors who for whatever reason wish to do harm to the public and duly constituted order, and it is here stipulated that some level of withholding of information regarding facilities of this type has a legitimate role in upholding public well being. This necessarily poses a difficult challenge to duly constituted authorities, perhaps especially so in a democracy, in establishing an appropriate balance between such secrecy and transparency as necessary to the need of the public to know in order to have confidence in the basic soundness of the civil nuclear enterprise. Our task here is not to define that balance, but rather to establish that there are reasons to believe India places a rather higher premium on secrecy in its nuclear enterprise than is the international norm. We believe the preceding discussion has met that objective.

Given existence of this unusually high reliance on secrecy, what could be responsible for it? India has been subject to many unusual circumstances in the historical evolution of its nuclear program. Among these are:

- India is globally unique in having two neighboring nuclear-armed antagonists, each of which it has had multiple armed conflicts with during the past half century.
- India has an exceptionally high degree of intertwining between the civil and military aspects of its nuclear program, which has only recently and arguably somewhat hesitantly begun to achieve some level of separation under its 2006 “separation plan” (GOI, 2006).
  - Regarding the characterization of progress toward separation as “hesitant.” In a recent interview (Jai, 2011) Dr. Srikumar Banerjee, Secretary of the DAE, indicated that “the new BARC campus in Vishakhapatnam ... will also be a mixed facility looking at both strategic and civilian research.” This certainly appears to be well within the rights of the GOI, in light of the international agreements that it is party to and the pronouncements it has made. However, if this intent is carried out it will leave India without any major laboratory having both a significant capability to carry out research in nuclear energy and a mission dominated by civil nuclear energy.
  - See Ramana (2009, esp. pp. 45-46) for some interesting historical vignettes regarding how this close connection came about.
- India has an exceptionally small portion of the global supply of the only naturally occurring fissile isotope (uranium-235), albeit an exceptionally high portion of one of the two naturally occurring fertile isotopes (thorium-232).

The first item in this list is widely held responsible for India's decision to become a nuclear-armed state, and prior to that to develop a program that would enable acquisition of nuclear weapons. That is, of course, not intended to deny existence of critics of that decision who would contend nuclear weapons are more harmful than helpful to India's national security, notwithstanding existence of the two afore-mentioned nuclear-armed neighbors. Extreme secrecy is central to many nuclear weapon programs, and that of India seems to be no exception (for example, *cf.* Basrur, 2009). The second major item in the preceding list then plausibly would have led this element of secrecy to become more a part of the Indian civil nuclear culture than likely would be the case in a typical state having a civil nuclear energy program, but no nuclear weapon program. (As is, for example, the case for Japan, and most Western European states.) This readily could have contributed to development of a culture of civil nuclear energy with an unusually high degree of emphasis upon safety, especially given a very legitimate concern that civil nuclear energy facilities could be the target of security attacks by sabotage or theft.

Finally, the last item in the above list made India's civil nuclear energy program exceptionally vulnerable to the international embargo on nuclear materials and technology to India that ultimately emerged in response to India's 1974 nuclear explosion. As the basic point of contention between India and the international community revolved about the nature of safeguards that appropriately should be applied to India's nuclear program, it is unfortunate but should not be surprising that a certain amount of disdain for the topic of international safeguards crept into the culture of the Indian nuclear establishment. More specifically, the question was whether only nuclear materials and technology imported by India, or derived from such imports, would be subject to international safeguards, and therefore unavailable for use in the weapons program, or all nuclear materials and technology would be so subject, and therefore there could be no such weapons program. Once in 2005 the international community signaled willingness to accept the former, which was more-or-less India's long-held position, an agreement enabling the flow of international materials and technology to India was in sight, although ultimately not reached without considerable diplomatic negotiation and maneuvering. Nonetheless the skepticism and suspicion toward safeguards seems deeply embedded in the DAE culture, which tends to make it difficult to engage in a dialog with them on that topic, or even on related problems that are purely scientific or technical in nature.

While it is important to understand the history that has led to the current point in time, it is more important (and challenging) to understand the opportunities for the future. It is our belief that it remains an open case as to whether the concept of "synergies between safety, safeguards and security" can evolve beyond being a mere slogan, and become a principle that enhances all three of these "Ss" while at the same time enhancing the economic competitiveness of nuclear energy. Determining the answer to that question seemingly will require a significant research program, elements of which already were outlined in subsection 4.2.5.

Arguably because of the globally unique history of its nuclear program, India is in a position to contribute significantly to such a research program, and possibly to benefit from it. In particular, and as discussed in subsection 4.2.5, the skilled scientific and technical staff associated to India's Department of Atomic Energy is well-suited to contribute significantly to some of the analytic issues that seeming must be addressed in such a research program. At least equally significantly, India's plans to develop civil nuclear energy aggressively over the coming decades, and its unique position with respect to the nuclear nonproliferation regime, provide it with unparalleled opportunities to provide testbed facilities, as called for in subsections 4.2.3 and 4.2.5, for the design-level implementation of economically and operationally meaningful synergies among the 3Ss (i.e., for 3SBD).

### *4.3.3 A tabular summary of synergies and tensions among the 3Ss*

Table II comprises an effort to summarize and organize, in an extensible format, the various measures that have been discussed elsewhere in this report as providing mechanisms for achieving synergies among the 3Ss. The entries in the first of the four columns indicate the particular set of "Ss" affected by the corresponding measure(s), as in the corresponding third column. Those in the second column describe the particular generic function that the measure is intended to perform. Of course multiple generic functions can affect a particular synergistic set, so each entry in column 1 in principle corresponds to multiple entries in column 2.

As already indicated, the third column contains specific measures intended to perform some generic function. Again in principle a generic function may correspond to multiple specific measures, although in its current form Table II displays only one instance of that. Finally, the fourth column contains an abbreviated list of unresolved issues associated to the particular measure. These unresolved issues may or may not be associated to one of the 3Ts (tensions) previously discussed. Where there is such an association, the particular "T" involved is indicated by bracketed capital letters (e.g., "[THREAT]"). Questionable assertions of unresolved issues are noted by question marks.

For examples, the synergistic set "Safety & Security" corresponds to by far the largest number of generic functions (six) and measures (seven). Two measures ("security deposit" and "use of accelerator-driven sources") are suggested for meeting the generic function is "disposal of isotopic sources." (Strictly speaking use of accelerator-driven sources does not dispose of isotopic sources, but it negates the need for such disposal.) Finally, the measure "enhanced preparation" seems to have the largest and perhaps most interesting variety of unresolved issues, one of which is associated to a "T" (threat), but two of which do not. (The latter two, in a sufficiently broad view, relate to cost-benefit analysis, in comparison to alternative measures or even alternative generic functions.)

Table II - Some steps that potentially impact multiple Ss

<b>Areas benefitting from synergy</b>	<b>Generic function</b>	<b>Measure</b>	<b>Unresolved issues [“T” leading to tension]</b>
<b>Safety &amp; safeguards</b>	Management of nuclear material	“Criticality and accounting control” (Suzuki <i>et al.</i> , 2010)	Possible operator or host state access to information intended to be limited to inspectorate [THREAT]
	Waste management	Passive isolation systems (engineered and geological barriers)	Contrary to legal obligation to maintain safeguards regime [THREAT]
<b>Safety &amp; security</b>	Disposal of isotopic sources	Security deposit	
		Use of accelerator-driven sources	Loss of portability
	Emergency preparedness and consequence management	Enhanced preparation	Benefits security attack by sabotage, but not security attack by theft [THREAT]. Costs better spent for prevention? How to compare?
	Enhance public confidence	High(er) degree of transparency	Could inform security adversary [THREAT, TRANSPARENCY]
	Limit risk of public and plant personnel radiological exposure	Passive safety systems for nuclear power plants (Khali <i>et al.</i> , 2009)	None? Will enhance both safety and security to attack by sabotage
	Limit risk of public and plant personnel radiological exposure and of theft	Physically limit access	Also limits egress and ingress, both of which could be undesirable post-event [sometimes – incorrectly – described as a tension between safety and security, but more accurately a tension between security attack by sabotage and security attack by theft]
	Prevent radiological release	“Double-entry doors to keep negative pressure and prevent radioactive release” (Suzuki <i>et al.</i> , 2010)	None?
<b>Safeguards &amp; security</b>	Management of nuclear material	Use of “containment and surveillance and remote monitoring camera” (Suzuki <i>et al.</i> , 2010)	Possible undesirable inspectorate access to information intended to be limited to operator, and operator or host state access to information intended to be limited to inspectorate [THREAT]
	Nonproliferation	Development of reactor fuel that is unattractive for nuclear explosives	Successful development is uncertain, except possibly in the case of relatively

			unsophisticated adversaries (Bathke <i>et al.</i> , 2008)
<b>Safety, security &amp; safeguards</b>	Legal and regulatory structure	Make single entity administratively responsible for all (or multiple) Ss	Risk of diluting responsibility for one or more of the Ss
	Relative cost-benefit analysis for optimization of design or operation (“performance indicators” – <i>cf.</i> International Nuclear Safety Group, 2010; “regime harmonization” – <i>cf.</i> <a href="#">Luongo, Squassoni and Wit, 2011</a> )	“Harmonization of risk notions” (Suzuki <i>et al.</i> , 2010) (Develop commensurate measure of consequences of personnel exposure and misappropriation of material)	How to quantify misappropriation of material as risk to the public? [THREAT]
		Develop techniques for evaluating probable frequency of adversarial attack	How to quantify expected frequency of security attacks (by either sabotage or theft) by active antagonist, including dependence upon countermeasures taken to defeat any such attack? [THREAT]

## 5 CONCLUSIONS AND RECOMMENDATIONS

Following are the significant conclusions and recommendations emerging from this study, along with references to the portions of the preceding text, mostly in Section 4, in which the basis for the particular conclusion or recommendation is developed more fully:

- How or whether India or any state might achieve benefits from synergies among the 3Ss is a complex issue that this study cannot hope fully to address.
  - In any effort to achieve synergies between safety, safeguards and security, India might benefit from building upon the active IAEA programs that are directed toward such synergies (*cf.* Section 2, and Subsection 4.1), thereby capitalizing upon its traditionally strong relationship with the IAEA.
  - In return India could materially assist the IAEA and the international community in determining the extent to which the concept of synergies among the 3Ss can rise above mere “sloganeering,” and achieve the level of tangible benefits in design, construction and operation that provide cost savings or improvements in one or all of safety, safeguards and security. (See further recommendations below.)
- The potential effect, upon attaining synergies between the 3Ss, of further separating the AERB from the remainder of the Indian nuclear establishment (Section 3) seems worthy of very careful consideration in determining the details of that separation.
  - In particular, the proposed reorganization of nuclear regulatory responsibility in India could adversely impact efforts to achieve synergies between safeguards and either of safety or security (see subsubsection 4.2.4.1). In turn this could affect negatively India’s ability to export its pressurized heavy water reactor technology (subsubsection 4.2.5).
    - For example, to what extent might it be advisable for the AERB to have responsibility for matters of safeguards and security, in addition to its traditional regulatory role for safety? (This could, for example, help to facilitate development of rational paths to development of a common approach to evaluation of the safety and the security benefits of proposed measures; *cf.* Section 4.)
- The international community conceivably could benefit from a better understanding of India’s experience in applying root-cause analysis to improve counter-terrorism efforts, pursuant to the discussion in subsubsection 3.3.2.
- India is perhaps uniquely positioned among the states having advanced civil nuclear power programs in having both significant potential benefits and potential opportunity to fully realize the benefits of

the synergies between safety, safeguards and security that have been perceived by many. This possibility was already foreseen nearly ten years past by now retired DAE Secretary Kakodkar (2002). (See subsections 3.3.2 and 3.3.3 for more details)

- The international community might consider attempting to engage the considerable mathematical and computational modeling skill resident in the DAE toward developing methodologies for technologically neutral evaluations of the proliferation resistance afforded by various approaches to safeguards (*cf.* subsection 4.2.1).
- Control of and accounting for radioactive sources is an area of commonality between safety and security that has been actively recognized for some time, and India has been an active participant in international efforts in that regard. Nonetheless, this also is an area where substantial challenges seem to remain. (See subsection 4.2.2.1 for details.)
- It is recommended that the IAEA contemplate initiating a new task directed toward development of guidelines, somewhat more detailed than those currently existing, for designers and operators to take advantage of synergies and deal with tensions between safety and security at future nuclear cycle facilities. Further details are in subsection 4.2.2.2.
- The DAE might contemplate potential advantages attendant to offering the international community one of its soon-to-be constructed civil facilities as the object of a study to obtain tangible experience in the specifics of exploiting synergies and dealing with tensions between safety and security in the engineering design of nuclear facilities. A more detailed discussion can be found in subsection 4.2.2.2.
- For both facility design and operational considerations it might be beneficial to develop a better, ideally even somewhat quantitative, understanding of the tradeoffs between the need to limit access in order to lower the exposure to safety-related incidents or the likelihood of security-related events, and the need to facilitate ingress by authorized responders to an incident arising from materialization of threats related to either safety or security. (See subsection 4.2.2.3.)
- Although India is under no compulsion to do so, some significant potential benefits would seem to derive from directing a modest amount of its expertise in nuclear science and technology toward research and development of methodologies for simultaneously enhancing safeguards and security. (See subsection 4.2.3 for more details).
  - Enhancement in the dual yet secure use of equipment, especially communications equipment, for control and accounting of nuclear material, is one instance of a direction for research and development that has mutual benefits for both safeguards and security. (See subsection 4.2.3.)



- Methodologies for either harmonizing consequences across the 3Ss, or for evaluating *a priori* the probability of incidents related to safeguards or security (“attacks”), could significantly enhance the ability to achieve synergies across the 3Ss, even at the level of conceptual design. (See subsection 4.2.4.2). In turn this could have at least an indirect impact toward enhancing the economic competitiveness of any effort to export Indian technology for civil nuclear energy (see subsection 4.2.5).



Figure 13 - Dr. S. K. Jain, Chairman and Managing Director of the Nuclear Power Corporation of India, Limited. (Source: Nuclear Power Corporation of India, Limited, by permission)

- The DAE/GOI might wish to consider possible advantages to India’s efforts to sell its indigenous nuclear technology on the international market that might stem from offering its planned “new national reprocessing facility dedicated to reprocessing safeguarded nuclear material under IAEA safeguards” (*cf.* Clause 6.iii of US Department of State (2007)) as a testbed for 3SBD (*cf.* subsection 4.2.5), although some less complex facility might be preferable for initial tests. (Again, a more detailed discussion appears in subsection 4.2.5).
  - This suggestion seems consistent with the vision of S. K. Jain (2010): “The proliferation risks associated with nuclear power make it inevitable that the cooperation (within the Asian

region, on nuclear power) has to be in accordance with the IAEA safeguards mechanism, with monitoring of all nuclear activities.”

- In order to enable any serious effort to capitalize upon synergies among the 3Ss in the design of nuclear facilities, it likely will be necessary to execute a multiyear multistep research program having components of both development and testing of proposed methodologies for analyzing approaches to the design and construction of actual facilities. (See subsection 4.2.5 for more detailed descriptions of some of the possible elements of such a program.)
  - The history, capabilities and current intentions of India’s nuclear program place it in a unique position to contribute toward any international effort to understand better the potential for meaningful design-level synergies among the 3Ss (subsection 4.3.2 contains more detail.)

## **ACKNOWLEDGMENTS**

An abbreviated and preliminary version of this work was presented, in poster format, at the 2011 meeting of the Institute for Nuclear Materials Management, and was published in the proceedings of that meeting (Ankush and Nelson, 2011). This report is a substantial revision of a dissertation submitted by Ankush Batra to the Pandit Deendayal Petroleum University, in partial fulfillment of the requirements for the M. Tech. in Nuclear Engineering. Much of the revision was carried out in September 2011, during a visit by Mr. Ankush to the Nuclear Security Science and Policy Institute of the Texas Engineering Experiment Station and the Department of Nuclear Engineering, at Texas A&M University. The US Department of State partially supported Mr. Ankush's visit to the Texas Engineering Experiment Station.

We are much appreciative to the following individuals for comments and suggestions: Dr. Paulo Barretto (NSSPI-TAMU), Dr. Sunil Sunny Chirayath (NSSPI-TAMU), Mr. Adam Hetzler (TAMU), Dr. Taraknath Woddi (ScienTech) and Mr. Mark Soo Hoo (SNLA). Any errors are of course the sole responsibility of the authors, as are the conclusions reached and opinions expressed in this report. Such conclusions or opinions do not necessarily represent official positions or views of any of the organizations with which the authors might be or have been affiliated.

## REFERENCES

- AERB, 1999. Preparation of Site Emergency Preparedness Plans for Nuclear Installations, AERB Safety Standard No. AERB/SG/EP-1, AERB, Mumbai 400 094, October. <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-EP-01.PDF>, accessed November 20, 2011.
- AERB, 1999a. Preparation of Off-site Emergency Preparedness Plans for Nuclear Installations, AERB Safety Standard No. AERB/SG/EP-2, AERB, Mumbai 400 094, October. <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-EP-02.PDF>, accessed November 20, 2011.
- AERB, 2001. AERB SAFETY GUIDE NO. AERB/SG/G-8, [www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-G-08.PDF](http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-G-08.PDF), accessed April 5, 2011.
- AERB, 2001a. Testing and Classification of Sealed Radioactive Sources, AERB Safety Standard No. AERB/SS/3 (Rev. 1), AERB, Mumbai 400 094, October 5. <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SS-03-REV1.PDF>, accessed November 20, 2011.
- AERB, 2005. AERB Safety Glossary, March 2005, <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-GLO.PDF>, accessed April 5, 2011.
- AERB, 2007. Consenting Process for Nuclear Power Plants and Research Reactors, Guide No. AERB/NPP&RR/SG/G-1, AERB, Mumbai 400 094, March. <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-G-1.pdf>, accessed November 20, 2011.
- AERB, 2009. Design of Pressurised Heavy Water Reactor Based Nuclear Power Plants, Code No. AERB/NPP-PHWR/SC/D (Rev. 1), AERB, Mumbai 400 094. <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SC-D1.pdf>, accessed November 20, 2011.
- AERB, 2011. Annual Report, 2010-2011, AERB, Niyamak Bhavan, Anushakti Nagar, Mumbai. <http://www.aerb.gov.in/T/annrpt/2010/annrpt2k10.pdf>, accessed November 20, 2011.
- AERB, 2011a. Security of Radioactive Sources in Radiation Facilities, Guide No. AERB/RF-RS/SG-1, AERB, Mumbai 400 094, March. <http://www.aerb.gov.in/T/PUBLICATIONS/CODESGUIDES/SG-RF-RS-01.pdf>, accessed November 20, 2011.
- Abousahl, S., *et al.*, 2010. Integration of Nuclear Safeguards and Security at the JRC, presented at the IAEA Safeguards Symposium 2010, Vienna, November 1-5. <http://www.iaea.org/OurWork/SV/Safeguards/Symposium/2010/Documents/PapersRepository/2255344543972513139540.pdf>, accessed November 28, 2011.
- Ankush and P. Nelson. Safety, Safeguards and Security in Indian Nuclear Power Plants (3S-INPP). Presented at INMM 2011, Palm Desert, California, and published in the Proceedings of that conference.
- Anonymous, 2011. Workshop on Protection against Sabotage and Vital Area Identification: a report, BARC Newsletter, Issue No. 318, p. 4, Jan.-Feb. 2011, <http://www.barc.gov.in/publications/nl/>, accessed June 25, 2010.
- Arai, T. and K. Naito, 2009. The New Nexus, 3Ss: Safeguards, Safety, Security, and 3S-Based Infrastructure Development for the Peaceful Uses of Nuclear Energy, *Journal of Nuclear Material Management*, Vol. XXXVII, No. 4 (Summer), pp. 6-10. Also available at [www.inmm.org/ScriptContent/JNMM\\_Archive\\_Files/Vol.../V.37\\_4.pdf](http://www.inmm.org/ScriptContent/JNMM_Archive_Files/Vol.../V.37_4.pdf), accessed May 28, 2011.

Argonne National Laboratory, 2005. Radiological Dispersal Device (RDD), Human Health Fact Sheet, August. <http://www.evns.anl.gov/pub/doc/rdd.pdf>, accessed October 31, 2011.

Bajaj, S.S., 2010. Challenges of Atomic Energy Regulation in Indian Context, Asian Nuclear Prospects 2010, Challenges of Atomic Energy Regulation in Indian Context, <http://www.igcar.ernet.in/events/anup2010/SSBajaj.pdf>, accessed June 25, 2011.

Banerjee, S., 2010. Statement to the 54<sup>th</sup> General Conference of the IAEA, Vienna, September 22, <http://www.dae.gov.in/gc/gc54.doc>, accessed June 25, 2011.

Banerjee, S., 2010a. BARC Celebrates Founder's Day, BARC Newsletter, Issue No. 310, pp. 6-10, Sept.-Oct. 2010, <http://www.barc.gov.in/publications/nl/>, accessed June 22, 2010.

Basrur, R. M., 2009. Minimum Deterrence and India's Nuclear Security, NUS Press, Singapore.

Bathke, C.G., *et al.*, 2008. An Assessment of the Proliferation Resistance of Materials in Advanced Nuclear Fuel Cycles. In: Peterson, D. (Ed.), The 8th International Conference on Facility Operations – Safeguards Interface, Portland, OR, American Nuclear Society.

Bjornard, T. *et al.*, 2008. Achieving the Benefits of Safeguards by Design, <http://www.inl.gov/technicalpublications/Documents/4045030.pdf>, accessed June 12, 2011.

Bloomberg News, 2008. Nuclear Waste Gets Recycled Into Goods, Los Angeles Times, November 12. <http://articles.latimes.com/2008/nov/12/business/fi-radioactive12>, accessed October 30, 2011.

Bunn, Matthew, 2008. Safety, Security, Safeguards: Enabling Nuclear Energy Growth, Presentation to the Global Nuclear Future Workshop, American Academy of Arts and Sciences, May 5-6, [http://belfercenter.ksg.harvard.edu/files/bunn\\_safety\\_security\\_safeguards\\_08.pdf](http://belfercenter.ksg.harvard.edu/files/bunn_safety_security_safeguards_08.pdf), accessed January 2011.

Cavina, A., 2009. Enhancing Cybersecurity in Nuclear Infrastructure, A Presentation to the Technical Working Group on NPPIC, May 9, [http://entrac.iaea.org/i-and-c/twg\\_npp\\_ci\\_2009\\_05/Presentations/Plenary/Cyber\\_Security\\_Cavina.ppt](http://entrac.iaea.org/i-and-c/twg_npp_ci_2009_05/Presentations/Plenary/Cyber_Security_Cavina.ppt), accessed June 19, 2011.

Chernus, Ira, 2002. Eisenhower's Atoms for Peace, Texas A&M University Press Consortium.

Conlin, J. L., *et al.*, 2011. On Using Code Emulators and Monte Carlo Estimation to Predict Assembly Attributes of Spent Fuel Assemblies for Safeguards Applications. Nuclear Science and Engineering, Vol. 169, pp. 314-328.

Cooley, J.N., *et al.*, 2009. Safeguards by Design – Concept, Implementation and Future Development, Proceedings (CD) of the 50<sup>th</sup> Annual Meeting of the Institute for Nuclear Materials Management, Tucson, July 12-16.

DAE, 2003. Atomic Energy in India: a Perspective, DAE, September, <http://www.dae.gov.in/publ/persp/persp03/persp03.pdf>, accessed June 21, 2011.

DAE, 2006. Department of Atomic Energy (India), A Perspective: Department of Atomic Energy, <http://www.dae.gov.in/publ/persp/persp06/start.pdf>, accessed October 9, 2011.

Delattre, D. 2011. Education and Training for Capacity Building in Nuclear Safety and Security, [http://www.iaea.org/inisnkm/nkm/pages/2011/NEMschool2011/topics/topic7/02\\_Session%207%20August%2016%20-%20IAEA%20Capacity%20Building%20Education%20and%20Training%20in%20Nuclear%20Safety.pdf](http://www.iaea.org/inisnkm/nkm/pages/2011/NEMschool2011/topics/topic7/02_Session%207%20August%2016%20-%20IAEA%20Capacity%20Building%20Education%20and%20Training%20in%20Nuclear%20Safety.pdf), accessed November 19, 2011.

Dicus, G. J., 1999. USA Perspectives: Safety & Security of Radioactive Sources. IAEA Bulletin, Vol. 41, No. 3, pp. 22-27.

Dighe, P. M. *et al.*, 2010. Quantification of Fissile Materials by Photon Activation Method in a Highly Shielded Enclosure, presented at the IAEA Safeguards Symposium 2010, Vienna, November 1-

5. <http://www.iaea.org/OurWork/SV/Safeguards/Symposium/2010/Documents/PapersRepository/049.pdf>, accessed November 2, 2011.

Dikshit, Sandeep, 2011. US circulates ‘thought paper’ on Indian membership of NSG, The Hindu, June 25, <http://www.thehindu.com/news/national/article2132635.ece>, accessed July 3, 2011.

DNA, 2011. Lessons from abroad for an autonomous AERB- article by A Gopalakrishnan, Press Release, May 26, 2011, [http://www.dnaindia.com/india/analysis\\_lessons-from-abroad-for-an-autonomous-aerb\\_1547509](http://www.dnaindia.com/india/analysis_lessons-from-abroad-for-an-autonomous-aerb_1547509), accessed September 15, 2011.

DNA, 2011a. Mumbai edit: End this secrecy, December 2, 2011. [http://www.dnaindia.com/analysis/editorial\\_mumbai-edit-end-this-secrecy\\_1620126](http://www.dnaindia.com/analysis/editorial_mumbai-edit-end-this-secrecy_1620126), accessed December 4, 2011.

Editor, Frontline, 1999. Nuclear Power: Issues of Nuclear Safety, Vol. 16, No. 6, Mar. 13 – 26, <http://www.hindu.com/fline/fl1606/16060820.htm>, accessed June 24, 2011.

Eisenhower, Dwight D., 1953. *Atoms for Peace Speech*, [http://iaea.org/About/atomsforpeace\\_speech.html](http://iaea.org/About/atomsforpeace_speech.html), accessed June 17, 2011.

Eldridge, C. (Rapporteur), 2005. Protection, Control, and Accounting of Nuclear Materials: International Challenges and National Programs -- Workshop Summary, National Research Council, Washington, pp. 39-41. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1232\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1232_web.pdf), accessed October 9, 2011.

Fischer, David, 1997. IAEA: The First Forty Years, IAEA, Vienna.

Fischer, David, 2007. Nuclear Safeguards: The First Steps. IAEA Bulletin, Vol. 49, No. 1, pp. 7-11.

Flory, Denis, 2010. Safety and Security: Working together for a responsible nuclear development, presented at the WINS Workshop on the effective integration of S&S – Vienna, October 12, <http://www-ns.iaea.org/downloads/coordination/ddg/ddg-wins-workshop-2010.pdf>, accessed June 19, 2011.

Garcia, M.L., 2008. The Design and Evaluation of Physical Protection Systems. Butterworth Heinemann, Woburn, Massachusetts, 2<sup>nd</sup> Edition.

Ghosh, J. K., 2006. Management of Radioactive Sources Ensuring Safety and Security: The Indian Scenario, in IAEA (2006c), pp. 269-275. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1262\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1262_web.pdf), accessed October 28, 2011.

GIF, 2008. Basis for the Safety Approach for Design & Assessment of Generation IV Nuclear Systems (Revision 1), GIF/RSWG/2007/002., November 24. [http://www.gen-4.org/Technology/horizontal/documents/Basis\\_for\\_the\\_Safety\\_Approach\\_for\\_Design\\_Assessment\\_of\\_Generation\\_IV\\_Nuclear\\_Systems\\_000.pdf](http://www.gen-4.org/Technology/horizontal/documents/Basis_for_the_Safety_Approach_for_Design_Assessment_of_Generation_IV_Nuclear_Systems_000.pdf), accessed October 16, 2011.

GIF, undated. About the GIF. <http://www.gen-4.org/GIF/About/index.htm>, accessed October 16, 2011.

Goddard, B., W. Charlton, C. Gariazzo and P. Peerani. 2011. A Concept for Quantitative NDA Measurements of Advanced Reprocessing Product Materials. Proceedings of GLOBAL 2011, Makuhari Messe, Chiba, Japan, Dec. 11-16, Paper No. 385211, Atomic Energy Society of Japan.

GOI, 1962. Atomic Energy Act, 1962, September 15, AERB, [http://www.aerb.gov.in/T/actsrules/atomicenergyact\\_amendment1987.htm](http://www.aerb.gov.in/T/actsrules/atomicenergyact_amendment1987.htm), accessed June 21, 2011.

GOI, 1998. Evolution of India’s Nuclear Policy, A Paper laid on the Table of the Lok Sabha, May 27, <http://www.fas.org/news/india/1998/05/980527-goi1.htm>, accessed June 21, 2011.

GOI, 2006. Implementation of the India-United States Joint Statement of July 18, 2005: India’s Separation Plan, DAE, tabled in Parliament May 11, <http://www.dae.gov.in/press/sepplan.pdf>, accessed June 24, 2011.

GOI, 2010. Constitution of the Atomic Energy Commission, as amended, February 18, <http://www.aec.gov.in/resolution.pdf>, accessed March 22, 2012.

GOI, undated. Global Centre for Nuclear Energy Partnership, DAE, [http://www.dae.gov.in/press/global\\_centre.pdf](http://www.dae.gov.in/press/global_centre.pdf), accessed June 25, 2011.

GOI, undated a. Nuclear Fuel Cycle in India, [http://india.gov.in/sectors/science/nuclear\\_cycle.php](http://india.gov.in/sectors/science/nuclear_cycle.php), accessed June 25, 2011.

GOI, undated b. Central Industrial Security Force, Ministry of Home Affairs, <http://cisf.nic.in/>, accessed June 25, 2011.

GOI, undated c. Defence & Paramilitary Personnel, india.gov.in, <http://india.gov.in/govt/armedforces.php>, accessed June 25, 2011.

Gopalakrishnan, A., 1999. Issues of Nuclear Safety, Frontline. Vol. 16, No. 6, Mar. 13 – 26, <http://www.flonnet.com/fl1606/16060820.htm>, accessed December 4, 2011.

Gopalakrishnan, A., 2011. [Lessons from abroad for an autonomous AERB - India - DNA](http://www.dnaindia.com/india/analysis_lessons-from-abroad-for-an-autonomous-aerb_1547509), May 26, [http://www.dnaindia.com/india/analysis\\_lessons-from-abroad-for-an-autonomous-aerb\\_1547509](http://www.dnaindia.com/india/analysis_lessons-from-abroad-for-an-autonomous-aerb_1547509), accessed June 24, 2011.

Gopi Rethinaraj, T.S., 1999. In the Comfort of Secrecy, Bulletin of the Atomic Scientists, Vol. 55, Issue 6, pp. 52-57.

Hammoud, K., 2008. The IAEA Legislative Assistance Programme, Presentation at VERTIC Technical Coordination Meeting, Development House, London, <http://oldsite.vertic.org/assets/IAEA.pps>, accessed January 29, 2008.

Hashim, W. *et al.*, 2011. Integration of Nuclear Safety, Security and Safeguards Systems, GNEII Capstone project, 2011. Format

Hough, C.D. *et al.*, 1975. The Technical Objective of Safeguards. IAEA Bulletin, Vol. 17, No. 2, pp 13-17. <http://www.iaea.org/Publications/Magazines/Bulletin/Bull172/17203401317.pdf>, accessed October 17, 2011.

IAEA, 1956. Statute of the IAEA, Vienna International Centre, Vienna, October 26. [http://www.iaea.org/About/statute\\_text.html](http://www.iaea.org/About/statute_text.html), accessed November 4, 2011.

IAEA, 1968. The Agency's Safeguards System (1965, as Provisionally Extended in 1966 and 1968), INFCIRC/66/Rev. 2, IAEA, September 16. [INFCIRC/66/Rev.2 - The Agency's Safeguards System \(1965, as Provisionally Extended in 1966 and 1968\)](http://www.iaea.org/Publications/Documents/Infcirc/66/Rev.2-The-Agency's-Safeguards-System-(1965-as-Provisionally-Extended-in-1966-and-1968).pdf), accessed November 4, 2011.

IAEA, 1970. Treaty on the Non-proliferation of Nuclear Weapons,” April 22, INFCIRC/140, IAEA, <http://www.iaea.org/Publications/Documents/Infcirc/Others/infcirc140.pdf>, accessed June 18, 2011.

IAEA, 1972. International Atomic Energy Agency, The structure and content of agreements between the agency and states required in connection with the treaty on the non-proliferation of nuclear weapons, INFCIRC/153 (Corrected), IAEA, Austria, June. <http://www.iaea.org/Publications/Documents/Infcirc/Others/infcirc153.pdf>, accessed March 30, 2011.

IAEA, 1975. Systems of Accounting for and Control of Nuclear Material, IAEA Bulletin, Vol. 17, No. 2, pp. 18-24. <http://www.iaea.org/Publications/Magazines/Bulletin/Bull172/17204801824.pdf>, accessed November 15, 2011.

IAEA, 1980. Guidelines for States' Systems of Accounting and Control of Nuclear Materials. IAEA/SG/INF/2, IAEA, Vienna. [http://www-pub.iaea.org/MTCD/publications/PDF/iaea\\_sg\\_inf\\_2\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/iaea_sg_inf_2_web.pdf), accessed October 24, 2001.

IAEA, 1980a. The Convention on the Physical Protection of Nuclear Material, INFCIRC/274/Rev. 1, May, <http://www.iaea.org/Publications/Documents/Infcircs/Others/inf274r1.shtml>, accessed March 21, 2012.

IAEA, 1993. Against the Spread of Nuclear Weapons: IAEA Safeguards in the 1990s, Limits to the Safeguards System. Booklet 93-04459, IAEA/PI/A38E, December, <http://www.iaea.org/Publications/Booklets/Safeguards/pia3810.html>, accessed March 26, 2012.

IAEA, 1995. Evolution of Safeguards. International Nuclear Verification Series No. 2, [http://www-pub.iaea.org/MTCD/publications/PDF/NVS2\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/NVS2_web.pdf), accessed October 4, 2011.

IAEA, 1997. Further Analysis of Extended Storage of Spent Fuel. IAEA-TECDOC-944, Vienna. [http://www-pub.iaea.org/MTCD/publications/PDF/te\\_0944\\_scr.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/te_0944_scr.pdf), accessed October 23, 2011

IAEA, 1997a. Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected), September, <http://www.iaea.org/Publications/Documents/Infcircs/1997/infirc540c.pdf>, accessed March 22, 2012.

IAEA, 1998. Design Measures to Facilitate Implementation of Safeguards at Future Water Cooled Nuclear Power Plants, Technical Report series No. 392, IAEA, Vienna, January (1999). [http://www-pub.iaea.org/MTCD/publications/PDF/trs392\\_scr.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/trs392_scr.pdf), accessed November 3, 2011.

IAEA, 2003. Safeguards Techniques and Equipment, International Nuclear Verification Series No. 1 (Revised), IAEA, [http://www-pub.iaea.org/MTCD/publications/PDF/NVS1-2003\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/NVS1-2003_web.pdf), accessed June 18, 2011.

IAEA, 2004. Code of Conduct in the Safety and Security of Radioactive Sources. IAEA, Vienna, January. [http://www-pub.iaea.org/MTCD/publications/PDF/code-2004\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/code-2004_web.pdf), accessed October 28, 2011.

IAEA, 2005. Code of Conduct on the Safety and Security of Radioactive Sources and the Supplementary Guidance on the Import and Export of Radioactive Sources, IAEA INFCIRC/663, Vienna, December 29. <http://www.iaea.org/Publications/Documents/Infcircs/2005/infirc663.pdf>, accessed October 29, 2011.

IAEA, 2005a. Key IAEA Publications Related to Safety and Security of Radioactive Sources, IAEA, Vienna, IAEA/PI/A.86 / 05-09551, September. [http://www.iaea.org/Publications/Booklets/SealedRadioactiveSources/pdfs/fs\\_keypubl.pdf](http://www.iaea.org/Publications/Booklets/SealedRadioactiveSources/pdfs/fs_keypubl.pdf) , accessed October 29, 2011.

IAEA, 2005b. Measures to Strengthen International Cooperation in Nuclear, Radiation and Transport Safety and Waste Management: Nuclear Safety Review for the Year 2004, GC(49)/INF/7, 29 August. [http://www.iaea.org/About/Policy/GC/GC49/GC49InfDocuments/English/gc49inf-7\\_en.pdf](http://www.iaea.org/About/Policy/GC/GC49/GC49InfDocuments/English/gc49inf-7_en.pdf), accessed November 19, 2011.

IAEA, 2005c. Nuclear Security - Measures to Protect Against Nuclear Terrorism; Amendment to the Convention on the Physical Protection of Nuclear Material, September 6, GOV/INF/2005/10-GC(49)/INF/6, <http://www.iaea.org/About/Policy/GC/GC49/Documents/gc49inf-6.pdf>, accessed March 21, 2012.



IAEA, 2006. IAEA Safety Glossary: Terminology used in nuclear, radiation, radioactive waste and transport safety, Version 2.0, September, IAEA, <http://www-ns.iaea.org/downloads/standards/glossary/glossary-english-version2point0-sept-06-12.pdf>, accessed June 17, 2011.

IAEA, 2006a. Promoting Nuclear Security: What the IAEA is Doing, IAEA Division of Public Information, 06-30961 / FS Series 1/03 Rev.1/E, February, <http://www.iaea.org/Publications/Factsheets/English/nucsecurity.pdf>, accessed June 19, 2011.

IAEA, 2006b. Nuclear Security - Measures to Protect Against Nuclear Terrorism, IAEA Director General Report GOV/2006/46-GC(50)/13, August 16, [http://www.iaea.org/About/Policy/GC/GC50/GC50Documents/English/gc50-13\\_en.pdf](http://www.iaea.org/About/Policy/GC/GC50/GC50Documents/English/gc50-13_en.pdf), accessed June 4, 2011.

IAEA, 2006c. Fundamental Safety Principles, IAEA Safety Standards series No. SF-1, Vienna, November. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf), accessed November 2, 2011.

IAEA, 2006c. Safety and Security of Radioactive Sources: Towards a Global System for the Continuous Control of Sources throughout Their Life Cycle: Proceedings of an International Conference, Bordeaux, 27 June–1 July 2005. IAEA, Vienna, November. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1262\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1262_web.pdf), accessed October 28, 2011.

IAEA, 2007. Milestones in the Development of a National Infrastructure for Nuclear Power. IAEA Nuclear Energy Series No. NG-G-3.1, Vienna.

IAEA, 2007a. Engineering Safety Aspects of the Protection of Nuclear Power Plants Against Sabotage, IAEA Nuclear Security Series No. 4, IAEA, Vienna, January. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1271\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1271_web.pdf), accessed November 2, 2011.

IAEA, 2008. Preventive and Protective Measures Against Insider Threats, IAEA Nuclear Security Series No. 8, September, [http://www-pub.iaea.org/MTCD/publications/PDF/pub1359\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/pub1359_web.pdf), accessed June 28, 2011.

IAEA, 2008a. Report of the Commission of Eminent Persons on the Future of the Agency, IAEA GOV/2008/22-GC(52)/INF/4, May 23, [http://www.iaea.org/About/Policy/GC/GC52/GC52InfDocuments/English/gc52inf-4\\_en.pdf](http://www.iaea.org/About/Policy/GC/GC52/GC52InfDocuments/English/gc52inf-4_en.pdf), accessed June 23, 2011.

IAEA, 2008b. Nuclear Material Accounting Handbook. IAEA Services Series No. 15, May, [http://www-pub.iaea.org/MTCD/publications/PDF/svs\\_015\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/svs_015_web.pdf), accessed October 4, 2011.

IAEA, 2008c. Nuclear Security Culture, IAEA Nuclear Security Series No. 7, September, [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1347\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1347_web.pdf), accessed March 21, 2012.

IAEA, 2009. Agreement between the Government of India and the International Atomic Energy Agency for the Application of Safeguards to Civilian Nuclear Facilities. INFCIRC-754, May 29, IAEA, <http://www.iaea.org/Publications/Documents/Infcircs/2009/infcirc754.pdf>, accessed October 9, 2011.

IAEA, 2010. IAEA, <http://recruitment.iaea.org/documents/orgchart.pdf>, accessed June 18, 2011.

IAEA, 2010a. Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste. IAEA Nuclear Energy Series No. NW-T-1.21, Vienna, IAEA. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1414\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1414_web.pdf), accessed October 23, 2011.

IAEA, 2011. Factsheets and FAQs: Nuclear Safety, June 16, <http://iaea.org/Publications/Factsheets/English/ns.html>, accessed June 18, 2011.

IAEA, 2011a. List of States that have made a Political Commitment with Regard to the Code of Conduct on the Safety and Security of Radioactive Sources and the Supplementary Guidance on the Import and Export of Radioactive Sources. IAEA, September

5. [http://www.iaea.org/Publications/Documents/Treaties/codeconduct\\_status.pdf](http://www.iaea.org/Publications/Documents/Treaties/codeconduct_status.pdf), accessed October 29, 2011.

IAEA, 2011b. IAEA Guidance on the Import and Export of Radioactive Sources: List of Points of Contact, IAEA, June 29. <http://www-ns.iaea.org/downloads/rw/imp-export/import-export-contact-points.pdf>, accessed October 29, 2011.

IAEA, 2011c. Control and Management of Radioactive Material Inadvertently Incorporated into Scrap Metal: Proceeding of an International Conference on Radioactive material Inadvertently Incorporated into Scrap Metal, Tarragona, Spain, February 23-27, 2009, IAEA-STI/PUB/1502, Vienna, July. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1502\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1502_web.pdf), accessed October 30, 2011.

IAEA, 2011d. Nuclear Security Recommendations on Radioactive Material and Associated Facilities , IAEA Nuclear Security Series No. 14, IAEA, Vienna, January. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1487\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1487_web.pdf), accessed November, 2011.

IAEA, 2011e. Indian 220 MWe PHWR (IPHWR-220), Status Report for Advanced Nuclear Reactor Designs – Report 74, updated April

4. [http://aris.iaea.org/ARIS/download.cgi?requested\\_doc=report&doc\\_id=74&type\\_of\\_output=pdf](http://aris.iaea.org/ARIS/download.cgi?requested_doc=report&doc_id=74&type_of_output=pdf), accessed November 3, 2011.

IAEA, 2011f. IAEA Fact-Finding Team Completes Visit to Japan, IAEA Press Release pr 2011/07, June. [IAEA Fact-Finding Team Completes Visit to Japan](#), accessed November 19, 2011.

IAEA, 2011g. National Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), January, [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1481\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1481_web.pdf), accessed March 21, 2012.

IAEA, 2012. Amendment to the Convention on the Physical Protection of Nuclear Material, [http://www.iaea.org/Publications/Documents/Conventions/cppnm\\_amend\\_status.pdf](http://www.iaea.org/Publications/Documents/Conventions/cppnm_amend_status.pdf), March 16, accessed March 21, 2012.

IAEA, undated. IAEA Safety Glossary, Terminology used in Nuclear Safety and Radiation Protection, [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1290\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1290_web.pdf), accessed February 23, 2011.

IAEA, undated a. IAEA publications- Radioactive Waste Management Glossary, [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1155\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1155_web.pdf), accessed February 25, 2011.

IAEA, undated a1. IAEA Safety Standards, Concepts and Terms, <http://www-ns.iaea.org/standards/concepts-terms.asp?s=11&l=90>, accessed March 27, 2011.

IAEA, undated b. IAEA Organizational Chart, <https://recruitment.iaea.org/documents/orgchart.pdf>, accessed February 26, 2011.

IAEA, undated b1. Making the Real Difference: Working for the IAEA, <https://communities.acs.org/servlet/JiveServlet/previewBody/3397-102-1-3758/Making%20a%20Difference%20-%20Working%20at%20the%20IAEA.pdf>, accessed June 25, 2011.

IAEA, undated c. Statute of the IAEA, [http://www.iaea.org/About/statute\\_text.html](http://www.iaea.org/About/statute_text.html), accessed June 17, 2011.

IAEA, undated c1, Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA Nuclear Energy Series, No. NG-G-3.1, 2007 International Atomic Energy Agency, Vienna ISBN 978-92-0-107707-3.

IAEA, undated d. A Short History of the IAEA, <http://iaea.org/About/history.html>, accessed June 17, 2011.

IAEA, undated e. IAEA nuclear security series no.7, Nuclear Security Culture, [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1347\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1347_web.pdf), accessed June 20, 2011.

IAEA, undated f. The “Atoms for Peace” Agency, <http://iaea.org/About/about-iaea.html>, accessed June 18, 2011.

IAEA, undated g. Nuclear Installations Safety, <http://www-ns.iaea.org/home/ni/dir-ni-message.asp?s=2&l=16>, accessed June 18, 2011.

IAEA, undated h. Employment: Department of Nuclear Safety and Security (NS), Division of Radiation, Transport and Waste Safety (NSRW), <http://www.iaea.org/About/Jobs/ns.html>, accessed October 8, 2011.

IAEA, undated i. Nuclear Safety and Security, <http://www-ns.iaea.org/>, accessed June 18, 2011.

IAEA, undated j. Department of Safeguards: Delivering Effective Nuclear Verification for World Peace, <http://www.iaea.org/OurWork/SV/Safeguards/index.html>, accessed June 18, 2011.

IAEA, undated k. About Safeguards, <http://www.iaea.org/OurWork/SV/Safeguards/about.html>, accessed June 18, 2011.

IAEA, undated l. Department of Safeguards (SG), <http://www.iaea.org/About/Jobs/sg.html>, accessed June 18, 2011.

IAEA, undated m. International Atomic Energy Agency, Department of Safeguards, <http://www.iaea.org/About/Jobs/sg.html>, accessed June 18, 2011.

IAEA, undated n. International Conventions and Agreements, <http://www.iaea.org/Publications/Documents/Treaties/index.html>, accessed June 18, 2007.

IAEA, undated o. What We Do, <http://www.iaea.org/OurWork/SV/Safeguards/what.html>, accessed June 18, 2011.

IAEA, undated p. Safeguards Analysis Tools, <http://www.iaea.org/OurWork/SV/Safeguards/analytical-services.html>, accessed June 18, 2011.

IAEA, undated q. Topical Booklets & Articles, <http://www.iaea.org/Publications/Booklets/sv.html>, accessed June 18, 2011.

IAEA, undated r. Nuclear Energy Handbook, NSNS: Office of Nuclear Security, <http://www.iaea.org/inisnkm/nkm/ws/d3/r2760.html>, accessed June 19, 2011.

IAEA, undated s. Nuclear Safety & Security, <http://www-ns.iaea.org/coordination/organi-chart.asp>, accessed June 19, 2011.

IAEA, undated t. Nuclear Security Fund (NSF), <http://www-ns.iaea.org/security/nsf.asp?s=4>, accessed June 19, 2011.

IAEA, undated u. Nuclear Security, <http://www-ns.iaea.org/security/>, accessed June 19, 2011.

IAEA, undated v. Nuclear Security Guidelines, [http://www-ns.iaea.org/security/nuclear\\_security\\_series.asp?s=5&l=35](http://www-ns.iaea.org/security/nuclear_security_series.asp?s=5&l=35), accessed June 19, 2011.

IAEA, undated w. Educational Programme in Nuclear Security, IAEA Nuclear Security Series No. 12. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1439\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1439_web.pdf), accessed June 25, 2011. Also Edit

IAEA, undated x. The IAEA’s Safeguards System: Ready for the 21<sup>st</sup> Century. <http://www.iaea.org/Publications/Booklets/Safeguards2/intro.html>, accessed October 24, 2011.

IAEA, undated y. The Incident and Emergency Centre (IEC): Answering the Request for Emergency Assistance Worldwide, Division of Public Information 07-04311 / FS Series 1/04/E. <http://www.iaea.org/Publications/Factsheets/English/iec.pdf>, accessed November 19, 2011.

IAEA, undated z. IAEA Safeguards Overview: Comprehensive Safeguards Agreements and Additional Protocols. [http://www.iaea.org/Publications/Factsheets/English/sg\\_overview.html](http://www.iaea.org/Publications/Factsheets/English/sg_overview.html), accessed December 12, 2011.

Indian Express, 2010. AERB withdraws DU's Authorisation to use Radioactive Source, Mumbai, September 15. <http://www.indianexpress.com/news/aerb-withdraws-dus-authorisation-to-use-radioactive-source/681919/0>, accessed October 29, 2011.

International Nuclear Safety Group, 2010. The Interface between Safety and Security at Nuclear Installations. IAEA, Vienna, August. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1472\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1472_web.pdf), accessed November 2, 2011.

Jai, S., 2011. Enrichment capacity enough to fuel nuke subs, IBNLive, November 26. <http://ibnlive.in.com/news/enrichment-capacity-enough-to-fuel-nuke-subs/206066-61.html>, accessed December 3, 2011.

Jain, S. K., 2010. Inevitability of Nuclear Power in the Asian Region, paper presented at the Second International Conference on Asian Nuclear Prospects (ANUP 2010), Mamallapuram, India, October 11-13, 2010. [www.npcil.nic.in/pdf/CMD\\_Paper\\_for\\_ANUP\\_2010.doc](http://www.npcil.nic.in/pdf/CMD_Paper_for_ANUP_2010.doc), accessed December 8, 2011.

Jain, S.K., undated. Nuclear Power - An Alternative by Dr. S.K Jain, CMD NPCIL & BHAVINI, <http://www.npcil.nic.in/pdf/nuclear%20power-%20an%20alternative.pdf>, accessed June 25, 2011.

Japanese Ministry of Foreign Affairs, 2008. International Initiative on 3S-Based Nuclear Energy Infrastructure, a background paper for the G8 Summit 2008, Hokkaido, [http://www.mofa.go.jp/policy/economy/summit/2008/doc/pdf/0708\\_04\\_en.pdf](http://www.mofa.go.jp/policy/economy/summit/2008/doc/pdf/0708_04_en.pdf), accessed January 29, 2011.

Jog, S., 2011. Mobile System to Detect Radiological and Nuclear Hazards, Business Standard, Mumbai, October 6. <http://www.business-standard.com/india/news/mobile-system-to-detect-radiologicalnuclear-hazards/451658/>, accessed October 28, 2011.

Kakatkar-Kulkarni, M., 2010. A Naxal threat to India's nuclear arsenal?, India: The World Affairs Blog Network, June 29, <http://india.foreignpolicyblogs.com/2010/06/29/a-naxal-threat-to-indias-nuclear-arsenal/>, accessed May 6, 2011.

Kakodkar, A., 2002. Statement to the 46<sup>th</sup> IAEA General Conference, DAE, September 18, <http://www.dae.gov.in/gc/gc46.htm>, accessed June 25, 2011.

Kenn, R. and G. Verlini, 2009. The Evolving Landscape of Nuclear Security, IAEA Bulletin, Vol. 50-2, <http://www.iaea.org/Publications/Magazines/Bulletin/Bull502/50202042426.html>, accessed June 19, 2011.

Khalil, H. et al. (2009). Integration of Safety and Reliability with Proliferation Resistance and Physical Protection for Generation IV Nuclear Energy Systems. Proceedings of Global 2009, Paris, France, September 6-11, 2009, Paper 9396, pp. 2447-2452.

Kinney, J., P. S. Iontchev and T. Pochet. The Application of Safeguards to Civilian Nuclear Facilities in India (INFCIRC/754) - Challenges and Action Taken. Presented at INMM 2011, Palm Desert, California, and to appear in the proceedings of that conference.

Koenick, S., 2011. Safety and Security Interface, Presentation to the IAEA/ICPT School of Nuclear Energy Management, August

16. [http://www.iaea.org/inisnkm/nkm/pages/2011/NEMschool2011/topics/topic7/06A\\_Koenick\\_IAEA%20supplemental%20safety%20security%20interface.pdf](http://www.iaea.org/inisnkm/nkm/pages/2011/NEMschool2011/topics/topic7/06A_Koenick_IAEA%20supplemental%20safety%20security%20interface.pdf), accessed November 2, 2011.
- Kovacic, D. N. *et al.*, 2009. Nuclear Safeguards Infrastructure Development and Integration with Safety and Security, Procs. INMM Annual Meeting (Tucson). Also available at <http://info.ornl.gov/sites/publications/files/Pub20268.pdf>, accessed January 30, 2011.
- Kumar, S.V., 2007. Reprocessing in India: Development, Demonstration and Deployment, Founder's Day 2007 speech, <http://www.barc.ernet.in/talks/svkspeech.html>, accessed June 25, 2011.
- Lee, T-H, Y-S Kim and H-S Shin and H-D Kim, 2011. Hot-test Results of the Advanced Spent Fuel Conditioning Process Safeguards Neutron Counter for PWR Spent Fuel Rods. Nuclear Technology, Vol. 176, pp. 147-154.
- Linsley, G. and A. Fattah. The Interface between Nuclear Safeguards and Radioactive Waste Disposal: Emerging Issues. IAEA Bulletin, Vol. 36, No. 2, pp 22-26. <http://www.iaea.org/Publications/Magazines/Bulletin/Bull362/36202682226.pdf>, accessed October 23, 2011.
- Mahaprashasta, A. A., 2010. Importing Trouble, Frontline, Volume 27, Issue 11, May 22 - June 4. <http://hindu.com/fline/fl2711/stories/20100604271109800.htm>, accessed October 30, 2011.
- Mishra, R.K. (undated). Nuclear Proliferation Challenges and India's Response, <http://www.tandfonline.com/doi/abs/10.1080/09700160701662294>, accessed 25 June 2010.
- MTAR, undated. About Bhavini, <http://www.mtar.in/businessSegments/pfbr.php>, accessed June 25, 2011.
- NDMA, 2009. National Disaster Management Guidelines—Management of Nuclear and Radiological Emergencies, National Disaster Management Authority, Government of India, NDMA Bhawan, A-1, Safdajung Enclave, New Delhi – 110 029. <http://ndma.gov.in/ndma/guidelines/Management+of+Nuclear+&+Radiological+Emergencies.pdf>, accessed November 20, 2011.
- NDMA, undated. Evolution of NDMA, National Disaster Management Authority, Government of India, Bhawan, A-1, Safdajung Enclave, New Delhi. <http://ndma.gov.in/ndma/evolution.html>, accessed November 20, 2011.
- NDMA, undated a. Roles and Responsibilities, National Disaster Management Authority, Government of India, Bhawan, A-1, Safdajung Enclave, New Delhi. <http://ndma.gov.in/ndma/rolesrespons.html>, accessed November 20, 2011.
- Nelson, P., T.V.K. Woddi and W.S. Charlton, 2007. A Framework for Analysis of the Weapons Implications of the US-India Nuclear Accord. Report No. NSSPI-07-080, Nuclear Security Science and Policy Institute, Texas A&M University, October 10.
- Newslick, 2011. Complete independence of AERB an imperative- Interview with Dr. A. Gopalakrishnan, <http://newslick.in/international/complete-independence-aerb-and-full-transparency-imperative-interview-agopalakrishnan>, accessed September 9, 2011.
- NPCIL, undated. About NPCIL, <http://www.npcil.nic.in/main/AboutUs.aspx>, accessed October 9, 2011.
- N'TI, 2011. Facilities Description, December, <http://www.nti.org/country-profiles/india/facilities/>, accessed March 26, 2012
- Okko, O., *et al.*, 2010. Safeguards by Design – Experiences from New Nuclear Installation, presented at the IAEA Safeguards Symposium 2010, Vienna, November 1-5. <http://www.iaea.org/OurWork/SV/Safeguards/Symposium/2010/Documents/PapersRepository/024.pdf>, accessed November 3, 2011.

- Parthasarathy, K. S. (2008). Historical, Regulatory and Safety Aspects of Nuclear Energy in India, *Atoms for Peace: An International Journal*, Vol. 2, No. 1, pp. 102–119.
- Parthasarathy, K. S. (2009). Radioactive Contamination in Steel: A Wake-up Call, *The Hindu*, February 26. <http://blogs.thehindu.com/delhi/?p=15111>, accessed October 30, 2011.
- Press Information Bureau, 2010. Global Centre for Nuclear Energy Partnership, Press Release, Government of India, August 13, <http://pib.nic.in/release/release.asp?relid=64718>, accessed January 29, 2011.
- PRS, 2011. Nuclear Safety Regulatory Authority Bill 2011, <http://www.prsindia.org/uploads/media/Nuclear%20Safety/Nuclear%20Safety%20Regulatory%20Authority%20Bill%202011.pdf>, accessed September 16, 2011.
- Ramana, M. V., 2009. India's Nuclear Enclave and the Practice of Secrecy, Chapter 3 (pp. 41-67) in *South Asian Cultures of the Bomb: Atomic publics and the state in India and Pakistan*, Itty Abraham (Ed.), Indiana University Press, Bloomington.
- Raghuraman, K., 2005. The IAEA as a partner in nuclear security initiatives. In *Nuclear Security: Global Directions for the Future*, Procs. of an International Conference, London, March 16-18, 2005. IAEA, Proceedings Series, Vienna, pp. 217-224. [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1232\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1232_web.pdf), accessed October 9, 2011.
- Rundquist, D. E. and L. M. Watkins, 1984. Improving Safeguards Techniques: Instrumentation. *IAEA Bulletin*, Vol. 26, No. 3, pp 13-19. <http://www.iaea.org/Publications/Magazines/Bulletin/Bull263/26303451319.pdf>, accessed October 17, 2011.
- Sacchetti, D., 2009. The Tools of Today & Tomorrow. *IAEA Bulletin*, Vol. 50, No. 2, pp 64-65. <http://www.iaea.org/Publications/Magazines/Bulletin/Bull502/50202456465.pdf>, accessed October 17, 2011.
- SAPIERR II, 2008. Strategic Action Plan for Implementation of European Regional Repositories: Stage 2, October, [ftp://ftp.cordis.europa.eu/pub/fp6- Euratom/docs/sapierr-2-4-safety-and-security-of-regional-repositories\\_en.pdf](ftp://ftp.cordis.europa.eu/pub/fp6- Euratom/docs/sapierr-2-4-safety-and-security-of-regional-repositories_en.pdf), accessed June 15, 2011.
- Scheinman, L., 1987. *The International Atomic Energy Agency and World Nuclear Order*, Resources for the Future, Washington, DC.
- Sevini, F., *et al.* (2010). Development of IAEA High Level Guidelines for Designers and Operators, presented at the IAEA Safeguards Symposium 2010, Vienna, November 1-5. <http://www.iaea.org/OurWork/SV/Safeguards/Symposium/2010/Documents/PapersRepository/2171467729401189384089.pdf>, accessed November 3, 2011.
- Singh, K. Natwar, 2005. India and the NPT, Inaugural Address for the Conference on Emerging Nuclear Proliferation Challenges, IDSA and Pugwash, New Delhi, March 28, <http://www.dae.gov.in/iaea/npt.htm>, accessed June 25, 2011.
- Singh, K. R. and S. P. Agarwal, 2011. Radioactive Contamination in Steel Products – Indian Experience, pp. 263-271 in IAEA (2011c). [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1502\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1502_web.pdf), accessed October 30, 2011.
- Stein, M. *et al.*, 2009. Safety, Security, and Safeguards by Design – An Industrial Approach. Proceedings of Global 2009, Paris, France, September 6-11, 2009, Paper 9307, pp. 2262-2672.
- Sundararajan, A. R., 1991. Emergency Preparedness in the Indian Nuclear Power Stations, *Risk Analysis*, Vol. 11, No. 3, pp. 389-391.

Suzuki, M. *et al.*, 2010. Investigating 3S Synergies to Support Infrastructure Development and Risk-Informed Methodologies for 3S by Design. Presented at IAEA Safeguards Symposium 2010, Vienna, October. <http://www.iaea.org/OurWork/SV/Safeguards/Symposium/2010/Documents/PapersRepository/0647160806199588803977.pdf>, accessed October 6, 2011.

Suzuki, M., T. Burr and J. Howell, 2011. Risk-informed Approach for Safety, Safeguards and Security (3S) by Design. Procs. ICONE 19, 19<sup>th</sup> International Conference on Nuclear Engineering, May 16-19, Chiba, Japan, Paper No. ICONE19-43154.

Talbott, S., 2004. Engaging India: Diplomacy, Democracy and the Bomb. Brookings Institution Press, Washington, D.C.

Taniguchi, T., 2009. Global Nuclear Safety and Security, Remarks presented at US Nuclear Regulatory Commission Regulatory Information Conference, March 10, <http://www.iaea.org/newscenter/statements/ddgs/2009/taniguchi100309.html>, accessed March 26, 2011.

The Economic Times, 2011. Supreme Court Holds Back Order on Nuclear Safety PIL, December 6, [http://articles.economictimes.indiatimes.com/2011-12-06/news/30481698\\_1\\_nuclear-safety-nuclear-plants-regulatory-body](http://articles.economictimes.indiatimes.com/2011-12-06/news/30481698_1_nuclear-safety-nuclear-plants-regulatory-body), accessed March 27, 2012.

The Hindu Business Line, 2011. Apex Court Seeks Details on Nuclear Regulators in Other Countries, December 4, <http://www.thehindubusinessline.com/industry-and-economy/article2687093.ece>, accessed March 27, 2012.

The Telegraph, 2011. Fukushima's Shadow. Calcutta, October 12, [http://www.telegraphindia.com/1111012/jsp/opinion/story\\_14612520.jsp](http://www.telegraphindia.com/1111012/jsp/opinion/story_14612520.jsp), accessed October 20, 2011.

Times of India, 2011. DAE, CSIF Review security of Nuclear Power Plants, April 30, [http://articles.timesofindia.indiatimes.com/2011-04-30/india/29490337\\_1\\_cisf-central-industrial-security-force-nuclear-power-plants](http://articles.timesofindia.indiatimes.com/2011-04-30/india/29490337_1_cisf-central-industrial-security-force-nuclear-power-plants), accessed June 25, 2011.

Times of India, 2011a. Six DU Professors Charged for Mayapuri Radiation Leak, Delhi, September 3. [http://articles.timesofindia.indiatimes.com/2011-09-03/delhi/30109365\\_1\\_national-radiation-emergency-response-mayapuri-scrap-gamma-irradiator](http://articles.timesofindia.indiatimes.com/2011-09-03/delhi/30109365_1_national-radiation-emergency-response-mayapuri-scrap-gamma-irradiator), accessed October 29, 2011.

US Department of State, 2007. Agreement for Cooperation between the Government of the United States of America and the Government of India concerning peaceful uses of nuclear energy (123 Agreement), August 3, Media Note 2007/658, August 3. [http://www.reading.ac.uk/web/FILES/123agreement/TEXT\\_123\\_AGREEMENT.pdf](http://www.reading.ac.uk/web/FILES/123agreement/TEXT_123_AGREEMENT.pdf), accessed November 26, 2011.

US NRC, 2009. Safety/Security Interface Requirements for Nuclear Power Reactors, March 27, 10CFR 73.58, March. <http://www.nrc.gov/reading-rm/doc-collections/cfr/part073/part073-0058.html>, accessed November 20, 2011.

US NRC, 2009a. Managing the Safety/Security Interface, Regulatory Guide 5.74, US NRC Office of Nuclear Regulatory Research, June. <http://pbadupws.nrc.gov/docs/ML0916/ML091690036.pdf>, accessed November 2, 2011.

US NRC, 2010. For the Record: NRC Statement on Contaminated Scrap Metal and Consumer Products, Washington, D.C. June 12. <http://www.nrc.gov/reading-rm/doc-collections/for-the-record/2009/ml091630471.pdf>, accessed October 30, 2011.

US NRC, 2011. Office of Nuclear Material Safety and Safeguards. <http://www.nrc.gov/about-nrc/organization/nmssfuncdesc.html>, updated October 14, accessed October 23, 2011.

US NRC, 2011a. Probabilistic Risk Assessment (PRA). March 31. <http://www.nrc.gov/about-nrc/regulatory/risk-informed/pr.htm>, accessed December 1, 2011.

Wikipedia, 2011. International Atomic Energy Agency, [http://en.wikipedia.org/wiki/International\\_Atomic\\_Energy\\_Agency](http://en.wikipedia.org/wiki/International_Atomic_Energy_Agency), accessed March 24, 2011.

Williams, A. D. *et al.*, 2011. Gulf Nuclear Energy Infrastructure Institute (GNEII): Overview and Status Update. Presented at INMM 2011, Palm Desert, California, and published in the proceedings of that conference.

Wolf, I., 2009. Scripps Howard News Service Response to Comments from the US Nuclear Regulatory Commission on SHNS' "Recycled Radiation," July 22. <http://www.scrippsnews.com/content/scripps-howard-news-service-response-comments-us-nuclear-regulatory-commission-shns-recycled>, accessed October 30, 2011.

World Nuclear Association, 2011. Small Nuclear Power Reactors, <http://www.world-nuclear.org/info/inf33.html>, August 11, 2011, accessed September 12, 2011.

World Nuclear Association, 2011a. Nuclear Power in India, <http://www.world-nuclear.org/info/inf53.html>, August 11, 2011, accessed September 9, 2011.

World Nuclear News, 2011. Nuclear regulation bill introduced to Indian Parliament, [http://www.world-nuclear-news.org/RS-Nuclear\\_regulation\\_bill\\_introduced\\_to\\_Indian\\_parliament-0909117.html](http://www.world-nuclear-news.org/RS-Nuclear_regulation_bill_introduced_to_Indian_parliament-0909117.html), September, accessed September 23, 2011.

Woddi, T.V.K., W.S. Charlton and P. Nelson, 2009. India's Nuclear Fuel Cycle: Unraveling the impact of the US-India nuclear accord. Morgan and Claypool, San Rafael, California.

Yue, M., L. Cheng and R. Rari, 2008. A Markov Model Approach to Proliferation-Resistance Assessment of Nuclear Energy Systems. Nuclear Technology, Vol. 162, pp. 28-44.