CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES

A COLLECTION OF PAPERS FROM THE 2010 PONI CONFERENCE SERIES

PROJECT ON NUCLEAR ISSUES

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About the Project on Nuclear Issues

The Center for Strategic and International Studies launched the Project on Nuclear Issues (PONI) in 2003 in order to help address the problems resulting from the trend of declining interest and expertise in nuclear weapons issues. At its outset, PONI sought to fulfill two primary objectives. First, it endeavored to build a sense of community for young experts from across the enterprise by connecting those from the nuclear laboratories, military, industry, academia, and policymaking circles. Second, PONI sought to provide a forum where young experts and their senior counterparts could interact and generate new ideas on how to address key technical and policy issues. As PONI has grown into a multifaceted program consisting of several concerted efforts, it has taken on a third and more specific objective of developing the next generation of leaders in the field.

PONI's yearly conference series strives to promote new thinking in the field and bring people together to network and discuss the ideas presented. The Nuclear Scholars Initiative, a six-month seminar series for a selected class of graduate students and young professionals, brings some of the best and brightest young analysts together with high-level senior experts for monthly workshops. The PONI Debates the Issues blog provides daily analysis of new developments. The PONI Live Debate series features in-depth analysis of critical nuclear strategy and policy dilemmas. The Next Generation Working Group, a task force comprised of rising experts within the community, is researching next steps in bilateral arms control. PONI is also organizing bilateral exchanges and other efforts to help engage young experts from other countries and develop relationships among future leaders in the field. Finally, PONI holds an essay contest to help encourage new and innovative thinking from young scholars in the field.

In all of these efforts, PONI seeks to bridge the gap between junior and senior experts in the field and between the technical and policy communities. Now in its seventh year of operation, PONI has grown to include over 1,100 members from the U.S., UK and France, as well as other countries. The project is lead by its director, Dr. Clark Murdock, who is also a Senior Adviser at CSIS. A Board of Advisers, consisting of a mix of junior and senior PONI members, also provides advice on how PONI can achieve its objectives and leverage resources within its membership ranks to improve the quality of its programs and continue to increase its value to the community.

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Introduction

The Center for Strategic and International Studies launched the Project on Nuclear Issues (PONI) in 2003 in order to revitalize and strengthen a community of nuclear weapons experts that had been shrinking in size and increasingly thin in critical technical skills and policy expertise, especially among younger generations. The PONI conference series was created in order to promote new and innovative thinking on how to address key questions associated with the evolving role of nuclear weapons in international security and to bring people together from across the enterprise to discuss these ideas. To that end, the conference series has always placed a strong emphasis on featuring the ideas of newcomers to the field, who are uniquely positioned to generate creative insights and who represent the future of intellectual leadership in relevant technical and policy areas.

The 2010 conference series included events at the Center for Strategic and International Studies in April, at Sandia National Laboratories in August, and at the Atomic Weapons Establishment in September before concluding with a Capstone Conference at Offutt Air Force, home of U.S. Strategic Command, in December. The papers included in this volume are a selection of some of the presentations delivered at the Capstone Conference. Though few in numbers, they cover a wide range of technical and policy issues and will hopefully advance discussion in each area among PONI members and the nuclear community writ-large.

Mark Jansson
Deputy Director, Project on Nuclear Issues

Engaging the Scientific Enclave in India towards Nonproliferation post Indo-US Civil Nuclear Agreement

Saurabh Dutta Chowdhury[1]

India has started to embark on an ambitious nuclear renaissance in the next few decades to meet her energy needs. The Indo-US Nuclear deal provides India access to nuclear reactors and nuclear fuel from the NSG (Nuclear Supplier's Group) in return for putting her "civilian" nuclear reactors under the International Atomic Energy Agency (IAEA) safeguards. However, one of the drawbacks of the Indo-US Nuclear deal has been India's decision to keep the Prototype Fast Breeder Reactor (PFBR) and reprocessing plant at Indira Gandhi Center for Atomic Research IGCAR in Kalpakkam, India, out of IAEA safeguards. The fast breeder reactor is part of the second stage of the three stage thorium (a naturally occurring, slightly radioactive metal) program championed by the Indian scientific enclave led by the Indian Department of Atomic Energy (DAE). The PFBR is a plutonium fueled breeder reactor. This reactor uses the plutonium (Pu) recovered from the PHWR as input along with thorium to generate more Pu and Uranium-233(U-233). The U-233 is then supposed to be used as input to the Advanced Heavy Water Reactor (AHWR) (third stage) to generate electricity using thorium (a naturally occurring, slightly radioactive metal) as part of the three stage program. Unfortunately, the fast breeder reactor is risky both from a proliferation and safety point of view. Most other countries with sodium cooled fast reactors have shelved the program based on safety issues in Japan and France with the exception of the BR-800 reactor from Russia. In this study, some diplomatic solutions such as the offer of US collaboration with the Indian scientific enclave, in the areas of Advanced Light Water Reactor's or Generation IV Reactors (ALWR's) and Accelerator Driven Systems (ADS), are proposed as options to persuade the Indian scientific enclave to put PFBR and the Kalpakkam reprocessing plant under safeguards in return. The viability of each of the options is considered along with the possible outcomes for scenarios where such options are not pursued.

Introduction

The Indian Nuclear Program (both civilian and military) has long been plagued by fuel shortages. This is due to the lack of major uranium reserves in India, coupled with a lack of access to the worldwide supply of such fuel, following the embargo imposed on India post its 1974 nuclear test. This scenario has led India to focus on breeder technology development to become self sufficient in nuclear fuel and utilize the vast thorium reserves. However, this process has proved challenging. As the Indian economy stands on the cusp of ten percent annualized growth for the next few decades, its energy resources are woefully in short supply. Pressure from the world community to control its greenhouse emissions has made matters worse. Nuclear power is carbon free, hence, there has been an increased interest to pursue this option in India. However, lack of access to outside sources of fuel threatens the current nuclear program. Having realized these challenges, the Indian government embarked on negotiations with the US on a civil nuclear agreement starting in 2005. This agreement has now been approved by legislatures in both the US and India, giving access to nuclear fuel from the US and other members of the Nuclear Suppliers Group (NSG) in return for India putting its civilian

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nuclear power plants under IAEA safeguards (albeit in a phased manner) thereby ending three decades of nuclear isolation.

Having realized that nuclear fuel is the "achilles heel" in the Indian civilian nuclear program, the US correctly used access to nuclear fuel as the central negotiating theme during the Indo-US civil nuclear deal. This resulted in some assurances from India regarding putting civilian nuclear programs under IAEA safeguards, despite the fact that India is not a signatory to the NPT. Additionally, access to advanced components supply is another weakness of the Indian nuclear program that can be leveraged by the US to further the non-proliferation agenda with India. As a follow up to the Indo-US nuclear agreement, this paper argues that US collaboration with the Indian scientific enclave, in the areas of Advanced Light Water Reactor's or Gen IV Reactors (ALWR's) and Accelerator Driven Systems (ADS) are options to persuade the Indian scientific enclave to put Prototype Fast Breeder Reactor (PFBR) and the Kalpakkam reprocessing plant under safeguards. Pros and cons for three different policy scenarios concerning scientific engagement are explored and a recommendation is made about the optimum policy option.

Three Stage Program: Cornerstone of the Indian Civilian Nuclear Program[2]

In October 2008, at the 52nd General Conference of the International Atomic Energy Agency (IAEA) in Vienna, Dr. Anil Kakodkar, Chairman of India's Atomic Energy Commission, reported on the urgency of the development of India's atomic energy program. India's Planning Commission projects that by 2032, India's share of global fossil fuel use could increase from 13% to 21%. Kakodar argued that placing an emphasis on using more nuclear energy to generate electricity is much more ecologically sustainable.

The long term goal for India's nuclear energy program is to achieve energy independence using its vast reserves of thorium. To this end, India is implementing a three-stage program to develop fast breeder reactors that convert thorium into nuclear fuel. The thorium based fast breeder reactor technology (PFBR) that India is developing, uses a closed fuel cycle which reduces the need to transport radioactive fuel as the fuel is produced in the reactor itself. Thorium-232 is not fissile, but inside the reactor it is converted to uranium-233, which is used as the breeder fuel.

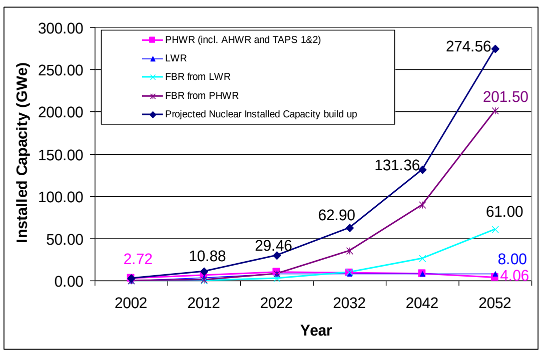
The first stage of the program was the development of Pressurized Heavy Water Reactors (PHWR) based on Canada Deuterium Uranium (CANDU) reactors supplied to India in the 1960's by Canada. The spent fuel from these reactors contains unused uranium, plutonium, and other fissile materials. Rather than disposing of this as waste, the spent fuel is reprocessed and used in the development of Fast Breeder Reactors (FBR) in the program's second stage to keep with the commitment of maintaining a closed fuel cycle and to feed the third stage of the program. The third stage includes the development of thorium based fast breeder reactors, which is being advanced currently with the Advanced Heavy Water Reactor (AHWR).

A forerunner to the PFBR is the Fast Breeder Test Reactor (FBTR) at Kalpakkam, which has been operational for the past 19 years. France and India signed an agreement whereby France would help India in building an experimental reactor, which can generate 40 MWt/13MWe. A team of engineers from India were trained on the rapsodie reactor in France. The French gave the Indians the design to build a small breeder reactor at Kalpakkam and the fuel to be used was enriched uranium.

[2] *www.dae.gov.in/publ/3rdstage.pdf*

Future Roadmap of Three Stage Program as per the Atomic Energy Commission (AEC)

The first prototype fast breeder reactor with capacity of 500 MWe will be complete by 2010. After that, there are plans to build more similar units. AEC has planned four in the program until 2020. The development of the fast-breeder technology will go on at the Indira Gandhi Center for Atomic Research (IGCAR). In this development, AEC will proceed in two ways. The first, is to go for higher capacity reactors, possibily developing 1,000 MWe reactors. The second, is to use the reactor design and its associated fuel cycle, which will have a shorter doubling time as we get into a higher and higher generating capacity through the breeding process. The faster the breeding, the quicker the rise in the fast-breeder reactor's capacity. Therefore, AEC plans to pursue both the directions: one is the higher reactor unit size, and the other, the fuel cycle, which has a shorter doubling time. Light Water Reactors (LWR) imported from the West, Russia/Japan or South Korea are viewed as stopgaps until the FBR's are ramped up[3].



Reactor Types and Capacities	Capacity (MWe)	Cumulative Capacity (MWe)
17 Reactors at Six Sites in Operation; Tarapur, Rawatbhata, Kalpakkam, Narora, Kakrapar, Kaiga	4,120	4,120
3 PHWRs under Constructon at: Kaiga 4 (220 MWe), RAPP 5 & 6 (2 x 220 MWe)	660	4,780
2 LWRs under Construction at Kudankulam (2 x 1,000 MWe)	2,000	6,780
PFBR under Construction at Kalpakkam (500 MWe)	500	7,280
Total Installed Capacity by ~ 2012		**7,280**
Future PHWRs by 2010 - 2020 (8 x 7oo MWe)	5,600	12, 880
Future FBRs 2012 – 2020 (4 x 500 MWe)	2,000	14, 880
Future AHWR (1 x 300 MWe)	300	15,180
Total Year 2012 Capacity Plus India Technology Nuclear Plants by 2020		**15, 180**
Future Imported LWRs 2012 - 2020 (6 x 1,000 MWe)	6,000	21,180
Total Installed Capacity by 2020		**21,180**

Plans to Commercialize the Indian Prototype Fast Breeder Reactor (PFBR)

Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)[4] is a wholly owned enterprise of the Government of India under the administrative control of the Department of Atomic Energy (DAE). Its objective is to constructe and commission the first 500 MWe Fast Breeder Reactor (FBR) at Kalpakkam in Tamil Nadu and to pursue construction, commissioning, operation and maintenance of subsequent FBRs for the generation of electricity. It will use plutonium-uranium oxide as fuel, and liquid sodium as a coolant. The design life of the reactor is 40 years and it can be extended by another 20 years. BHAVINI will operate the PFBR as a commercial power plant and sell the power to state electricity boards. When the PFBR starts generating electricity in 2012[5], it will be sold at competitive price according to the Indian Department of Atomic Energy(DAE). A series of "FBR parks," each with two to four FBRs, a reprocessing plant and a fuel fabrication plant, are proposed to be set up. At Kalpakkam also, a reprocessing plant and a fuel fabrication plant will be set up. Kalpakkam can accommodate two more breeders according to DAE. The FBRs will use the reprocessed plutonium and depleted uranium from the country's PHWRs. Enough spent fuel was already available with the existing PHWRs, and three

[3] Chaim Braun at CISAC in Stanford University, Palo Alto, CA
[4] Department of Atomic Energy, Government of India
[5] Start date of 500 MWe PFBR has been delayed. Originally scheduled for 2010 and now stated at 2012.

reprocessing plants were operational at Trombay, Tarapur and Kalpakkam to enable these plans. S.K. Jain, Chairman and Managing Director of both the Nuclear Power Corporation of India (NPCIL) and BHAVINI, pointed out that the country, during the first stage of its nuclear electricity program, had built up a comprehensive capability in designing, developing, building, operating and maintaining PHWRs. Besides, the DAE was engaged in a life extension program of these reactors. Twelve PHWRs are operational now and six are under construction. The program has now entered the commercial domain of breeder reactors.

> Breeder technology is certainly one of the most advanced and difficult undertakings in nuclear power engineering. That India, relying almost exclusively on its own resources, is able to embark on a breeder program bears witness to its great accomplishments in science and the resourcefulness of its engineers.

This is the impression of Hans Blix after his visit to the Reactor Research Centre at Kalpakkam, Tamil Nadu, in December 1982 as the Director-General of IAEA.

Proliferation Risks to the Fast Breeder Reactors (FBR's)

However, one of the main drawbacks of the Indo-US civil nuclear agreement, with the non-proliferation community, has been India's insistence on keeping the "fast breeder" nuclear reactors and reprocessing facilities at Indira Gandhi Center for Atomic Research-Kalpakkam outside the ambit of international safeguards. Non-proliferation experts like Alex Glasser and MV Rammana at Princeton have done detailed studies showing how the fast breeder facilities could be used to increase India's Plutonium stock over five fold in a few years[1]. PHWRs and FBRs allow India to produce and divert weapon grade plutonium up to 170 Kg per year from one FBR alone according to them. Needless to say, the risks increase as India installs more Fast breeder reactors (FBR) in the near future. Finally, theft, unknowingly at the FBR site, in spite of the best wishes of the Indian AEC still remains a distinct possibility.[6]

US Diplomacy Options with the Indian Scientific Enclave on Fast Breeder Reactors

I. Indo-US Private Sector Cooperation on Light Water Reactor's for Nuclear Power (Commercial Collaboration)

Light water reactors have proven to be the workhorse technology for civil nuclear power plants world over. However, the Indian internal program has been hitherto focused on Pressurized Heavy Water Reactors (PHWR). US companies such as GE and Westinghouse have good leadership position in this technology which could be leveraged vis a vis India.

In line with the growing energy needs of India, one has seen announcements indicating a larger number of ALWR's (Advanced Light Water Reactors) expected to be installed by 2020, specifically more 60 GWe, rather than 8 GWe in the pre-agreement estimate of 2005. Inflated numbers of all nuclear plants to be installed at 63 Gwe by 2030, are estimated to increase to a further 470 GWe by 2050.[7] Thus, based on the above reality, the introduction of foreign vendors and deals with private sector Indian suppliers, could reduce DAE's monopoly over the Indian

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[6] Alex Glasser and MV Ramana,"Weapons Grade Plutonium Production Potential in the Indian Prototype Fast Breeder Reactor"., Science and Global Security Vole 15, 2007

7 If the Country Thinks Big and Executes its Plans *correctly"* per Prime Minister Singh, on September 2009

nuclear program which may be beneficial to US and other western commercial interests[8]. Therefore, access to advanced LWR's from the west and an invitation to join Generation IV might be the market forces necessary to counter the FBR monopoly led by DAE in India.

II. Acceleration Driven Systems (Scientific Collaboration)

Acceleration Driven Systems (ADS) are another avenue for collaboration. This technology is being looked at as an option for nuclear waste transmutation study in the near future. However, there are long term possibilities of using the same technology for nuclear power generation. This second option is based on the Energy Amplifier concept proposed by Carlo Rubbia at the European Organization for Nuclear Research (CERN) for an accelerator driven power reactor utilizing abundant thorium as the primary nuclear fuel without the need for breeder reactors to produce uranium-233 or plutonium-239 (the current Indian three stage program is calling for a breeder program with ultimate thorium use).

Recently, laboratories under DAE, such as the Raja Ramanna Centre for Advanced Technology (RRCAT) have made overtures to CERN, The High Energy Accelerator Research Organization (KEK), Fermi lab and the National Accelerator Authority (SLAC) to start proceedings to develop an Indian spallation source program. A Memorandum of Understanding (MOU) was signed between Fermi lab and RRCAT in October, 2007. Access to the US Spallation Neutron Source may be an alternative method to the use of fast breeder reactors to achieve the same goal in the long run.

The Spallation Neutron Source (SNS), at Oak Ridge National Laboratory, is an accelerator based neutron source. This facility provides the most intense neutron source in the world. US technological leadership in the SNS arena, coupled with India's large thorium reserves, provides a "win-win" possibility for both sides.

Technological developments in the ADS arena since the late nineties has resulted in a rethinking in India to the existing three stage nuclear program. Indian scientists are now looking at an indigenous SNS facility to take advantage of this new option. This makes logical sense for success, as this technology may someday lead to a world where plutonium and enriched uranium has no place, rendering the existing three stage program useless. India does not want to be left behind, especially from the promise of a new way to use thorium fuel cycle to generate nuclear power, considering her vast thorium reserves.

Therefore, it is not surprising to discover that since early 2000, the Department of Atomic Energy (DAE) in India has expressed its desire to consider programs looking into the development of subcritical reactors using ADS. The aim for this program seems to be an alternative to the existing three stage fast breeder and AHWR reactor based nuclear power generation program using the thorium fuel cycle. Subsequently, the DAE has started dialogue with Fermi lab in addition to ongoing relationships with CERN and KEK in Japan. The desire by India to collaborate was made clear during a series of visits made by Dr. Sekhar Mishra of Fermi lab and Dr. V Bhardwaraj of SLAC to India resulting in the signing of a MOU between Fermi lab and Raja Ramana Center for Advanced Technology (RRCAT) in Indore, India on October 2, 2007. RRCAT is under the ambit of the DAE chartered to lead the development of the Indian spallation neutron source. Such moves, on part of the scientific enclave in India, is a clear indication of the desire to collaborate with the US and an admission that the three stage fast

[8] http://www.india-server.com/news/ge-hitachi-to-develop-nuclear-power-7284.html

breeder and AHWR based thorium fuel cycle championed by India, for the last 30 years, is not the only way forward.

Risks of Collaboration on ADS and ALWR's (Generation IV Reactors) with India

Concerns for ADS Collaboration:

India's potential misuse of ADS technology, may lead to furthering the enrichment of reprocessed plutonium to perfect their thermonuclear arsenal. There have been reports that the Indian nuclear test of 1998, did not produce satisfactory yield for its thermonuclear weapon as expressed by K Santhanam, Project Director at Pokhran II, from the Defense Research and Development Organization (DRDO) involved in the tests. This could be the real motive with the thorium based Energy Amplifier project being a "cover". The fact that ADS collaboration with Fermi lab is being pursued by RRCAT, which is a non-safe guarded facility, is of concern. RRCAT is also involved in laser enrichment work and therefore, the military nature of RRCAT makes collaboration risky. However, Chaim Braun, of the Center for International Security and Cooperation (CISAC), at Stanford has argued that ADS is too pre-mature a technology for India to take it seriously.

Concerns for Generation IV Reactor Collaboration:

India could use the collaborative information to launch a commercial competition to the US nuclear industry. This risk is viable since the US industry is just coming out of a thirty year hiatus following the Three Mile Island incident. According to Chaim Braun, from CISAC, the Indian industry is already very sophisticated, thus, incentives for Generation IV collaboration, on advanced LWR's and US fast reactors, may not be enough leverage for India. Instead, it may encourage India to become a commercial competitor, "hawking" proliferation risky FBR's to other non-nuclear states.

US Policy Alternatives to Enable Safeguards of Indian FBR and Reprocessing Plants

US Labs and Companies Collaborating Individually with Indian Counterparts

This is the current status quo as evident from the signing of MOUs between Fermi lab and RRCAT on ADS which possibly bear the financial burden of Fermi lab's Project X on India.

Advanced reactors and nuclear services provider, GE Hitachi Nuclear Energy (GEH), has made an agreement with Larsen & Toubro (L&T) for developing nuclear power plants in India. Under the deal, both GEH and L&T will develop the proposed Advanced Boiling Water Reactor (ABWR) for a nuclear power station. GEH will provide the technological support for the project. It will also offer engineering and technical advisory services for the nuclear power plant projects.

Unfortunately, such actions in isolation do little to further the broader US non-proliferation and commercial goals while risking export control violations under the guise of academic collaboration. From India's perspective, this may be the preferred option as it provides technology transfer, albeit slowly, but with no obstacles attached to such transfers. If allowed unchecked, such policies may lead India to develop its own spallation neutron source in the long term and kill the new leverage that the US now possess in this arena. However, this scenario keeps the preeminence of Indian scientists within the Indian program intact without the risk of "brain drain" related proliferation by Indian scientists.

Manage these Collaborations Under the Ambit of "Non-proliferation Aims" of the Department of State

This policy would call for an offer of access to a spallation neutron source, missile defense and advanced LWR's (Generation IV) to India through a US government sponsored direct initiative, managed by the Department of Energy and Defense in consultation with the Department of State. In return the US should ask for:

i. Safeguards to be included in the fast breeder reactor program.

ii. India agreeing to sign the Fissile Material Cutoff Treaty (FMCT) sooner.

iii. India agreeing to sign and ratify the Comprehensive Test Ban Treaty (CTBT).

iv. Encouragement to turn India away from proliferation of the risky fast breeder reactor based reprocessing options to Generation IV consortia options.

v. India guaranteeing not to sell unsafeguarded FBR's to any non-nuclear weapons state.

vi. Invite India to join the NSG as a supplier of nuclear reactor technology state.

The benefit of such an approach from the US non-proliferation standpoint is obvious but there are benefits to India, such as:

i. India would receive access to ADS technology "real time" helping it to develop an ADS based thorium reactor.

ii. India would obtain access to accelerator based transmutation of nuclear waste materials hitherto unavailable to India.

iii. Confidence would be built between US and Indian scientists in an environment free from the threat of export controls. Operation would be on par with European and Japanese scientists collaborating with US; and

iv. Techno-globalism would be encouraged over techno-nationalism as propounded by elements of the Indian scientific enclave, such as Dr. R.A. Mashelkar.

Such a policy may be opposed by the current insular Indian scientific enclave but the US may make such an initiative "risk free" for Indian scientists by inviting them to a Generation IV consortium and nuclear fuel bank technology development consortia providing them exposure to showcase their work and gain international recognition. In return, this level of cooperation with the Indian scientists may allow US commercial entities closer access to the Indian reactor and military market than the current status quo.

Discourage such Collaborations and Place Them Under Export Control Regime

Such an option would be a return to the period from 1974 to 2005. During this period, the isolated Indian scientists operated inefficiently but without help from abroad. Such a situation will provide commercial benefits of access to the Indian markets to countries that are willing to collaborate better with the Indian scientists in preference over US companies. Such a scenario, may ultimately lead to marginalization of Indian scientists within India's commercial nuclear arena, as their local technology become replaced and outdated. In such an environment, "brain drain" risks of Indian nuclear scientists leading to proliferation risks, in addition to the proliferation risks from the Fast breeder reactors, enhances as Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), a wholly owned enterprise of the Government of India, tries to look for commercial successes in "rogue" break out states.

Conclusions

Three possible areas of cooperation in advanced reactors (ALWRs or Generation IV) and ADS are proposed as leverage to steer India away from proliferation risky fast breeder reactors and allow safeguards to reprocessing sites at Kalpakkam. However, the current trends suggest that collaboration in these areas are happening independent of each other without the "non-proliferation" goals of putting FBRs under safeguards. On the other hand, the logical "way forward" option, for the US non-proliferation and commercial interests, would be to tie offers of ADS collaboration, Generation IV consortia invitation and ALWR installations to safeguards on fast breeder reactors. Successful collaboration with India can lead to progress in other areas also, such as, India signing on to FMCT, CTBT as well as help India return to the non-proliferation regime. This approach is not free from risks but looking at India's past non-proliferation record highlights positive contribution to the counter of proliferation regimes, such as the Proliferation Security Initiative (PSI). One has to argue for such collaboration over the risks against it. Furthermore, the discontinuation of US-India scientific, military and nuclear commercial collaboration would be most counterproductive to US non-proliferation and commercial interests, making an adversary out of India at a juncture when the US needs India as a counterbalance to rising Chinese and Islamist terrorism in the region.

Table 1: Policy Alternatives

Policy Alternatives	Outcomes Assessed by Criteria			
	Leverage on India to put Safeguards on Fast Breeder Reactor	Leverage on India to make it sign the FMCT	Rate of adoption of US Technology by Indian Nuclear Power Industry	Chances of Export Control violations
Allow individual US-India collaborations on accelerator technology and LWR's	Low	Low	Medium	High
Manage US India collaborations on accelerator technology and LWR's under the ambit of strengthening non-proliferation regime	High	High	High	Low
Stop US-India collaborations on accelerator technology and LWR's	Low	Low	Low	Low

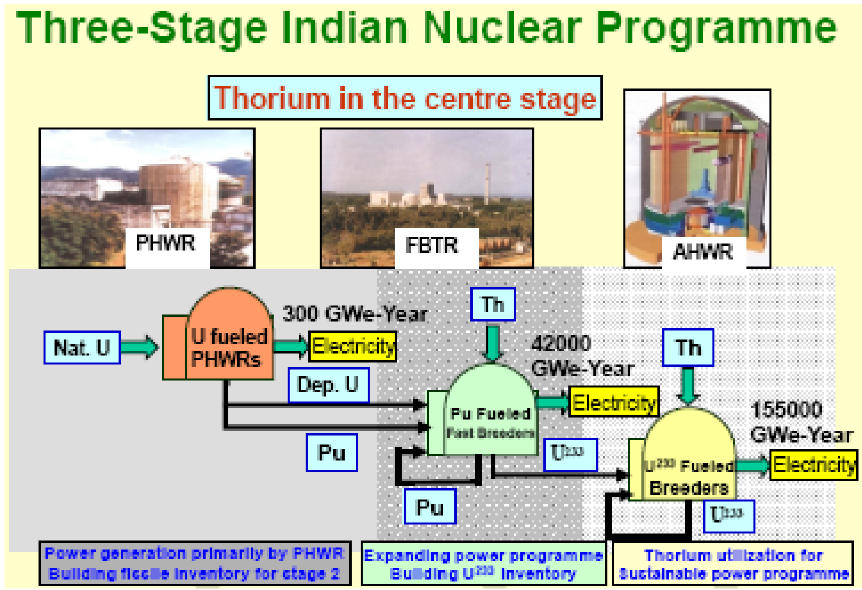
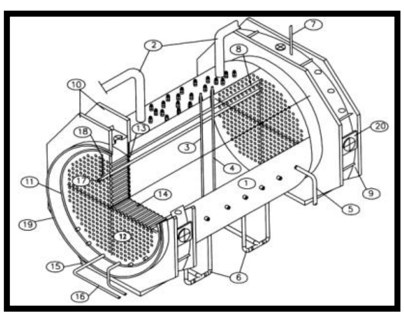
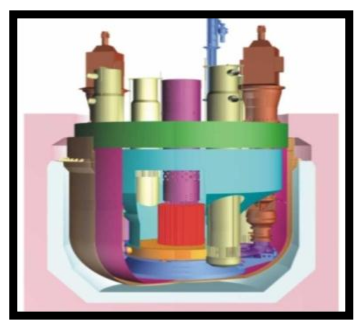


Fig 1: The Three Stage Indian Nuclear Power Program Championed by the Indian AEC

Fig 2: Reactor Core PHWR



Reactor Core FBR



Parameters	**Thermal Neutron Reactors (PHWR)**	**Fast Neutron Spectrum Reactors (PFBR)**
Fuel	**Natural UO_2**	**(Pu-U) O_2**
Clad material	**Zircaloy-2**	**20% CW 15Cr-15Ni-Mo-Ti**
Coolant	**Heavy Water**	**Liquid Sodium**
Core outlet temp, ^oC	**293**	**547**
Core power density, W/cm^3	**100**	**400**
Neutron energy	**0.025 ev**	**> 100 kev**
Burnup	**6,700 MWd/t**	**100,000 MWd/t**
Neutron Flux, $n/cm^2/s$	**10^{14}**	**$4.5x10^{15}$**
Life of core	**~180 Days**	**2 Years**

Cosmic Ray Muon Scattering Tomography for Security Applications

Lindsay Cox[1]

Cosmic ray Muon Scattering Tomography (MST) is an innovative technique that uses naturally occurring background radiation to detect the presence of high Z material. MST works by measuring the trajectories of muons as they enter and leave an object. Those muons passing through high density material will tend to scatter through greater angles, allowing the distribution of material within the object to be inferred from determinations of many scattered muon tracks. Advantages of this technique include the passive nature of cosmic ray muons, the amount of material the highly penetrating muons can traverse and the ability of the tomographic reconstruction to produce an image, or density profile, of the item of interest. As such, this presentation proposes and discusses applications of MST in the areas of homeland security (e.g., cargo scanning), treaty verification, and nuclear fuel storage (e.g., material security).

Introduction

Cosmic ray Muon Scattering Tomography (MST) is an innovative technique for detecting the presence and distribution of dense, high atomic number (Z) material. It is one of several techniques being studied by the Enhanced Detection team at AWE with the potential to address the problem of detecting illicitly trafficked Special Nuclear Material (SNM). It is the intention of this paper to describe the background to this work, outline the technique and supporting technologies, and discuss the relevance of this technique to some suggested security applications, including cargo screening, safeguards and treaty verification.

Background

The threat from terrorism is severe and sustained[2], and several terrorist groups have expressed their desire to utilise radiological or nuclear weapons[3]. A look at the IAEA illicit trafficking database[4] shows that the trafficking of nuclear materials is ongoing – and this only includes those that are intercepted.

However, detecting SNM is a real challenge. In particular, High Enriched Uranium (HEU) can prove difficult to detect, as it emits only low energy, 'soft' gamma rays which are easily shielded, and emits neutrons at a rate comparable to the background flux. Following a Royal Society meeting on this topic, a comprehensive review of potential techniques was conducted. This focussed particularly on the cargo screening problem, primarily due to the vast number of containers shipped internationally, and the significant amount of shielding that can surround the source and shield it from detection. The report took into consideration the feasibility and maturity of various techniques, as well as the areas where existing AWE capabilities could add most value. It then identified several areas with the potential to address

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[1] National Nuclear Security Division, Atomic Weapons Establishment, UK.
[2] http://www.cpni.gov.uk/TheThreat
[3] https://www.mi5.gov.uk/output/terrorist-methods.html
[4] IAEA ITDB Factsheet September 2009

the problem. One of the techniques identified was cosmic ray Muon Scattering Tomography (based on previous work conducted at Los Alamos National Laboratory[5,6]).

Cosmic Ray Munos

Muons are charged particles created when primary cosmic rays, primarily protons, collide with molecules in the earth's upper atmosphere. They are essentially heavy electrons (~200 m_e) but can be either positively or negatively charged. These naturally occurring particles form the dominant component of cosmic radiation at sea level, with approximately one arriving through an area the size of your hand every second at sea level. The range of muon energies is wide, ranging from <100 MeV to >10 GeV, with the modal value being 3-4 GeV. Both the flux and energy vary with a number of factors, including angle from the vertical, height above sea level, and the solar cycle.

Muons are a highly penetrating form of radiation, and have been used in the past to image magma chambers in volcanoes and look for the presence of voids in pyramids, as they travel through significant depths of rock. Indeed, physics experiments wishing to avoid the muon background are buried hundreds of metres underground for this very reason[7].

Using cosmic muons therefore has some key advantages. It uses a free source of naturally occurring particles, making it completely passive. In addition, the fact that muons are so highly penetrating means they are virtually impossible to shield against – an important feature when trying to detect illicitly trafficked material.

Muon Scattering Tomography

Muon Interactions

Muons are charged particles and interact with other atoms predominantly via the electric, or Coulomb, force. As they pass through matter they undergo many small angle deviations due to the influence of the charges on constituent parts of the atom in the material. This is known as multiple Coulomb scattering. After many such interactions there can be a significant and measurable change in the muon trajectory. It is the spread in overall scattering angles over many muons that are significant, as the distribution is dependent on the radiation length, X_o, which is material dependent and a function of atomic number (Z) and density.

[5] KN Borozdin et al, *Radiographic Imaging with Cosmic-Ray Muons*, Nature 422, p277 (20 Mar 03)
[6] LJ Schultz et al*, Image Reconstruction and Material Z Discrimination via Cosmic Ray Muon Radiography*, Nucl Inst Meth Phys Res A 519, 687-694 (2004)
[7] Peter K F Grieder, *Cosmic Rays at Earth: Researcher's Manual and Reference Book,* (Elsevier, 2001), Chapter 4. 3.

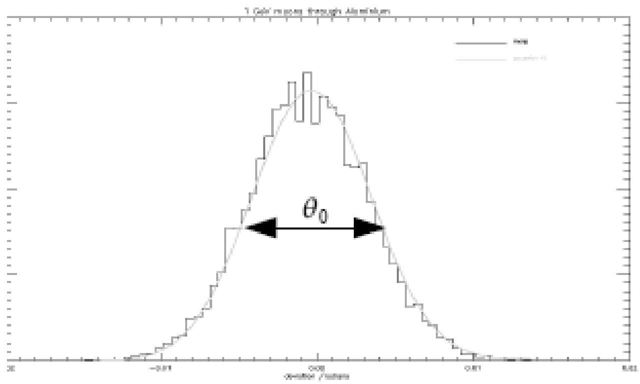

Fig. 1 – Typical Gaussian distribution of muon scattering angles

An expression for the width of this distribution, θ_o, is given below, where p is muon momentum, x is the length of material traversed and X_o is the radiation length.

$$\theta_0 \approx \frac{13.6MeV}{p}\sqrt{\frac{x}{X_0}} \qquad (1)$$

Typical radiation lengths and scattering angles are given in the table below. It is clear that radiation length decreases for dense, high Z material. It is this distinction which enables MST to determine the presence of dense materials such as uranium and plutonium.

Muon Detection

The muon is tracked as it enters and leaves the inspection volume by placing several planes of position-sensitive detectors above and below the object of interest. The position of the muon is located as it passes through each of the detector planes, and by plotting a line through a minimum of two points, the incoming and outgoing muon trajectories can be determined. The intersection of these two vectors localises the interaction and enables the scattering angle to be calculated.

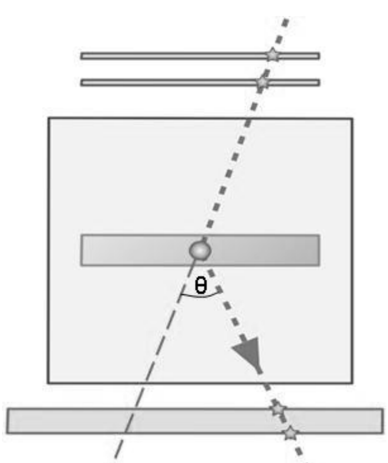

Fig 2 – Schematic of muon scattering in an object

To maximise the number of muons detected, and avoid having "blind-spots", the detectors should be larger than the object itself. Therefore, the detectors used in an operational system would need to be not only position sensitive (with spatial resolution requirements likely to be sub-mm), but also robust and scalable to large areas at reasonable cost. These requirements are very similar to those of the detectors used in High Energy Physics experiments, such as the Large Hadron Collider at CERN[8]. Expertise already exists in the construction of large tracking detectors for these experiments. Examples of such detectors include drift chambers, resistive plate chambers and segmented plastic scintillators.

Muon Reconstruction

The intersection of the incoming and outgoing muon trajectories is known as the point of closest approach. (This is because in three dimensions, it is unlikely that the vectors intersect exactly as this assumes a single point of scatter as opposed to the multiple small angle scatters that do in fact take place. In this instance, the mid-point of a line joining the closest point of the vectors is used). The most basic form of reconstruction simply takes each of these points and assigns them to a voxel, or three dimensional pixel, within a virtual grid dividing up the inspection volume.

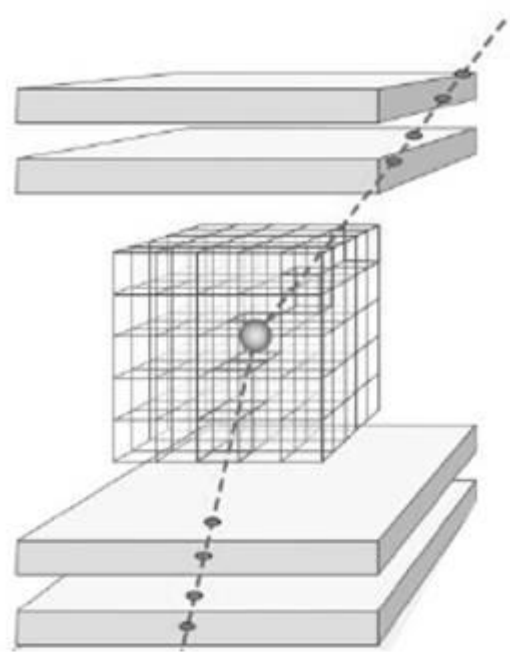

Fig 3 – Schematic to show voxellation of inspection area

The number of scattering points within each voxel is then tallied and a three-dimensional histogram populated.

[8] C-E Wultz (CMS Collaboration), *Measurement technologies for the CMS collaboration,* Meas. Sci. Technol. 18 (2007) 2424–2431.

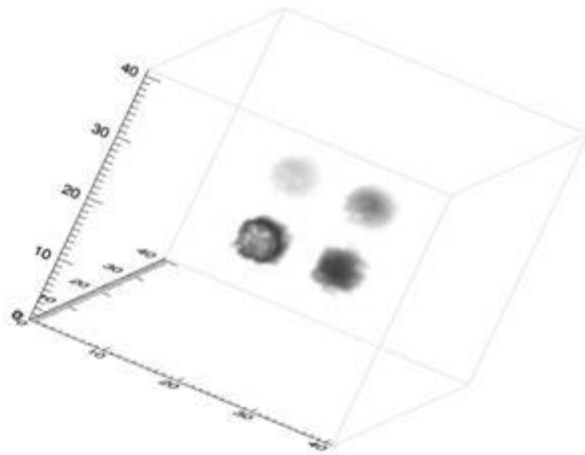

Fig 4 – Point of closest approach reconstruction of various materials (clockwise from top: plastic, aluminium, iron and uranium).

This simple method is quick, easy and computationally undemanding. However, it assumes a single point of scatter, and only shows relative scattering densities rather than absolute values. By treating each muon individually, it also dismisses some information that could be built up by considering them in combination, which could be very valuable if captured effectively. More advanced reconstruction techniques use the point of closest approach method as a starting point for algorithms that consider the contribution of all muons to each voxel they travel through, returning a grid that is populated with the most likely scattering density values given the data collected.

Potential Applications

Cargo Screening

The initial motivation for looking at this technique was for cargo screening applications. In the UK and worldwide, radiation portal systems are situated at points of entry to detect illicitly trafficked nuclear and radiological material. These are based on passive neutron and gamma detectors, designed to alarm if the radiation levels increase significantly above background in the presence of a vehicle. If the primary portal alarms, the vehicle is then taken aside for further secondary inspection. The aim of this further examination is to identify the reason for the alarm, and determine whether or not it is due to naturally occurring radioactive material (NORM) or a potential threat object.

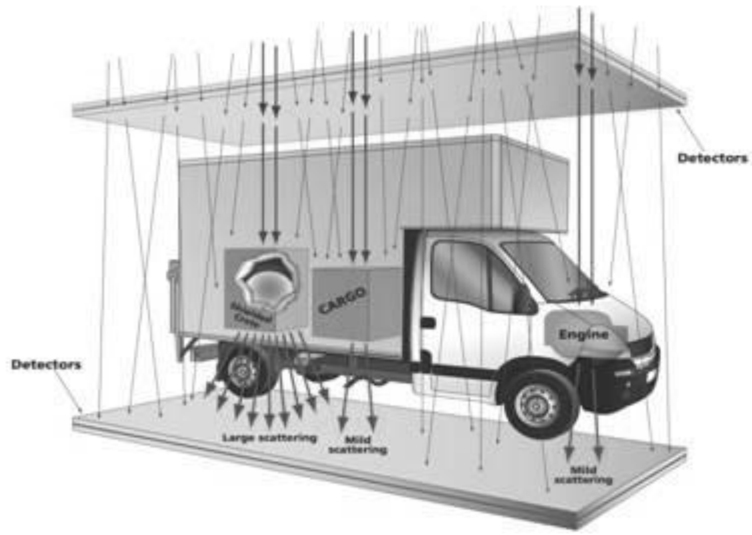

Fig 5 – Potential use of MST for cargo screening

Due to the scale of the shipping and freight operations at international ports of entry, a great deal of emphasis is placed on not impeding commerce. Any technology that requires vehicles to stop and wait introduces a choke point to the process. This operational constraint would have to be overcome if MST was to be of value in the primary screening process. Work is ongoing to reduce the amount of time a vehicle would need to be inside a muon detector, with times of the order -1 minute believed to be feasible [ref]. It has been suggested that a way of overcoming the time required would be to construct 'tunnels' of muon detectors [ref], increasing the solid angle of the detector system by completely surrounding the vehicle with detectors, and keeping the traffic moving whilst data is collected. However, such tunnels would impose a significant footprint on the port, where space is at a premium.

Alternatively, it is envisaged that MST could be used as a secondary inspection tool. As such, it could be used to examine those vehicles meeting one or more of the following criteria:

- Alarmed in the primary portal.
- Suspicions raised for other reasons (e.g. likely trafficking route etc).
- Randomly selected for deterrence purposes.

In the secondary inspection area, the limitations placed on time would be much less severe, enabling a sufficiently large data set to be collected and a three-dimensional density profile to be reconstructed.

Naturally occurring material is more likely to be distributed within the load, whereas an individual source will be more localised; therefore, an image of the contents, in combination with the radiation signature, would be valuable. MST provides a density profile, and whilst not all radioactive materials are high density, materials used to shield the gamma emmissions (such as lead) would be revealed by this technique.

The combination of a radiation alarm from the primary portal and the location of a high scattering region using MST would be indicative of a threat object and escalated accordingly. Conversely, the absence of any high-Z material would imply no nuclear or shielding material was present.

As a cargo screening tool, the ability of MST to detect the presence of dense, high-Z material complements passive radiation detection and introduces the possibility of detecting not only the radiological or nuclear material, but also the material used to shield it.

Safeguards

The merits of MST may also enhance existing capability in the field of safeguards technologies, utilised by the IAEA to verify declarations on the exclusively peaceful use of nuclear material made by States under safeguards agreements[9]. The objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons[10]. This is achieved through a number of methodologies;

- Environmental sampling
- Containment and surveillance
- Non destructive assay
- Destructive assay

It is proposed by the author that MST could fall under both the non-destructive assay and containment and surveillance categories.

Non-destructive assay forms part of nuclear material accountancy, with the aim being to independently verify and identify treaty accountable items, such as fuel rods. Measurements taken as part of the inspection regime are compared with the State's declared figures, with the intention of highlighting any anomalies that might indicate diversion. Typical NDA techniques include gamma spectrometry and neutron counting but can also be as simple as measuring the weight of a container. It is the combination of multiple signatures that increases confidence in the verification process. MST could be used to accurately gauge the presence of material in combination with gamma and neutron assay, particularly in geometries where a significant amount of shielding is in place, which is typical of spent fuel storage, such as cooling ponds. Whilst the large amount of scattering might make counting difficult, muons will still penetrate the material and enable the location of the high Z components to be located. The longer counting times and known geometries mean that background subtraction might also be used to increase detection sensitivity.

Containment and surveillance complements nuclear material accountancy by providing confidence during the period between inspections that stored material is not moved. This can take the form of close-circuit cameras, or tags and seals. Electronic data can be monitored remotely, for example in Vienna, and alarms triggered when changes or movement is detected. MST could form part of this regime by monitoring the presence of dense material in storage. The background over lengthy periods of time would be stable, within statistical variations, and used as a baseline for the amount of material presence. Any significant differences in scattering distribution would imply movement of material, and could trigger an alarm. If this system was also networked with legal waste or treaty verification, the prospect of detecting or characterising material would be more probable.

[9] 'Future Safeguards Verification Tools', M. Zendel, N. Khlebnikov, M. Aparo, IAEA-CN-148/32, 2007.
[10] IAEA INFCIRC 53, 1972.

Legacy Waste

An alternative application that could make use of the highly penetrating nature and three-dimensional reconstruction that MST offers is that of imaging legacy waste. Vast numbers of drums, containers and bunkers house unknown waste that might include fuel rod fragments, concrete and potentially voids. It is often necessary to identify the content of the drum before it can be treated or compacted. A density profile might be of value, particularly in those cases where there is sufficient material to make the object opaque to radiographic techniques. The sensitivity of this technique to high and low density materials would make it suited to looking for fuel rod fragments and voids.

Treaty Verification

Under a future arms control treaty aimed at reducing or eliminating nuclear warheads, a verification regime will need to be put into place to provide high confidence that the agreement is being adhered to. At the same time, this must be done without revealing sensitive, classified or proliferant information.

The information that MST could reveal is the presence, and potentially distribution, of dense, high Z material within a container. The technique cannot distinguish between uranium and plutonium or extract any isotopic information on the material, making it less intrusive than many other assay techniques. If the risk of divulging any spatial information is deemed too sensitive, then the data can be constrained in such a way that no significant image can be reconstructed – for example by limiting collection time, or the spatial resolution of the detectors. Unlike techniques such as high resolution gamma spectroscopy, where information barriers have to be introduced to protect the classified data on which a decision is based, an MST system could potentially be designed in such a way that there is an intrinsic, physical limit to the fidelity of the result. The combination of this information with other, independent measurements, such as neutron counting, could form part of an authentication process that would provide the monitoring party with appropriate confidence without compromising national security concerns.

Conclusions

Muon scattering tomography is an innovative technique that utilises naturally occurring particles to determine the presence and distribution of dense, high atomic number material. Advantages include the fact that it is completely passive, highly penetrating, and provides a three dimensional density profile of the inspection volume. Due to the finite collection time required to collect a statistically significant data set, along with the absence of any isotopic information, MST is a candidate for next generation cargo screening, to complement the existing radiation detection capability. However, the technique also lends itself to applications requiring detection or characterisation of nuclear materials and confirmation of their presence over time. These might include civil nuclear safeguards, legacy waste characterisation, or arms control treaty verification. Data fusion with other assay methods could lead to increased confidence levels of monitoring parties, without compromising national security concerns.

Nuclear Forensics Analysis Center: Forensic Analysis to Date Interpretation

Theodore F. Nichols[1]

The Nuclear Forensics Analysis Center (NFAC) is part of Savannah River National Laboratory (SRNL) and is one of only two USG National Laboratories accredited to perform nuclear forensic analyses to the requirements of ISO 17025. SRNL NFAC is capable of analyzing nuclear and radiological samples from bulk material to ultra-trace samples. NFAC provides analytical support to the FBI's Radiological Evidence Examination Facility (REEF), which is located within SRNL. SRNL is engaged in research and development efforts to improve the USG technical nuclear forensics capabilities. Research includes improving predictive signatures and developing a database containing comparative samples.

History and Background

The basic principles employed in nuclear forensics started with the first nuclear weapons test at Trinity. Those techniques were developed to determine yield, and later expanded to determine materials used, design details of nuclear explosions carried out by the US and latter by other countries. Next, the capability to measure and access risk was developed to monitor environmental concerns surrounding nuclear facilities. The advent of modern terrorism and the potential threat of a nuclear or radiological dispersal device (RDD) increased the need to safeguard and develop the capability to identify where nuclear material was produced. The need for robust nuclear forensics to assist in attribution of nuclear material has become increasingly important as a result of potential terrorist attacks.

The US government responded in a number of ways to handle this new threat, one of them was the creation of the Department of Nuclear Detection Office (DNDO). DNDO was established on April 15, 2005. Its mission is to "improve the Nation's [US] Capabilities to detect and report unauthorized attempts to import, possess, store, develop, or transport nuclear or radiological material for use against the Nation [US], and to further enhance this capability over time." [2] In October 2006, DNDO established the National Technical Nuclear Forensics Center (NTNFC) and designated it with two main goals. First, the NTNFC is to act at a national-level as a systems integrator for exercising, joint planning and evaluating national capabilities.[3] The second is to invest in technical capability advancement.[3]

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[1] Theodore F. Nichols is a Post Doctoral Scientist at Savannah River National Laboratory (SRNL) in the United States of America. His research is focused on developing research reactor models for use as digital signatures for nuclear forensics. He holds a Ph.D. in Nuclear Engineering from the University of Tennessee, Knoxville campus. The views expressed are those of the author's and do not necessarily reflect the official policy or position of the FBI, Department of Energy (DOE), Savannah River National Laboratory, or the U.S. Government.

[2] Department of Homeland Security web site, "Domestic Nuclear Detection Office", Accessed on December 7, 2010, http://www.dhs.gov/xabout/structure/editorial_0766.shtm

[3] *The Domestic Nuclear Detection Office: Can It Overcome Past Problems and Chart a New Direction?*, Opening statement of Warren M. Stern, Director of DNDO, September 30, 2010.

March 24, 2009 the House of Representatives passed H.R. 730: Nuclear Forensics and Attribution Act, the Senate passed the bill on December 23, 2009 and President Obama signed the bill into law on February 16, 2010. The bill "establish[es], within the Domestic Nuclear Detection Office, the National Technical Nuclear Forensics Center to provide centralized stewardship, planning assessment, gap analysis, exercises, improvement, and integration for all Federal nuclear forensics and attribution activities."[4] H.R. 730 further recognizes the need to maintain expertise. It establishes undergraduate scholarships and graduate fellowships. The graduate fellowship includes a requirement, if possible, to spend at least two summers interning at a National Laboratory or appropriate Federal agency and each fellow commits to serving two years in a post-doctoral position in a technical nuclear forensics-related specialty. Both the academic and the intern/post-doctoral work are to be performed in an area of technical nuclear forensics.

Savannah River Site (SRS) was constructed during the early 1950s to be a facility that primarily produced tritium and plutonium for US nuclear weapons. At its height, SRS was operating five heavy water production reactors, two separation canyons, fuel fabrication, tritium facility, a heavy water production plant, along with laboratories that supported site missions. Savannah River Laboratory supported the missions of SRS and provided environmental monitoring. In 2004, Savannah River Laboratory was designated a National Laboratory under the Department of Energy (DOE) office of Environmental Management. The Nuclear Forensics Analysis Center (NFAC) resides in the Non-proliferation Technologies Section (NTS) of the SRNL which is involved in supporting non-proliferation activities and conducting research and development to improve or create new methods used in non-proliferation work.

NFAC utilizes persons with expertise in chemistry, physics, engineering, oceanography, meteorology, nuclear engineering, biology, material science, and other disciplines which are utilized to analyze nuclear forensic samples. This allows NFAC to provide technical nuclear forensics analysis for the US government.

Technical Basis

There are two types of physical processes which are exploited for a nuclear weapon: fission and fusion. Nuclear fission is defined as neutrons colliding with atoms which may cause the nucleus to split apart. The breaking of nuclear bonds results in the release of energy, for example approximately 200 MeV[5] per neutron is released from the fissioning of U^{235}. If all the atoms in one gram of U^{235} fissioned, there would be 8.2115×10^{10} Joules released[6]. For comparison, 1 ton of TNT releases 4.184×10^{9} Joules[7]. This illustrates that breaking of nuclear bonds releases more energy than breaking chemical bonds.

Fusion is the process in which two or more atomic nuclei are fused together to form a single heavier nucleus. The binding energy of the nuclei involved determines the amount of energy released from a fusion reaction. The use of hydrogen and tritium in thermo-nuclear weapons produces a yield much larger than a fission device.

[4] H.R. 730, Nuclear Forensics and Attribution Act

[5] MeV is an abbreviation for Mega-electron Volt or 1 Million electron volts. An electron volt is defined as the kinetic energy of an electron as it falls through a 1 volt potential. 1 eV = 1.60219×10^{-19} Joules

[6] This is a calculated value with the assumptions of pure U^{235} and complete fission of all U^{235} atoms. An idealized situation used to illustrate the difference in energy between breaking chemical and nuclear bonds.

[7] The amount of energy released from TNT is a defined value and not directly measured as agreed to by treaties. See NIST Guide to the SI entry for TNT http://physics.nist.gov/Pubs/SP811/appenB8.html

An RDD spreads radioactive material using an explosion in an area resulting in the spreading of the radioactive material. Radioactive material is composed of radionuclides which are atoms that undergo spontaneous nuclear transformation by releasing energy. All elements have radioactive isotopes[8] and all atoms with more than 82 protons are radioactive with the exception of Bi^{209}. There are two types of radioactive decay, alpha and beta. Alpha decay is where an unstable nucleus emits a Helium atom (2 neutrons and 2 protons also called an alpha particle), see Equation 1. Beta decay is where a nucleus simultaneously emits an electron and an antineutrino see Equation 2. Gamma decay is where an atom is in an excited state and releases a gamma ray (photon). Alpha and beta decay often times has an associated gamma ray.

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

Equation 1 Example of Alpha decay, radium decays into radon releasing a helium atom and releasing 94.45% of the time 4.784 MeV and 5.55% of the time 4.601 MeV.

$$^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ^{0}_{-1}\beta + ^{0}_{0}\bar{\nu}$$

Equation 2 Example of beta decay, Cobalt 60 decays into Nickel 60 with a release of 2.820 MeV.

The energy released from a radionuclide, is quantized and discrete, with each radionuclide releasing an alpha, beta, or gamma particle at a different energy than other radionuclides. For example, 94.45 percent of decays from radium 226 emit a 4.784 MeV alpha particle and 5.55 percent of decays emit a 4.601 MeV. The difference in energies between radionuclides can allow the determination of what radionuclides are present.

Exploiting the physical characteristics of the elements and isotopes, i.e. mass, decay spectrum etc, a determination of the composition of material can be made. These characteristics can yield information about what processe(s) may have produced the material. Each isotope that undergoes fission has a probability of breaking into different isotopes. This is referred to as fission yields and varies by isotope and by what neutron spectrum it was exposed to. Figure 1 plots the fission yields for ^{235}U from thermal and fast spectrum (14 MeV), neutrons. Note how the fast spectrum has higher probability of having fission products between the two peaks and the thermal higher probability of producing fission products in the peaks. Fast and thermal neutron spectrums are presented to highlight how a changing fission spectrum will change the relative quantities of the fission products. Different reactors and other processes have different neutron spectrums; analysis of the fission products and actinides can help determine which reactor and/or process was used to produce the material.

[8] Isotope is an atoms that have the same number of protons but a different number of neutrons. It is important to note that isotopes cannot be separated chemically. Examples of isotopes: Uranium 235 and Uranium 238, both have 92 protons, but U^{235} has 143 neutrons while U^{238} has 146 neutrons.

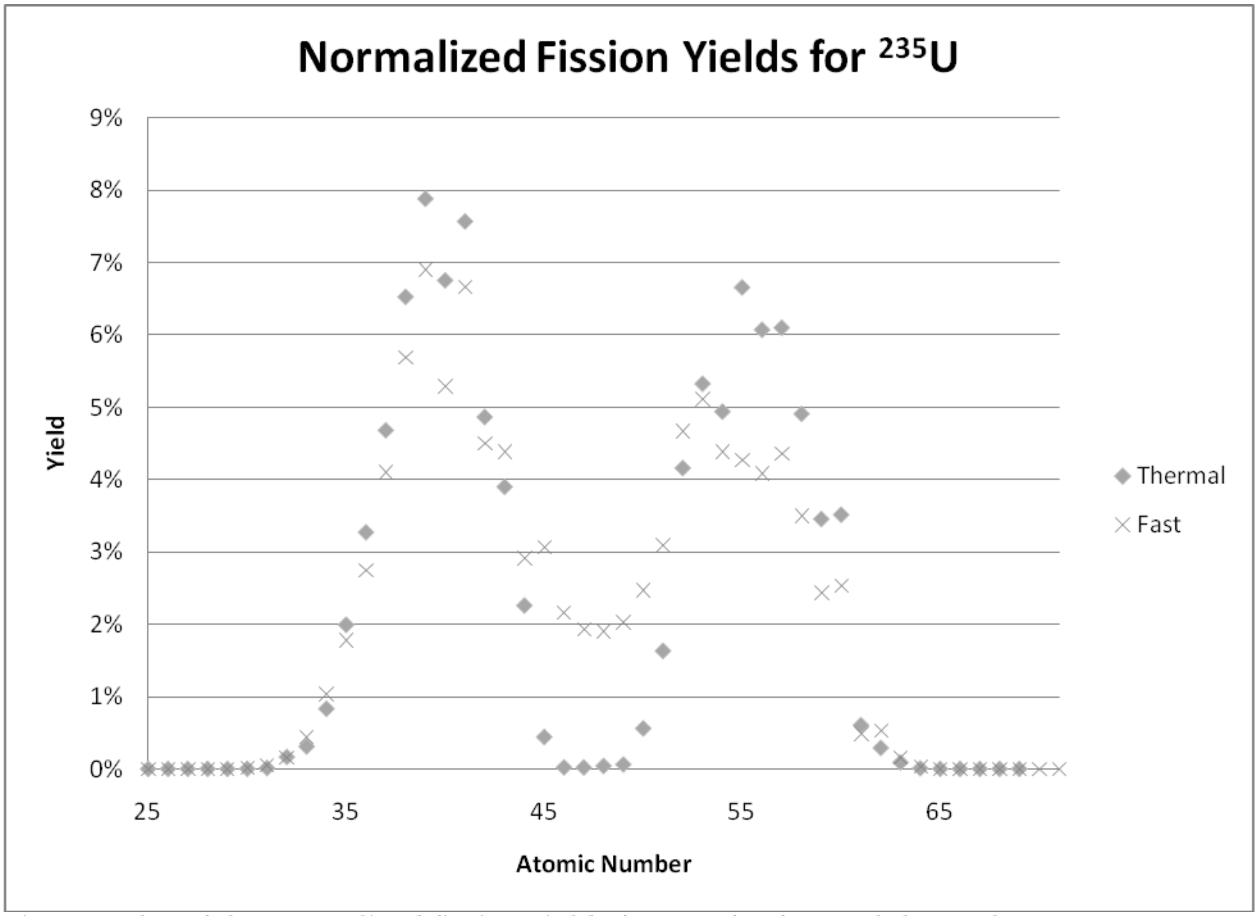

Figure 1 Plot of the normalized fission yields for ²³⁵U for fast and thermal spectrum. Note the double peak, isotopes with atomic numbers between 35 to 45 and 50 to 60 are more probable, especially with fission from thermal neutrons.[9]

Material Handling and Analysis

Nuclear materials must be handled carefully and with appropriate protection based on what health risks are posed. NFAC has several capabilities to handle nuclear materials over a large range of activities. First, radioactive materials with a very high dose rate, for example spent fuel, must start out in shielded cells. These contained enclosures have thick shields to protect the operators from receiving a harmful dose of radiation. The material is handled with "manipulators", which are mechanical arms with a simple grasping appendage. Manipulators allow the material to be moved, samples to be taken etc… without risk of exposing the operator. The Shielded Cells are kept under a slight vacuum to ensure any leak will pull air from the outside in and be filtered before being released to the environment. Material that is radioactive, but has a lower whole body dose, such as plutonium, can be placed in a glove box. Glove boxes provide some shielding of the whole body and protect extremities (i.e. hands) by the use of lined gloves. These shielded boxes are kept under a slight vacuum and allow the technician to put his or her hands inside long thick gloves in the box to manipulate material. Next, you have radiological hoods which are similar to chemistry fume hoods except they are able to contain

[9] The fission yield data was obtained from Lawrence Berkeley National Laboratory (LBL) and can be found at http://ie.lbl.gov/fission.html. Thermal and Fast data was from T.R. England and B.F. Rider, Los Alamos National Laboratory, LA-UR-94-3106; ENDF-349 (1993).

small amounts of radioactivity. Finally, there are environmental labs, which are permitted only very small amounts of radiation. Then, there are the clean laboratories were materials must have almost no radioactivity. Within the clean laboratories, is the Underground Counting Facility that is 50 feet underground, built out of steel taken from a battleship built before the first nuclear weapons test. This allows for very accurate gamma counting, as background radiation has been reduced close to zero.

NFAC has several analytical instruments at its disposal for identifying atomic composition of a material sample. One is a thermalionization mass spectrometer (TIMS) which has the best sensitivity and is operated in the clean labs. Another instrument is an inductively coupled plasma mass spectrometers (ICP-MS) of which there are two in the clean labs and one in the radiation laboratories. There is an inductively coupled plasma emission spectrometer (ICP-ES) located in the radiation laboratories. The Underground Counting Facility has four ultra sensitive gamma spectrometers. There are several alpha spectrometers and liquid scintillation spectrometers, which can be used primarily for beta spectrometry.

NFAC is able to detect Pu down to a femtogram (10^{-15}g) in solution. Full uranium isotopics can be obtained with approximately one nanogram (10^{-9}g) of material. NFAC is able to detect Cs-137 to one picoCi (10^{-12} Ci) of activity. These capabilities allow NFAC to determine what isotopes are in a given sample of material. These measurement techniques meet or exceed ISO 17025.

Nuclear Forensics

There are two main questions that nuclear forensics attempts to answer. First, what type of material is it and what threat does that material pose to the US. Specifically, is the material special nuclear material (SNM)[10] or radioactive material with potential use in an RDD. Material for an RDD just has to be a radionuclide. However, there are many legitimate reasons for having radionuclides, for example many medical tests and cancer treatment's use radionuclides. Both radionuclides and SNM are controlled by the US government.

The second question is where did the material come from? What nuclear reactor was it produced in? When was it produced? Has it been reprocessed? And was it made in the U.S. or in a foreign country? Any clues about where and when control of the material was lost are helpful. It is important to note that whoever made the material may not be the same as who lost control of the material. If possible, the answer to both those questions is desired. This is why traditional forensics is combined with nuclear forensics to improve the accuracy of the answer.

Figure 2 illustrates how interdicted material might be processed. Note that the traditional forensics work is performed separate from the tests performed by NFAC. Note that measured data must be compared to known compositions from a database. This database of isotopics has two components. First, are the directly measured isotopics, The second are predicted isotopics from reactor physics models. Currently, research is underway at SRNL to expand the isotopic database and to improve reactor physics models for nuclear forensics work. An example of this research is a project to sample domestic spent research reactor fuel at SRS. An aliquot of spent fuel is taken in the SRNL Shielded Cells and dissolved. A full suite of analyses are then performed on the sample. At the same time, the research reactor is modeled

[10] SNM is defined by Title I of the Atomic Energy Act of 1954 as plutonium, 233U or uranium enriched in the isotopes ^{233}U or ^{235}U.

using a variety of nuclear physics codes and with different amounts of detail in the model. This gives the ability to evaluate what parameters are important in the construction of models to obtain accurate answers. The exercise has three functions, first it aims to exercise the NFAC team CONOPS procedures and to uncover any problem or potential problems with the NFAC procedures, second it adds the isotopic composition of another research reactor to a database, and third, it determines how much detail and what reactor code or codes work best to model research reactors for the purpose of determining isotopic composition. Figure 3 is a flow chart that illustrates the steps taken to investigate how much detail about a research reactor is needed to enable a model to give accurate isotopic composition.

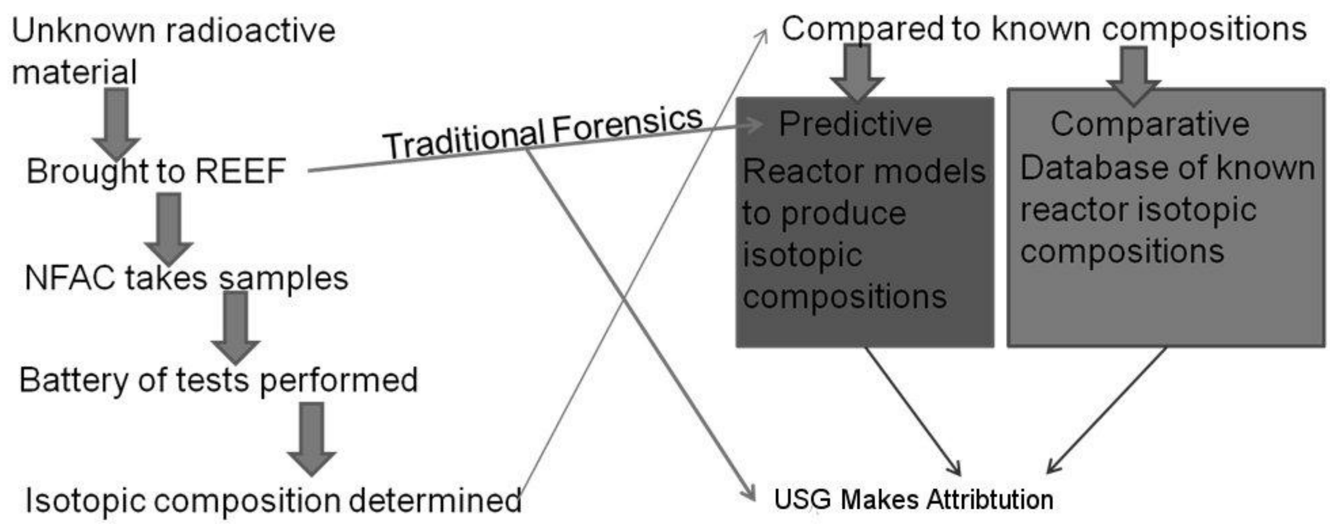

Figure 2 Example of interdicted material might be processed.

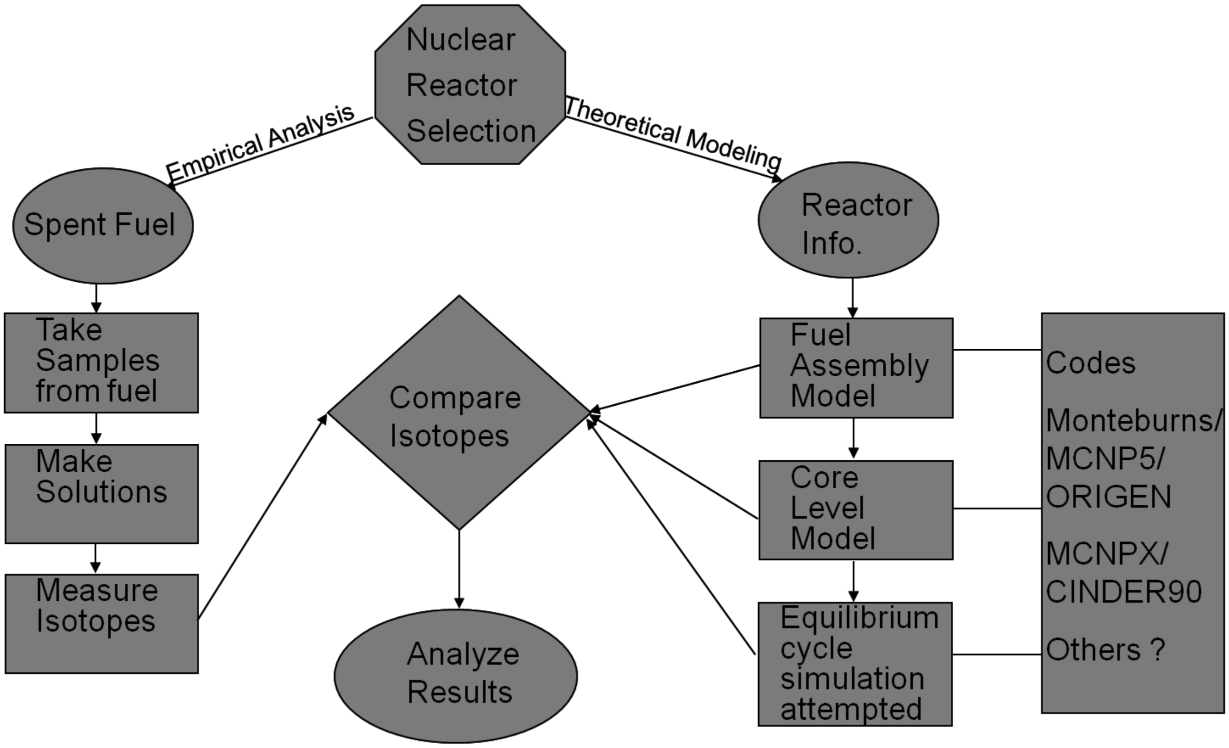

Figure 3 Flow chart of how research is being conducted to determine what information is important in a reactor model to obtain accurate isotopic composition information.

Currently, nuclear forensics faces several limitations. First, would a larger, more expansive isotopic database improve the accuracy of attribution. Efforts are underway to improve existing databases, but many countries or companies do not want to allow their spent fuel to be added to such a database. Another limitation is that scientists, engineers, and technicians involved in doing nuclear forensics are not able to work on it full time. All of them have other responsibilities and projects; therefore, care must be taken to maintain their expertise in areas needed in a nuclear forensics analysis. Another potential limitation is the aging work force.[11][12] Nuclear forensics has a problem that most of the practitioners are retiring or near to retirement. Radio-chemistry programs at US universities have diminished over the past decades with the remaining universities focused on radio-pharmaceuticals.[11] None of these limitations are insurmountable, but actions need to be taken to ensure the US does not loose its nuclear forensics capabilities.

Conclusion

NFAC analyzes radioactive material to help with the attribution of the material. NFAC is tasked with maintaining capabilities in the areas of nuclear forensics, improve methods through research, and train the next generation of scientists, engineers, and technicians in the art and science of nuclear forensics. NFAC is integrated with the NTNFC and is an integral part of the

[11] *Nuclear Forensics: Comprehensive Interagency Plan Needed to Address Human Capital Issues,* United States Government Accounting Office, Washington, D.C., April 30, 2009

[12] Joint Working Group of the American Association for the Advancement of Science and the American Physical Society, *Nuclear Forensics: Role, State of the Art, Program Needs* (Washington, D.C., February 2008).

nuclear forensics capabilities of the US. Nuclear forensics techniques are based on identifying the isotopes in material and determining what possible physical conditions could have created such a material. SRNL conducts research to improve methods in the area of nuclear forensics and the research gives the opportunity to test NFAC procedures. The Department of Homeland Security sponsored the production of this material under DOE Contract Number DE-AC09-08SR22470 for the management and operation of Savannah River National Laboratory.

Developing and Maintaining Weapon Design Expertise in a Comprehensive Test Ban Era

James H. Cooley[1]

In the 18 years since the last Underground Nuclear Tests (UGT) the United States has maintained a reliable and safe nuclear stockpile through surveillance, use of small and medium scale science experiments, improved simulation capabilities, and the experience of weapon engineers and designers versed in UGT knowledge. Over the 18 years of Stockpile Stewardship the nation's nuclear science laboratories have made great strides in several of these areas. However, as we move further away from the era of UGTs, the availability of weapon engineers and designers with UGT experience is decreasing. This article will focus on how the laboratories are addressing the training of new weapon engineers and designers and what additional actions should be taken to improve the long–term prognosis for this unique area of expertise.

Introduction

Nuclear weapons have been, and continue to be, a central part of the nation's strategic deterrence and the extended deterrence the United States offers to its allies. Nuclear weapons offer a level of deterrence that is unmatched in modern military technology and has been sighted by some as an important contributor to the prevention of a third world war. However, maintaining a robust and reliable nuclear deterrent is expensive and requires continued support.

The cost of ensuring a robust and reliable nuclear deterrent is not just in material capital but also includes human capital to ensure the long-term viability of the enterprise. This human cost is recognized by many and has been repeatedly emphasized by General Chilton, Commander Strategic Command. For instance, Air Force Times reported in September 2010 that General Chilton emphasized the need to recruit and retain the next generation of nuclear scientists, who could be prevented from testing nuclear warheads because of treaty obligations and political pressures. The Air Force Times quoted General Chilton saying,

> Imagine this. You're an aeronautical engineer, and here's the job opportunity in the future: When you graduate, we'll hire you to watch our Air Force airplanes rust. We're not going to let you do any design work. We're not going to let you build new airplanes," he said. "We're not going to let you increase their safety or enhance their security or increase their mission readiness. We just want you to watch them and every now and then let us know if you think they'll still fly.
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> How many would want to be aeronautical engineers? Zero. And it's the same in the nuclear weapons business."[2]

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[3][1]Los Alamos National Laboratory, The opinions presented in this article are strictly those of the author and do not necessarily reflect those of Los Alamos National Laboratory. LA-UR 11-01407

[2] Airforce Times. "STRATCOM boss: Nuke arsenal needs attention." Last modified September 20, 2010. http://www.airforcetimes.com/news/2010/09/air-force-chilton-says-nuke-arsenal-needs-attention-092010w/

Although nuclear weapons hold a unique position in strategic deterrence, since the end of the "Cold War" the cost of maintaining this unique capability and the associated political pressure from non-nuclear states has eroded the perceived relevance of nuclear weapons in the eyes of many policy makers and made the funding necessary to maintain the enterprise a ripe target for budget cuts in these hard economic times. It is the place for the Congress and the Administration to determine how to balance the financial books and I do not envy them this job; however, providing clear long-term guidance as to the level of relevance of the nuclear enterprise is one key in recruiting the future scientist and engineers that will be needed to maintain a nuclear deterrent. Human capital cannot be maintained on ever fluctuating and shrinking budgets, as I will discuss below. Although the Administration and Congress are currently attempting to stay the deterioration of the nuclear enterprise, it is the long-term commitment to the enterprise, which will prove to be critical for maintaining the human capital.

A Brief Primer on a Complex System

Nuclear weapons are very complex systems. We are fortunate in one sense, for this complexity helps decrease the proliferation risk of nuclear weapon technology to rogue states or non-state actors. Unfortunately, this complexity also necessitates years of training and effort on the part of the individuals that will provide the underlying science and engineering foundation for the weapons robustness and reliability. In this section I will try to provide a brief overview of some of the difficulties involved in nuclear weapons and explain why developing the human capital requires clear consistent commitment from policy makers.

Nuclear weapons present perhaps the most inter-disciplinary and multi-physics problem in applied science. The conditions that a nuclear weapon physicist must understand and deal with range from those similar to the room in which you are reading to the interior conditions of the sun. The time scales for physical processes range from seconds to nano-seconds (10^{-9} seconds). This range in conditions requires understanding beyond what most scientists are exposed to in their jobs.

Nuclear weapons, at their core, involve understanding nuclear and thermonuclear theory to release the energy. Nuclear theory involves neutrons coupling to matter so knowledge of neutron transport theory must be incorporated into understanding the problem. This knowledge must be combined with radiation transport theory along with radiation hydrodynamics. To accurately understand radiation theory one must understand atomic theory and opacities. Nuclear weapons begin as cold solids that use high explosives so knowledge of detonation theory and solid mechanics must be included.

Each of these areas of knowledge could represent a lifetime investment for very good scientists. However, the task facing the weapon design and analysis cadre at the national laboratories is to bring all these pieces of knowledge together in individuals. This does not mean that any individual is a world expert in each of these areas. Rather, they are integrators of them and need to understand how the different pieces fit together. It is the development of these individuals that I will focus on in this paper.

The Three Pillars of Nuclear Weapon Expertise

Shortly after the end of underground testing, the national laboratories began the "Science based Stockpile Stewardship Program" (SSSP) to ensure the safety and reliability of the nation's nuclear weapons. This initiative had three major parts. The first was stockpile surveillance through which we track changes in the weapons associated with aging or other unforeseen effects. The second was to develop modern and advanced computer codes to improve the ability to predict and analyze the changes, either expected or observed, with respect to the safety and reliability of the stockpiled weapons. Finally, more effort was committed to the basic science of nuclear weapons so that these advanced computer codes would benefit from more first-principles modeling. The first of these parts is critical and will not be discussed further in this article. I want to expand on the last two parts in what I call the three pillars of nuclear weapons expertise.

Pillar one - Sound foundations in basic science

Over the past 18 years there has been significant improvement in our understanding of basic material properties and response in conditions relevant to nuclear weapons. These improvements occurred partly due to the SSSP and partly due to the fact that many bright scientists focused on basic science once the drive to test in Nevada disappeared. However, these improvements, by necessity, are mainly in the material response at the less extreme range of conditions that nuclear weapons go through since the extreme conditions occur only during a nuclear explosion. Additionally, many of these scientific advances are based in isolated, "single physics," experiments and models, to simplify the analysis. Thus, many of the effects of physics coupling have been reduced or eliminated to enhance the understanding of the isolated physics. Although this improved basic understanding is important to nuclear weapons, it cannot be taken in isolation.

Pillar two - Competence in computational modeling of complex systems

The Advanced Computing and Simulation (ASC) program began in the late 1990's. The focus was on both developing state-of-the-art high performance computing systems and in developing advanced computer codes capable of utilizing the improved understanding in basic science to improve predictive capability. Over the last 15 years the nation has invested billions of dollars in this program. This investment has had many great successes both in high-performance computing e.g., the first peta-flop super computer[3], and in simulation modeling e.g., modeling and predicting how to deflect a potentially earth-destroying asteroid.[4] The individual physics models in these new codes are more first-principles than previous generations. However, there is still some uncertainty in the coupling between the physics due to the difficulty in isolating and analyzing the basic science in complex systems. These modern computational and simulation tools provide a better foundation for the national laboratories assessment of the nation's stockpile; however, one final pillar must be provided.

Pillar three - Integration of the complex physics into a consistent whole

As I discussed above, nuclear weapons are very complex systems. Additionally, as pointed out in pillars one and two above, the fundamental understanding, either in basic science or in computational science, of how different physics couples together remains a difficult research topic. Due to this complexity, it is still necessary to have a competent weapon designer or analyst involved in any decision involving nuclear weapons. Predictive capability is not yet

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[3] Computerworld. "All Hail Roadrunner's Petaflop Record; Now, What About the Exaflop? Last modified June 9, 2008.
http://www.computerworld.com/s/article/9095279/All_hail_Roadrunner_s_petaflop_record_now_what_about_the_exaflop_

[4] Plesko, C.S et.al. "Radiation Hydrocode Models of Asteroid Deflection by Stand-off Burst." Last modified December 2009. http://adsabs.harvard.edu/abs/2009AGUFMNH32A..07P

achievable with a computer simulation alone. The simulation results must be interpreted by an analyst who understands the physics and codes being used. Additionally, they must understand the strengths and weaknesses of the assumptions made in the development of the tools. As one seasoned weapon designer told me, "All codes lie, some codes are useful."

This pillar is the one that has been most neglected in the absence of underground testing. The reason for this neglect is two-fold. First, large, complex, and integrated experiments that are necessary to train and develop these weapon analysts are very costly and often do not return results that are easy to interpret or turn into improved models, so from a basic science perspective they have little value. Second, in performing these costly experiments many basic science experiments get postponed or canceled, so the science community at large is generally opposed to these experiments. The rest of this paper will concentrate on what is being done and should be done to improve and increase the capabilities of the weapon analyst that is responsible for this third pillar.

The Path to be a Weapon Analyst, Then and Now

The basic starting scientist, either historically or now, had similar backgrounds. Most people start the path to becoming a weapon analyst or designer having completed a PhD in some relevant area of science or engineering and generally one post-doctorate term. Their background will include some computational physics or experimental science. This means that the people beginning the process of learning how to integrate everything together are already an expert in one of the specific areas necessary for nuclear weapons.

Historically, a person entering the weapon design groups at the national laboratories would meet the above criteria. Upon receiving their security clearance they would be attached to a mentor and an upcoming experiment in Nevada. This mentoring process was an intense working relationship, which one designer described as a full-time job. The mentor and mentee would sit and work on modeling the experiment together and discuss every aspect of the physics. Once the particular experiment was completed, the mentee would be attached to another experiment either with the same mentor or a new mentor depending on the needs. This cycle would repeat for three to five nuclear experiments in the first 10 or so years, each time having the mentee do more of the design work and developing their intuition and understanding.

Finally, the mentee would become a lead designer on a nuclear experiment at around the ten year point in his or her career. At this point, the designer could try to stretch his understanding of the complex integrated physics by designing a somewhat novel experiment. These experiments sometimes had surprising results, which were difficult to understand. The process of learning from these surprises was responsible for the real training of these weapon designers. The surprise forced the designer to go back to the model and challenge their assumptions and what the codes were predicting to better understand where the code and coupling physics was wrong. This re-evaluation trained the designers to be circumspect with her conclusions. During this era of training through UGTs, between 10-20% of the people who began this process would end the process as "senior designers"

The assessment and certification process with underground testing was based largely on empiricism. Based on some basic assumptions and experience, the weapon designer would develop a hypothesis and an experiment to test it. Surprises from the experiment would inject new knowledge and understanding into the model. A new hypothesis would be developed and experiments proposed. Finally, the designer would understand the phenomena enough to certify the weapon.

The current process for training a new weapon designer or analyst attempts to be similar; it is, after all, based on the scientific method. However, we are limited to working within the established coupling physics models; we cannot propose a new nuclear test to challenge an assumption. We must mine the information from more then 1000 nuclear experiments that the United States has performed to help develop insight into the nuclear weapon physics. However, these historic experiments do not provide an opportunity for surprises that were so critical in developing the previous generation of weapon designers. We can use these historic tests to develop new hypothesis to challenge assumptions, but within a very limited range. One challenge in using this historic data is that the experimental diagnostics, although state-of-the-art at the time, are limited in resolution for resolving some important physics questions.

We can propose and field new non-nuclear experiments to develop physics and engineering intuition. However, as pointed out earlier, the experiments that would be most beneficial in developing the weapon designer are complex and costly. Additionally, these experiments are restricted to a small subset of the relevant coupling physics. In the case of high energy density physics, such as is being performed on the National Ignition Facility (NIF), this physics tends to be dominated by physics that is irrelevant to nuclear weapons, e.g., laser plasma instabilities.

With these current difficulties in mind there is a hypothetical path to becoming a "senior designer." When a new person is hired, satisfying the basic requirements described above, they are to begin a series of classes that last approximately three years. During this time they are assigned to a mentor and work on relevant research. After this initial stage, perhaps lasting five years, the analyst enters a "mid-career" stage. This stage lasts from about five to ten years and involves additional intensive research and development. Finally, at between 10-15 years a person can become a "senior designer." The difficulty with this path is that there is no clear metric on which to decide that some one is a "senior designer." This recognition is based largely on peer consensus rather then quantifiable measures, and peer consensus can be largely subjective. Remember that during the UGT training era only 10-20% of the people who began the process ended up as "senior designers", how do we know we are choosing the correct people now without quantifiable tests?

It is important to recognize that developing good physics and engineering judgment is a path and not an end-state. Scientists must practice and be tested throughout their career to gain experience and insight. New complex experiments must be proposed and fielded to help develop instinct. These experiments must include pre-shot predictions to provide focus, intensity and exposure to failure. We can use holdout data, "blind tests", from UGTs to test designer judgment on fully integrated tests; however, these test only the analytic skills and not the creative skills of the designer.

This hypothetical path to develop new weapon designers requires a disciplined process that stresses management of long-term training over short-term deliverables. Unfortunately, this hypothetical path has many difficulties. New hires are attached to near term deliverables early in their career. These deliverables distract from the long-term objectives. Additionally, often completion of deliverables does not involve both the mentor and mentee being on the same project for most of their time. Thus the teaching required for the mentor/mentee relationship to be successful occurs in spurts of time extracted from other work. This process does not allow for a deep technical relationship.

The necessity of fielding complex experiments must be planned for as part of the scientific cycle. These complex experiments not only compete with the more fundamental, basic science experiments, they also require significant time to field due to cost and safety requirements. Additionally, since these experiments are very expensive there is a strong incentive to not take risks and thus fail in the objectives. However, in training new people it is often these risks and failures that provide the most training value. Management must again be willing to take a long-term view rather then focusing on near-term success.

This hypothetical path requires a level of discipline that is hard to maintain over a significant period. The urgency of the moment often interferes with the importance of the long-term training. Even if the focus on the long-term objectives can be maintained, it is not clear how to objectively identify the future "senior designers." The idea that you will "know one when you see one" is inadequate given the importance of the mission. Further, without objective metrics you are likely to find that over the long-term the people being promoted are those individuals most aligned with managements objectives and not necessarily the most technically proficient. This promotion of the popular is human nature and does not mean that management has failed, only that we must be vigilant.

Three Actions to Motivate the Future Design Cadre

The purpose of this article is to describe some of the complexity of nuclear weapons and more importantly the difficulty in developing people with the intuition to understand the complex, multi-physics coupling involved in nuclear weapons. Among the largest difficulties in developing this future cadre of nuclear weapons analysts and designers is the need to recruit and retain the best people to carry out this mission. Every young scientist or engineer who achieves their PhD is highly driven and motivated to learn and excel, otherwise they would not spend five or more additional years in school.

A PhD in science or engineering is awarded for important and creative work that extends a field of study in some way beyond the current state of knowledge. Therefore, these people are driven to be creative and understand things that others have not yet figured out. Below I offer three specific actions that if taken could help to develop the next generation of nuclear weapon analysts without underground nuclear testing.

Make the mission clear and tangible

Most people want to know that their work is important. This is particularly true for people that are strongly driven, typical of people who achieve PhDs. As such it is important that the importance of their job be clear, otherwise they will look for work that is deemed important. I believe that the mission of the national laboratories is critical; however, there is little clarity in that mission or sense that the nation believes the mission is critical given the long neglected and declining budgets. The policy makers must determine where the limited available money will be spent, but if the nuclear weapons enterprise is important then the budgets need to be clear and stable. Otherwise young scientist will go where there is a clear mission.

Develop creativity

Studying and analyzing historic data from experiments is critical to understanding nuclear weapons fully. However, motivating your weapon design and analysis cadre over the long term requires a focus on what is involved in stimulating the scientist. Having the opportunity to be challenged and to develop new intuition is one significant motivator. It is important sometimes to sacrifice the necessity of the urgent for the benefit of the long-term. With this in mind, providing an opportunity for the weapon scientists to explore creative experiments can be beneficial to their development even if it is not directly related to an immediate question.

Provide for testability

The hypothetical path, if approached with long-term discipline and the curse of the urgent kept at bay, can provide a viable process for training the future weapon designer and analyst. However, even in a perfect world there remains the question of how a new senior designer is validated. Without underground testing there will never be the Admiral's test: "prove it to me". Even without this final test there is still hope, but only with careful consideration of testability to avoid peer consensus based on favoritism. We must put in place a process that will help guard against this problem. If the process of identifying senior designers is corrupted, it will be very difficult to undo with no new underground tests. Since the last weapon designers with underground test experience will reach retirement age in the next 10 years, putting a robust and testable process in place is an urgent need. The national laboratories cannot wait.

Conclusions

The nuclear weapons enterprise fills a critical and unique position in the strategic posture of the United States. However, often the importance of this mission is not clear given the volatile debate on the enterprise. It is important that a clear and consistent message be presented to encourage young scientists into this career. Additionally, young scientists must be provided an opportunity to develop creativity in their own work. It is difficult to attract and retain the best people if they are not encouraged to explore and expand their knowledge. This exploration is sometimes not directly aligned with the urgent needs of the program. We must have consistent leadership that places the long-term development of people ahead of the urgent, but sometimes less important, needs of the day. Finally, we must develop a method to validate future "senior designers." It is not clear how to accomplish this task without underground testing; however, there is an urgent need to develop this process given the imminent retirement of the remaining weapons designers with underground test experience.

Chinese Mobile Ballistic Missiles: Implications for U.S. Counterforce Operations

Matthew Hallex[1]

As part of an effort to build a more effective and survivable deterrent force, China has expanded the number of missiles it deploys and shifted a greater proportion of its nuclear forces to road mobile missile systems. These new mobile capabilities make the task of tracking and targeting China's deterrent forces as part of U.S. nuclear counterforce operations much more difficult. The U.S. track record with mobile targets- including U.S. operations against Iraqi ballistic missiles in the first Gulf War- suggests that current U.S. capabilities would be insufficient for conventional or nuclear counterforce operations. This paper will evaluate the ability of the United States to conduct counterforce operations against China and address proposed and novel solutions to dealing with this emerging challenge.

Introduction

Along with the modernization of its military that has marked China's rise into greater regional and global political prominence, China has undertaken an expansion and modernization of its nuclear deterrent. The 2010 Nuclear Posture Review (NPR) released by the U.S. Department of Defense expresses concern over this change in China's nuclear arsenal. While the NPR notes that China maintains a relatively small nuclear arsenal compared to other powers, it reflects concerns about the expansion of China's military, "including its quantitative and qualitative modernization of its nuclear capabilities."[2] The NPR also notes that a "lack of transparency surrounding its programs – their pace and scope as well as the strategy and doctrine guiding them– raises questions about China's future strategic intentions."[3]

As part of this effort to build a more effective and survivable deterrent force, China has expanded the number of missiles it deploys and shifted a greater proportion of its deterrent forces to mobile systems including road mobile missiles such as, the DF-21, DF-31, and DF-31A. These new mobile capabilities make the task of tracking and targeting China's deterrent forces as part of U.S. nuclear counterforce operations much more difficult. The U.S. track record of operations to locate and target mobile missile systems is mixed. Operations against Iraqi SCUD missiles (a tactical ballistic missile developed by the Soviet Union during the Cold War) were less than successful despite overwhelming Coalition air superiority. This raises questions about the ability of the United States to successfully conduct counterforce operations against road mobile nuclear missile systems. It is also worth noting that China deploys a large number of conventional missiles which would both complicate counterforce operations and may have implications for escalation control during a conflict.

Keir Lieber, an associate professor at Georgetown University and Daryl Press, an associate professor at Dartmouth, have proposed an expanded counterforce role for U.S. nuclear

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[2] Office of the Secretary of Defense, *Nuclear Posture Review Report,* April 2010, 5.
[3] Ibid., 5.

forces. They suggest that the fragility of Chinese Communist Party rule may lead to gradual nuclear escalation if China faces a defeat in the Taiwan Strait which would undermine the Party's legitimacy.[4] Lieber and Press' model of a U.S. nuclear attack on China's ICBM silos suggest that the United States would be able to successfully destroy China's nuclear missiles in a first strike.[5] This model, however, also suggests that three or four million Chinese civilians would be killed in the fallout that would result from a high yield nuclear explosion and suggest the development of smaller nuclear weapons in order to allow for counterforce operations with minimal risk to civilian populations. China's deployment of mobile missile systems would make a counterforce first strike extremely difficult with current U.S. forces without a large number of civilian causalities. It is unclear, however, if their suggestion of developing smaller nuclear weapons would improve the ability of the United States to conduct counterforce operations against China's mobile nuclear systems.

This paper will explore the ability of the United States to cope with the challenge posed by road mobile nuclear missiles through evaluation of previous cases of U.S. efforts to engage mobile targets during the Cold War and the first Gulf War. Additionally, it will evaluate the particular challenges posed by the Chinese systems. The potential risks created by Chinese deployment of conventional ballistic missiles systems will be addressed, as will the ability of the United States to undertake counterforce operations with minimal civilian casualties, as outlined by Lieber and Press. This paper will also suggest novel technical capabilities and policies the United States could undertake to make counterforce operations more effective.

China's Mobile Missile Systems

China currently deploys three road mobile missiles of concern to U.S. nuclear counterforce operations; the DF-21, DF-31, and DF-31A**.** These missile systems could target the continental United States, allies in East Asia or U.S. military bases in the region. The DF-31 is a three stage solid fueled missile similar to the JL-2 missile deployed on China's latest ballistic missile submarines. With a range of 4500 miles the DF-31 is capable of targeting locations throughout Europe and Asia as well as northwestern parts of the United States.[6] The limitations of the DF-31 and the failure of China's DF-41 missile program lead to the development of the DF-31A. The DF-31A boasts a range of 7500 miles allowing it to threaten targets throughout the continental United States.[7] The likely payload of the DF-31A is a single nuclear warhead as well as decoys and other penetration aids that would allow the missile to survive ballistic missile defenses.[8]

The DF-21 is a Medium Range Ballistic Missile (MRBM) that could threaten targets in East Asia including Taiwan, Japan and U.S. installations in Okinawa, Japan and South Korea. China deploys a number of DF-21 variants, including conventionally armed and anti-ship missiles in addition to nuclear armed missiles.[9] The deployment of both conventional and nuclear armed DF-21 missiles could pose difficulties for U.S. counterforce operations and pose a threat of unintentional escalation in a Sino-American conflict.

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4 Keir Lieber & Daryl Press, "Nuclear Deterrence for the 21st Century," *Foreign Affairs* 88, no. 6 (November/December 2009): 43.
5 Ibid., 46.
6 US Air Force Air and Space Intelligence Center, *Ballistic and Cruise Missile Threats 2009*, available at http://www.fas.org/programs/ssp/nukes/NASIC**2009**.pdf,19.
7 Ibid., 19.
8 Robert S. Norris & Hans M. Kristensen, "Chinese nuclear forces, 2008," *Bulletin of the Atomic Scientists* 64, no. 3, (July/August 2008): 42.
9 US Air Force Air and Space Intelligence Center, *Ballistic and Cruise Missile Threats 2009*, 16-17.

The Mobile Target Problem

Mobile nuclear weapons are not a new challenge for the United States. The Soviet Union developed a number of road and rail mobile nuclear weapons in the later years of the Cold War. In the 1980s the USSR deployed the road mobile SS-25 and the rail mobile SS-24. Both systems could be dispersed throughout the Soviet Union making targeting far more difficult than against targets in fixed silos. While the SS-24 was decommissioned in 2005, Russia continues to deploy over 200 SS-25 launchers.[10] In addition to these Cold War era weapons, Russia's latest ICBM the SS-27 is also road mobile.[11]

Recognizing the difficulties posed by these weapons, the United States attempted to reach an agreement to ban such systems in the negotiations for the first Strategic Arms Reduction Treaty (START).[12] As these efforts failed, other solutions were necessary to address the challenge posed by mobile systems. One solution was the development of the B-2 bomber, an aircraft with stealth capabilities that would allow it to penetrate Soviet airspace and locate mobile targets. While the B-2 would likely be survivable in the face of Soviet air defenses, the problem of locating mobile targets remained. Using radar systems to locate and track mobile targets would risk exposing the bomber to detection and thermal and optical sensors would be limited by weather, smoke or other conditions.[13] The limitations of aircraft sensors would be ameliorated by the use of space based systems that could locate and track mobile missiles. These sensors could also be degraded by jamming, weather conditions, or destruction by Soviet Anti-Satellite (ASAT) weapons.[14] The U.S. also improved its missile capabilities in order to hold mobile targets at risk. The U.S. Navy upgraded the targeting systems of Trident missiles to allow flexible and adaptive targeting of mobile missile systems.[15]

In peacetime, Soviet and Russian mobile missile systems were deployed in highly visible and unhardened garrisons. The visibility of these garrisons allowed for verification of arms control agreements.[16] Compliance with arms control measures would also allow U.S. nuclear forces to directly attack launchers in garrison. Were mobile missiles being dispersed, a barrage attack against the area surrounding the garrison would be launched. Were launchers being deployed and transiting nearby areas on the way to launch sites, a barrage attack would eliminate the mobile systems.

Iraq

Mobile ballistic missiles were a significant threat to U.S. and Coalition forces during the Gulf War. Iraq had a significant theater ballistic missile capability and deployed over 1000 SCUD missiles including several hundred of the extended range Al Hussein and Al Abbas variants. These weapons were deployed at a number of fixed launch sites as well as on mobile launchers. Iraq had acquired between 24 and 36 mobile Transporter Erector Launchers (TELs) from the

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[10] US Air Force Air and Space Intelligence Center, *Ballistic and Cruise Missile Threats 2009*, 21.
[11] Ibid., 21.
[12] Michael Brower, "Targeting Soviet mobile missiles," *Survival* 31, no. 5 (September/October 1989): 433.
[13] Ibid., 436-437.
[14] Ibid., 438.
[15] Hans M. Kristensen, Robert S. Norris & Matthew G. McKinzie, *Chinese Nuclear Forces and U.S. Nuclear War Planning*, (Washington, DC: Federation of American Scientists/Natural Resources Defense Council, November 2006), 51-52.
[16] Ibid., 52

Soviet Union and may have developed an indigenous TEL capability.[17] Iraq launched ballistic missiles against a number of targets in Israel and Saudi Arabia, killing U.S. troops and risking the expansion of the conflict should Israel have entered the war. In order to eliminate the ballistic missile threat and reassure, the Israeli government Coalition forces began a "SCUD Hunt" aimed at eliminating Iraq's TELs.[18]

In the opening day of the conflict Coalition airpower destroyed all of Iraq's fixed SCUD launch facilities but was unable to eliminate any mobile launchers. Iraq's mobile SCUDs proved to be more elusive targets than anticipated by U.S. intelligence analysts. U.S. planning had relied on information about Soviet preparations for the launch of SCUD missiles, which included significant time to set up and disassemble the launcher, providing a window in which Coalition aircraft could strike. By fueling the missiles before deploying to launch sites, sites which had been pre-surveyed to reduce the amount of time required for missile targeting, Iraq missile troops were able to reduce the time required to launch a missile from an anticipated 90 minutes, to a period as short as ten minutes.[19] In addition to reducing the window for Coalition airstrikes, Iraq made efforts to disguise its TELs and support vehicles. Launchers were hidden under highway overpasses, inside civilian buildings or otherwise camouflaged. Iraq also deployed a number of decoy launchers to confuse Coalition efforts.[20]

Coalition aircraft flew 1460 sorties against mobile missiles and associated targets including missile production facilities and potential hiding places for mobile launchers. An additional 1000 reconnaissance sorties were aimed at locating and tracking mobile launchers.[21] Despite the large number of sorties and initial reports of large numbers of kills of mobile launchers, post-war assessment suggested that Coalition forces eliminated far fewer Iraqi TELS and support vehicles than wartime claims would suggest. U.S. fighter aircraft assigned to hunt SCUD launchers were unable to successfully track launch vehicles even if informed of the location of a launch vehicle to within a one square mile area.[22] Even when launchers were successfully detected Coalition aircraft were often unable to track TELs with sufficient accuracy to attack them. In 42 instances in which patrolling aircraft were successful in detecting SCUD launchers, in only eight were they able to track the vehicles with sufficient accuracy to release ordnance.[23]

While Iraq's missiles did little real damage to Coalition forces, or to Israel, they did demonstrate the difficulty of locating and eliminating mobile missiles. It is worth noting that Coalition airpower was able to operate freely in the skies over Iraq. Iraq's own air force either fled to Iran or remained in hardened shelters during the conflict and its air defense network was outmoded. While Iraq could undertake measures to hide launchers from air and space-based reconnaissance and surveillance capabilities, it could not take direct action to degrade or eliminate these Coalition assets.

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[17] Anthony H Cordesman & Abraham R. Wagner, *The Lessons of Modern War: Volume Four - The Gulf War* (Boulder: Westview Press 1995), 935.
[18] Ibid., 937.
[19] Ibid., 365.
[20] Ibid., 936.
[21] Ibid., 365-366.
[22] Ibid., 368
[23] William Rosenau, *Special Operations Forces and Elusive Enemy Ground Targets: Lessons from Vietnam and the Persian Gulf War* (Santa Monica: California: RAND, 2001), 34.

China

Operations against mobile launchers in China may prove to be more difficult than in the cases of the SCUD hunt in Iraq. While the United States and its partners were able to operate in the skies over Iraq with minimal challenge from the outmoded Iraqi air defense network, it is highly unlikely that the United States would enjoy air superiority in a conflict with China. China has deployed significant number of highly advanced fighter aircraft, as well as advanced air defense systems including the Russian made S-300 and indigenously produced HQ-9 surface to air missiles.[24] These systems would limit the ability of the U.S. aircraft to operate over China, particularly non-stealthy strike aircraft such as the F-15 or surveillance assets like the JSTARS surveillance aircraft or UAVs.

Space-based sensors would also be under threat in a Sino-American conflict. In 2007 China successfully targeted and destroyed an obsolete weather satellite demonstrating its possession of a working ASAT capability. The development of ASAT weapons is driven by the challenge U.S. space assets pose to the Chinese military. Targeting these assets would degrade the information superiority enjoyed by the United States and reduce the combat effectiveness of U.S. combat forces. This would be necessary if the People's Liberation Army hopes to defeat the technologically superior U.S. military.[25] While China has no stated policy on the use of ASAT weapons, Chinese literature on the subject suggests that China will prioritize attacks on U.S. space based surveillance and intelligence assets.[26] Attacks on U.S. space based sensors would not only degrade the effectiveness of U.S. combat forces but also make the task of detecting and tracking mobile missile systems more difficult.

China is likely to deploy its missiles in a fashion unlike Soviet and Russian deployment of mobile missiles. Russian mobile missile garrisons are highly visible for the purpose of verification of arms control agreements. As China is not bound by any such agreements and lacks an early warning capability that would allow for the dispersal of mobile missile launchers upon warning of an attack, Chinese mobile missiles are likely to be deployed to underground bases or other protected shelters making them harder to track and target.[27] China may also deploy its weapons in more densely populated areas. In the case of medium ranged missiles, such as the DF-21, this is necessary to allow the missile to threaten targets to the east of China, including U.S. bases in the western Pacific. Longer ranged weapons such as the DF-31 and DF-31A may be deployed to such areas because of the increased density of the road network which would allow for greater mobility when dispersed.[28] People's Liberation Army Second Artillery[29] bases have also been relocated closer to populated areas in an effort to improve the standard of living of their soldiers and to allow for better access to communication networks.[30]

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[24] Office of the Secretary of Defense, *Military Power of the People's Republic of China 2009*, March 2009, http://www.defenselink.mil/pubs/pdfs/China_Military_Power_Report_2009.pdf, 22.
[25] Kevin Pollpeter, "Motives and Implications Behind China's ASAT Test," *China Brief* 7, no. 2, (May 9 2007), http://www.jamestown.org/single/?no_cache=1&tx_ttnews[tt_news]=4022.
[26] Roger Cliff Mark Burles, Michael S. Chase, Derek Eaton, & Kevin L. Pollpeter, *Entering the Dragon's Lair: Chinese Antiaccess Strategies and Their Implications for the United States* (Santa Monica, California: RAND, 2007), 59.
[27] Kristensen, Norris & McKinzie, *Chinese Nuclear Forces and U.S. Nuclear War Planning,* 51.
[28] Li Bin, "Tracking Chinese Strategic Mobile Missiles" *Science and Global Security* 15, no. 1, (January 2007): 8.
[29] The Second Artillery Corp is the branch of the People's Liberation Army responsible for strategic missiles.
[30] Mark Stokes, "China's Nuclear Warhead Storage and Handling System" (Occasional Paper, Project 2049 Institute, March 12, 2010), 7.

This poses several challenges to the United States. Deployment to developed and densely roaded areas would make Chinese missiles more mobile, allowing for them to cover a greater distance during the period between detection and attack, and would make them more difficult to distinguish from regular civilian road traffic. Additionally, deployment of missiles to these areas would also place them near a greater number of civilian targets which would raise the risk of collateral damage during counterforce operations.

Target Discrimination and Escalation Control

In addition to the challenge of tracking and targeting mobile missile systems, a further complication results from China's deployment of both nuclear and conventional ballistic missiles. A number of Chinese ballistic missiles are capable of being equipped with both nuclear and conventional warheads, including the DF-21, which is deployed in nuclear, conventional and anti-ship variants. This poses a significant problem to U.S. war planners as the United States cannot easily distinguish between missiles armed for conventional or nuclear missions. There is no apparent difference in the organizational structure of Second Artillery brigades with nuclear or conventional missions. Additionally, missiles armed with a nuclear warhead are visually identical to those armed with conventional warheads.[31] Further complicating the issue of discriminating between conventional and nuclear armed missiles, is China's centralized warhead storage system. China maintains a very low alert status and its ICBMs and other missile forces are not regularly deployed with nuclear warheads during peacetime.[32] This limits the ability of the U.S. to observe warhead mating during peacetime to discriminate between missiles and Second Artillery units with nuclear and conventional missions. While the U.S. could observe warhead mating as China increased the alert level of its nuclear forces during a crisis, China is likely to attempt to significantly degrade the ability of U.S. surveillance assets to make such a determination during a conflict or crisis that has escalated to a point that requires China to alert its nuclear forces.

Difficulty in distinguishing between nuclear and conventional forces complicates U.S. nuclear and conventional war planning. In the case of counterforce operations against China's nuclear deterrent, the inability to distinguish between nuclear and conventional forces increases the number of targets that the United States must locate and eliminate. In order to ensure the elimination of China's nuclear forces, the U.S. would find it necessary to eliminate all of China's mobile launchers as there would be no way to determine which launchers would be nuclear armed. Even should the U.S. develop a capability to discriminate between nuclear and conventional missiles, it may be necessary to eliminate missiles which are currently armed with conventional warheads that are capable of being equipped with nuclear weapons.

A more worrying implication of this target discrimination problem is the inability of the United States to distinguish between conventional and nuclear forces during a conventional conflict. Conventional ballistic missiles targeting U.S. command and control and logistics nodes, as well as airbases in the region, are a key part of China's anti-access strategy.[33] The DF-21 anti-ship variant would also likely be used against U.S. carrier groups deploying to the region in the event of a conflict with China.[34] The threat posed by these missiles makes them a likely

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[31] Mark Stokes, Personal Communications, March 17 2010.
[32] Stokes, "China's Nuclear Warhead Storage and Handling System," 8.
[33] Cliff et al, *Entering the Dragon's Lair*, 60-64.
[34] "Report: Chinese Develop Special "Kill Weapon" to Destroy U.S. Aircraft Carriers" US Naval Institute, March 13 2009, https://www.usni.org/forthemedia/ChineseKillWeapon.asp/.

target for U.S. attack, particularly in early stages of a conflict, in order to limit the ability of China to disrupt U.S. deployment into the theater. Without an ability to reliably discriminate between nuclear and conventional missiles, U.S. attacks aimed at conventional missiles may also target Chinese nuclear forces. A U.S. attack aimed at eliminating conventional and anti-ship missiles may be perceived as, or effectively be, a counterforce attack aimed at Chinese deterrent forces. This issue is further complicated by Chinese perceptions of the information superiority possessed by U.S. intelligence. China's response to the 1999 bombing of its embassy in Belgrade by U.S. aircraft was shaped by a belief in the infallibility of U.S. space-based intelligence assets. This crisis was escalated by China's conclusion that information superiority, that the U.S. would have as a result of these assets, indicated that the bombing was intentional, despite U.S. claims that it had resulted from the use of an outdated map in determining targets for air strikes.[35] Attacks against Chinese nuclear forces resulting from a U.S. inability to discriminate between nuclear and conventional targets could be met with a same degree of disbelief in the fallibility of U.S. intelligence and surveillance capabilities.

The problem of target discrimination could be resolved through arms control efforts. The Strategic Arms Limitation Talks (SALT) II treaty includes a number of provisions aimed at aiding the space based intelligence assets of the signatories in distinguishing between heavy bombers designated for nuclear and non-nuclear missions.[36] The introduction of features that would allow U.S. surveillance assets to distinguish between nuclear and conventional ballistic missiles would limit the risk of unintentional counterforce attacks. However, it is unlikely that China would enter into such an agreement. The survivability of China's nuclear deterrent is dependent on ambiguity about the number of missiles China deploys and the geographical location of mobile assets.[37] As China's nuclear arsenal is very small the risk to its survival posed by nuclear transparency may be too great for China to be willing to enter into an agreement that would explicitly identify its nuclear weapons and allow for verification of this information. The United States could also expand the scope of military to military contact or address this problem in other forums in order to provide reassurance that the United States would not seek to eliminate Chinese nuclear weapons in a conventional war unless the Chinese undertook certain threatening behaviors. While this would not address the problem of target discrimination directly, it may reduce the risk of escalation resulting from Chinese misperceptions of the intent of U.S. strikes against mobile missiles.

Is Counterforce Possible?

Operations in Iraq made it clear that the detection, tracking and targeting of mobile targets is a difficult undertaking. This process would likely be more difficult in a conflict with China due to advanced Chinese air defense and anti-satellite capabilities in addition to the already significant challenges posed by camouflage, deception and the problem of detecting a relatively small target in high traffic areas. This suggests that counterforce operations against Chinese mobile nuclear missiles would be difficult.

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[35]Paul H. B. Godwin, "Decisionmaking Under Stress: The Unintentional Bombing of China's Belgrade Embassy and the EP-3 Collision" in Andrew Scobell & Larry M. Wortzel, eds., *Chinese National Security Decisionmaking Under Stress* (Carlisle, Pennsylvania: US Army War College, September 2005), 164.
[36] U.S. Department of States, *Treaty Between the United States of American and the USSR On The Limitation of Strategic Offensive Arms, Together With Agreed Statements and Common Understandings Regarding the Treaty*, June 18, 1979, http://www.state.gov/www/global/arms/treaties/salt2-2.html.
[37] Li Bin "Appendix 3A. China and nuclear transparency" in Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: The Political and Technical Dimensions* (Oxford: Oxford University Press 2003), 52.

The success of counterforce operations will depend on the tolerance the United States has for collateral damage in China. While mobile launchers are soft targets that could be disabled with conventional weapons, this would require highly accurate information on the location of mobile launchers that would be difficult to achieve under adverse wartime conditions. As conventional weapons would require a level of accuracy that would be difficult to achieve, it would likely be necessary to use nuclear weapons in order to eliminate mobile targets.

Lieber and Press suggest the development of low yield nuclear weapons would allow the United States to conduct counterforce operations against Chinese silo-based nuclear weapons while reducing the number of civilian casualties due to fallout.[38] They suggest that low yield nuclear weapons would also reduce the problem of tracking mobile weapons as conventional weapons would require information about the location of missiles that was accurate within a few yards of the target while a five kiloton warhead would only require information that was accurate within a half mile.[39] The deployment of Chinese weapons to developed and densely populated areas, however, would result in even a small warhead dealing significant collateral damage to Chinese civilians. Should China be able to degrade U.S. intelligence and surveillance capabilities to a degree sufficient to make targeting within the projected half mile radius difficult, it would be necessary to conduct a larger nuclear barrage against potential launch areas in order to eliminate mobile missile systems. A larger barrage would increase the odds of eliminating mobile launchers, but such a large scale attack on populated areas would shade closely to a counter value attack against China's urban areas. The kind of clean counterforce operations envisioned by Lieber and Press is beyond the abilities of the United States at the moment.

The ability of the U.S. to conduct counterforce operations against China depends on two variables; the ability of U.S. surveillance assets to track weapons and the tolerance of the U.S. to accept collateral damage. The current limitations of U.S. surveillance technologies and the challenges posed by China would require the United States to be highly tolerant of collateral damage if it was to ensure the elimination of Chinese mobile missiles. The current ability of the United States to conduct counterforce operations against China's mobile missiles is less a question of technical capability but rather an ethical question. However, improvements in the ability of the United States to successfully locate and track targets would allow the risk of collateral damage to be reduced in the future.

Addressing the Problem of Mobile Targets in China

There are a number of ways in which the United States could improve its ability to detect and track mobile missile launchers, which would allow for the use of conventional or low yield nuclear weapons to be used to eliminate these targets. The development of novel technical capabilities could serve to make counterforce operations more feasible. Unmanned Aerial Vehicles (UAV) play an increasingly large role in U.S. military operations. Armed UAVs provided not only a persistent surveillance and reconnaissance capability but also a strike capability.[40] Currently, the United States operates UAVs in the relatively unchallenging aerial environments of Iraq and Afghanistan. China's advanced air defense systems and fighter aircraft would make the use of current U.S. UAVs in Chinese airspace extremely difficult. The

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[38] Lieber & Press, "Nuclear Deterrence for the 21st Century," 48-49.
[39] Keir Lieber & Daryl Press "Lieber and Press Reply" *Foreign Affairs* 89, no. 2 (March/April 2010): 152.
[40] Luther S. Turner III, Jason T. Adair & Louis Hamel "Optimizing Deadly Persistence in Kandahar: Armed UAV Integration in the Joint Tactical Fight," *Colloquium* 2, no. 2, (June 2009): 9.

United States could develop stealth UAVs that would be able to penetrate Chinese air defense networks and provide a persistent surveillance capability to track mobile missile launchers. These UAVs could be armed with conventional weapons that would allow for the elimination of mobile launchers upon detection, reducing the period of time between the detection and attack on the launcher during which time a mobile target could relocate itself. The United States could also deploy B-2 stealth bombers in a similar fashion, but the small number of these bombers and the high demand placed on them for conventional strike missions during a conflict would favor the use of an unmanned capability.

The United States could also improve the capabilities of its space-based reconnaissance and surveillance assets and harden these assets against attack. In addition to the space-based thermal and optical sensors that the United States deploys, it could also develop a space-based radar capability. Unlike thermal and optical sensors, radar would be able to penetrate cloud cover and the large dust clouds that would result from a nuclear explosion. The United States is currently planning the deployment of such a system and it would improve the prospects for tracking mobile targets.[41] Space based sensors would also need to be better protected against Chinese anti-satellite weapons. For instance, the United States could harden satellites against attacks by ground based lasers. Rather than deploy a small number of large surveillance satellites, the United States could deploy a constellation of smaller satellites, which would build a redundant capability into its space based systems and present a much larger number of targets that would need to be eliminated.[42]

Along with unilateral efforts to protect its space assets against ASAT attack, the United States could attempt to address the problem of the extension of war into space through diplomatic channels. China has drafted a number of working papers, both alone and jointly with other states, suggesting steps that could be taking to address weapons in outer space.[43] Engagement with China on this issue could result in an understanding, or perhaps a legal agreement, limiting the role of anti-satellite weapons and reducing the risk to U.S. space assets.

Conclusions

China's deployment of road mobile nuclear missiles does not make effective counterforce operations impossible but it does make such an undertaking difficult and costly. Current U.S. reconnaissance and surveillance capabilities are unable to effectively locate and track mobile targets in small scale conflicts in which the United States enjoys air and information superiority. This challenge would be exacerbated by China's ability to degrade U.S. tracking capabilities by directly attacking U.S. air and space based assets. Without highly accurate information on mobile launchers, it would not be possible to eliminate them with conventional weapons despite the fact that they are soft targets. Counterforce operations against Chinese targets would rely heavily on nuclear weapons which would likely inflict a great deal of collateral damage. The relatively clean counterforce strikes envisioned by Lieber and Press would not be possible even if the U.S. were to develop a low yield nuclear capability. While the United States could eliminate China's nuclear deterrent force with a high probability of success, it could not do so without killing a large number of Chinese civilians.

[41] "Fact Sheet: Space Radar," US Air Force Space and Missile Center, http://www.losangeles.af.mil/library/factsheets/factsheet.asp?id=5308.
[42] Theresa Hitchens, "Code Red? Chinese ASAT Test Raises Debris Threat to EO,"*Imaging Notes* 22, no. 2, *Magazine*, Summer 2007, http://www.imagingnotes.com/go/article_free.php?mp_id=99.
[43]Jeffrey G. Lewis, *The Minimum Means of Reprisal: China's Search for Security in the Nuclear Age* (Cambridge: The MIT Press, 2007),174.

Chinese mobile missiles also pose a risk of unintended escalation of a conflict. The inability of the United States to distinguish between Chinese conventional and nuclear missiles would not only complicate counterforce operations but also introduces the risk of unintentional attacks on China's nuclear deterrent. While this would be the result of serious limitations in U.S. intelligence and reconnaissance capabilities, Chinese leaders would likely perceive such attacks as intentional. Perceived counterforce attacks may put pressure on Chinese leadership to use nuclear weapons before they are eliminated by the United States, lowering the nuclear threshold in a Sino-American conflict.

In order to address these challenges, the United States will need to develop novel capabilities in order to bolster its ability to detect, track and strike mobile nuclear missile systems. Improvements in these areas would allow for a greater role for conventional weapons in counterforce operations reducing the risk of collateral damage to Chinese civilians. The United States also needs to engage with China and build a greater level of mutual trust in order to avoid inadvertent escalation of a conventional conflict into a nuclear exchange.

Tactical Nuclear Weapons, NATO and Russia

Grant Schneider

The focus of this paper is NATO's tactical nuclear posture since the end of the Cold War and the arms control and security issues that surround NATO's nuclear force. It begins with a brief overview of the threats and doctrine behind the deployments of tactical nuclear weapons in Europe during the Cold War. Next, changes to Russian and U.S. force posture and doctrine and the new Strategic Concept are covered followed by three key sets of countries' current views on tactical nuclear weapons: Germany, Belgium and the Netherlands; Baltic and Central European States; and Turkey. A discussion of the debate over the removal of tactical nuclear weapons from Europe follows. Finally, the author's thoughts on restructuring NATO's nuclear policy and opportunities for arms control with Russia are given.Tactical nuclear weapons are the last part of the Russian and U.S. arsenals not covered by arms control regimes. This doesn't make much sense today; these weapons are smaller, more widely dispersed and generally under weaker security regimes, in both NATO member states and in Russia, than their strategic siblings. Tactical nuclear weapons are also less desirable from a deterrence standpoint than strategic nuclear weapons; it is much more difficult to achieve Mutually Assured Destruction (M.A.D.) with shorter range weapons with countries so large as the United States and Russia. A layman may conclude that it would then be easier to negotiate limits or elimination on this class of weapons as opposed to others. This, however, has not been the case to the detriment of both Russia and NATO's security. This paper explores the thinking behind both side's postures as well as the capabilities they bring to bear and their effects on the dynamics of NATO alliance. Finally, it offers policy ideas for NATO moving forward, both in terms of its own policies and its relationship with Russia.

Definition of "Tactical Nuclear Weapons"

In beginning this research, the author was given an excellent piece of advice: have a strong definition of tactical nuclear weapons in your back pocket. In thinking about how to structure my research, a negative definition elicited the least amount of resistance: in discussing tactical nuclear weapons, theater nuclear weapons and other names for non-strategic weapons in this paper, the author is referring to any and all U.S. and/or Russian made nuclear warheads which are *not* covered under the START regime. Surely, one can find exceptions to this definition that complicate it, but, broadly, the definition allows for easier discussion of the issues surrounding theater nuclear forces.

NATO Posture, Past and Present

In the last two decades, significant changes occurred in the nature of the security environment in Europe and consequently, postures and doctrines of NATO, the United States and Russia changed as well. In order to understand the shifts, one must look to doctrine and force postures developed decades before. A key posture put into place by NATO that carved out a role for NATO tactical nuclear weapons was the doctrine of flexible response. After the Cold War, NATO and the United States abandoned this doctrine and significantly changed its force numbes as the threat of a large scale invasion by Russian forces disappeared. The United States began a large scale removal of warheads from Europe and limited the situations in which it considered the use of nuclear weapons acceptable, while not abandoning flexible response outright. That said, it is now unimaginable that NATO would be the first to escalate a conventional war to the nuclear level. Russia, on the other hand, experienced declining conventional strength in the post-Cold War world and began relying more heavily on its nuclear arsenal and tactical nuclear weapons in particular. This is the reversal of polarity that has, over the past two decades, beginning with the fall of the Berlin Wall, significantly altered the environment in which tactical nuclear weapons exist.

In the wake of the Berlin Crisis of 1961, European states began worrying more and more about the Soviet threat. This was both a change in perception of the Soviet Unions intentions and its conventional strength vis-à-vis NATO. This, in turn, led to a belief –and worry– that NATO's conventional forces were inferior to USSR conventional forces. Furthermore, some argued that "U.S.-Soviet nuclear interdependence,"[1] which began to emerge, increased the risk of conventional war in Europe due to Soviet's increasingly sophisticated nuclear arsenal. As the Soviet Union was able to inflict large scale nuclear destruction on the United States, many in Europe believed "it was therefore no longer credible to use strategic nuclear forces to deter conflict at lower levels."[2] European states looked to the United States for an increased and renewed commitment to deter the Soviet Union from invading Western Europe. As worries mounted, many European countries feared the United States would be unwilling and possibly incapable of defending the European continent from a Soviet invasion. Thus began a large debate within NATO to determine the proper way to defend and deter against the increased Soviet threat. Conventional and nuclear responses to the Soviet threat were devised, but this paper will focus on the nuclear.

The doctrine, in which NATO members replace massive retaliation doctrine, was called flexible response:

> This concept, which adapts NATO's strategy to current political, military, and technological developments, is based upon a flexible and balanced range of appropriate responses, conventional and nuclear, to all levels of aggression or threats of aggression. These responses, subject to appropriate political control, are designed, first to deter aggression and thus preserve peace; but, should aggression unhappily occur, to maintain the security and integrity of the North Atlantic Treaty area within the concept of forward defence.[3]

This doctrine permitted NATO to use nuclear weapons in response to a conventional attack, if, conventional defenses failed. As the Soviet nuclear arsenal increased in numbers, delivery capabilities and sophistication, the overriding American concern was to reduce the risks of escalation to general nuclear war that would threaten the American homeland.[4] Flexible response and the deployment of theater nuclear weapons in Europe had the virtue of allaying American concerns of escalation and bolstering NATO's deterrent. For the European members, flexible response and the deployment of tactical nuclear weapons in Europe, "tied" the United States to the defense of Western Europe in such a fashion that kept it unique in its strategic importance to the United States.[5] Tactical nuclear weapons as a political linkage between

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[1] Daalder, Ivo H. The nature and practice of flexible response : NATO strategy and theater nuclear forces since 1967, Columbia University Press (1991) p. 4

[2] Daalder, Ivo H. The nature and practice of flexible response : NATO strategy and theater nuclear forces since 1967, Columbia University Press (1991) p. 5

[3] NATO Ministerial Communiqué, December 1967 http://www.nato.int/docu/comm/49-95/c671213a.htm

[4] Halverson, Thomas E. *The Last Great Nuclear Debate : NATO and Short-Range Nuclear Weapons in the 1980s*. Houndmills, Basingstoke, Hampshire; New York, N.Y.: Macmillan Press; St. Martin's Press, 1995. p. 8

[5] Freedman, Lawrence. *The Evolution of Nuclear Strategy*. 3rd ed. Houndmills, Basingstoke, Hampshire ; New York: Palgrave Macmillan, 2003. p. 287

Europe and the United States continue to be a unique and salient point for many. This linkage was, and still is for some, vitally important to those who did not like the answers to Gallois' questions, posed after Nikita Khrushchev declared in 1957 that the USSR had a ballistic missile capable of carrying nuclear warheads:

> Could the Strategic Air Command be expected to use its weapons of mass destruction on behalf of third parties when to do so meant exposing America to such dreadful reprisals? What became of the indispensable credibility of the American response?"[6]

Deployment of tactical nuclear weapons, under the command of NATO, governed by the flexible response doctrine was a successful attempt to come to terms with a new security reality in Europe, albeit imperfectly. This doctrine, as well as the deployment of tactical nuclear weapons remained in place, with some changes, through the 1980's.

In 1991 the United States and Russia endeavored to bring arms control to bear on the both groups' large tactical arsenals. As the threat of a large scale attack faded away, thousands of theatre nuclear forces deployed throughout Europe were seen as anachronistic and a potential security risk due to their dispersal and size compared to strategic forces. The effort to change this manifested itself in the Presidential Nuclear Initiatives with President H. W. Bush unilaterally withdrawing the large majority of tactical nuclear weapons from NATO, leaving behind, eventually, about 200 weapons in six countries.[7] Soviet President Gorbachev, and later Boris Yeltsin, agreed to its own set of unilateral cuts. Unfortunately, the PNI regime was not legally binding, did not contain verification provisions or even formal data exchanges. Today, many believe Russia did not honor its promises and continues to maintain an arsenal that contradicts its claims. Since this time, there have been only unsuccessful efforts to create an arms control regime to limit the size and scope of tactical nuclear weapons despite the obvious security risks, reduced threat of war and anachronistic nature of the weapons.

The next important development in NATO tactical nuclear policy came with the 2010 NATO Strategic Concept. In the negotiations leading up to the approval of the Strategic Concept, President Obama's Prague speech of 2008 loomed large. There was a large disagreement among members and activist as to the importance, role and need for NATO's tactical arsenal. Yet, the document did not embody a bold change in NATO's nuclear policy. Instead, it made small changes that set the foundation for the removal, or at the very least, increase flexibility of NATO's nuclear forces. This resulted in key changes to the language from the 1999 Strategic Concept.

One of the most heralded changes in the document, among opponents of the treaty, from the 1999 Strategic Concept was the removal of language stressing the important political link that NATO's nuclear forces embody: "The fundamental purpose of the nuclear forces of the Allies is political: to preserve peace and prevent coercion and any kind of war."[8] This idea, as discussed earlier, was first employed in 1967 in official NATO declarations. The recently adopted Strategic Concept opted for more vague language ensuring that NATO will remain a nuclear alliance as long as nuclear weapons exist. While this is not an explicit attempt to reduce the role of nuclear weapons in NATO it does remove language that would have otherwise been an obstacle to the removal of NATO nuclear forces. While far from groundbreaking, the language

[6] Gallois, Pierre M. "New Teeth for NATO." *Foreign Affairs* 39.1 (1960): pp. 67-80

[7] "Russian Tactical Nuclear Weapons" FAS Blog, Hans Kristensen, http://www.fas.org/blog/ssp/2009/03/russia-2.php

[8] NATO Strategic Concept, 1999, Paragraph #62 http://www.nato.int/cps/en/natolive/official_texts_27433.htm

continues the trend in American deterrence policy of reducing the use and role of nuclear weapons. The 2010 Strategic Concept also makes more explicit that it is in fact primarily the United States *strategic* forces, as well as those of Britain and France, that make up NATO's nuclear umbrella which ensures NATO members are free from "coercion and war of any kind."[9] This further indicates the diminished role of tactical nuclear weapons in NATO.

Another important change in the 2010 document is the linking of NATO's current nuclear forces to those of Russia. The 2010 Strategic Concept makes clear that "in any future reductions our aim should be to seek Russian agreements to increase transparency on its nuclear weapons in Europe and relocate these weapons away from the territory of NATO members." In one sense then, the document can be seen as a hedge; opens up the possibility of removal of the weapons in one part but makes clear in another section that action should occur in conjunction with Russia, which still holds onto a massive arsenal of tactical weapons relative to NATO. In both documents, there is strong language relating to the importance of all members sharing the burden of the defense of the Alliance in ways in which they are able.

In short, NATO nuclear policy has moved, over the past few decades, from an expansive view on the uses of nuclear weapons to a more limited view. The same applies to the capabilities of NATO's tactical nuclear force. All weapons currently in Europe are gravity bombs which must be flown to their destination, making them nearly obsolete in the event of a nuclear war. General Cartwright, Vice-Chairman of the Joint Chiefs of Staff and former head of STRATCOM confirmed this view in discussing NATO's nuclear arsenal.[10] At this point, NATO's reliance on its nuclear forces for deterrence could scarcely decrease without removing the weapons completely. The single most important driver of these changes is NATO's unparallel convention capabilities in the context of a reduced threat from Russia.

Russian Posture: Past to Present

In the interest of space and focus, this paper will not address the Soviet doctrine in depth. Instead, it will focus on Russia's doctrinal changes after the end of the Cold War as they pertain more directly to the situation regarding NATO's tactical nuclear weapons today. Over the last two decades, both the relative military strength of NATO and Russia and the threats each side perceives, have changed dramatically. First and foremost, the Russian military witnessed dramatic decreases in funding and capability over the last two decades. Only in the last decade, as energy prices have climbed, has the Russian government been able to begin to reverse this decline. NATO capabilities, on the other hand, have increased dramatically, both relative to Russia and in absolute terms as well. In addition, both sides now see the threat of a large scale ground invasion as extremely unlikely. Yet, many now believe, both in Russia and in NATO, a small, limited war over small pieces of territory is the likely situation in which Russia and NATO would find themselves in conflict. Indeed, some argue that the chances of such a war have increased.

These changes in threat assessment and capability have driven a change in Russian doctrine. In 1993, Russia removed its no first use declaration from its military doctrine. While this change is important, it is the changes that came about post-1999, Nikolai Sokov argues, that are most troubling. Russia witnessed NATO's new capabilities in the war in Kosovo, chief among them, the devastating effects of precision guided munitions. Russian leaders began to worry that

[9] NATO Strategic Concept 2010, http://www.nato.int/strategic-concept/index.html
[10] http://www.cfr.org/publication/21861/nuclear_posture_review.html Panel on the Nuclear Posture Review, transcript

it would no longer be able to defend its territory adequately from a limited war using conventional means. As the threat large scale nuclear war was not seen as a credible response in deterring such an attack, Russian declarations called for a doctrine of de-escalation, which bears similarity to flexible response. This doctrine increased the uses of nuclear weapons within Russian doctrine as the Russian government calls for the use to nuclear weapons to suppress a potential overwhelming conventional threat that it perceives from NATO.[11] Indeed, these changes were "tested" and "implemented" in a war game organized by Russia and Belarus with a simulated nuclear attack on Poland. The war game simulated a NATO attack and subsequent invasion of Kaliningrad.[12] The war game likely buttressed conclusions of Russian officials that Russia would indeed not be able to deter or repel a NATO attack on Kaliningrad *without* the use of nuclear weapons. While it is extremely unlikely that NATO will find itself in a limited conflict of Russia where nuclear weapons would be called upon, these doctrinal impose greater requirements on the force structure of Russia's theater nuclear forces. With implications for NATO's nuclear force, this will affect NATO's nuclear doctrine, the debate surrounding their removal and the success or failure of any new efforts to negotiate with Russia on tactical nuclear weapons. The implications of these changes on efforts to alter NATO nuclear forces and possibly their removal will be discussed later on.

The history of Russian and Soviet nuclear doctrine tells the opposite story of NATO with regards to its reliance on nuclear weapons and tactical nuclear weapons specifically. As NATO has decreased its reliance on nuclear with increasing conventional strength, Russia has increased its reliance with increasing worries of NATO's conventional strength. This makes tactical nuclear weapons unique; Russia and the United States have found common ground in limiting other classes of nuclear weapons but have been unable to do so with tactical ones. This suggests a difference in the weapons, despite the tenuous definition of tactical and strategic weapons. Both sides, at one point in their doctrinal evolution, have linked conventional power to tactical weapons in a way that strategic weapons never were once MAD became a reality. This manifests itself in a number of ways; most recently, on both sides and a range of experts acknowledge that serious reductions in tactical weapons cannot occur without first ironing out differences in the Conventional Armed Forces in the Europe Treaty. The link to CFE suggests, again, that the road to removal and limitations of tactical nuclear weapons runs through the conventional military space; further complicating the efforts of many to reduce the threats posed by tactical nuclear weapons in Europe and Russia. Russian's de-escalation doctrine also links tactical nuclear weapons to conventional threats. This fact must be appreciated when attempting to negotiate tactical weapon reductions.

Germany, Belgium and the Netherlands: Less than Enthusiastic

Home to bases containing tactical nuclear weapons, these countries have similar views on NATO's nuclear force. All three countries have indicated some interest in doing their part to advance to a world free of nuclear weapons by removing the warheads from their soil. The Dutch Foreign Minister Maxime Verhagen put it: "Would it be possible for NATO to retain its nuclear mission without the presence of American nuclear weapons on its soil? I believe it would. As

[11] "Engaging China and Russia on Nuclear Disarmament" Cristina Hansell and William C. Potter, Eds. The *Evolving Role of Nuclear Weapons in Russia's Security Policy*, Nikolai Sokov, p. 77-78
[12] Day, Matthew. "Russia 'simulates' nuclear attack on Poland." Telegraph 01 Nov. 2009, http://www.telegraph.co.uk/news/worldnews/europe/poland/6480227/Russia-simulates-nuclear-attack-on-Poland.html

well, it's an option that merits serous consideration."[13] Similar statements have come out from members of the Belgian and German governments. In some cases, these countries face domestic political environments that are anti-nuclear, affecting the debate among all on tactical nuclear weapons over the last decade or so.

The most glaring example of differing opinions on the tactical nuclear weapon question is of Germany. In forming a governing coalition, Chancellor Angela Merkel was forced to accept a statement by the current Foreign Minister and head of the Free Democratic Party of Germany, Guido Westerwelle, stating that the coalition government would seek to remove NATO nuclear weapons deployed in Germany. As this was a political party document and not a change in government position it had little direct effect on the weapons but did affect the debate on tactical nuclear weapons wide open in advance of the Strategic Concept. Mr. Westerwelle knew, somewhat cynically, that German voters were anti-nuclear and that this would yield a domestic political benefit. In response, Franklin Miller, Lord Robertson and Kori Schake pushed back by reaffirming the need for NATO's nuclear mission and arguing that Germany was in effect asking to have the benefits of a nuclear umbrella while "shedding" the burden ostensibly shared by all member states.[14] While a healthy debate on NATO's nuclear policy is important and indeed needed, the fashion in which the issue was raised was rightly considered irresponsible by many.

Belgium, through lax security on the base that houses its share of NATO's tactical nuclear force, has also found its way into the headlines on this issue. A group of activists entered the base and were able to get near the cluster of buildings that are believed to house 10-20 nuclear weapons.[15] There is some disagreement as to how close the activists actually were to the weapons but the event and second breach by the same activists was alarming nonetheless. While many are predominantly worried about the safety and security of Russia's nuclear arsenal, clearly, there are reasons to worry about NATO's as well. While it is clear it would have been extremely difficult to successfully steal, let alone use one of these weapons, the work of five unarmed activists shows security should be taken more seriously. Furthermore, an Air Force report detailed the lax security at European bases with regard to NATO's nuclear weapons.[16]

This security breach, as well as the lack of interest on Germany's part to outfit its next generation fighter plane to be nuclear capable, are cited as more reasons to remove the weapons. In the case of the German's newest fighter, some argue that Germany's primary motivations are in fact, budgetary; that Germany no longer wants to incur the costs associated with its burden of the NATO nuclear mission.[17] Neither these arguments are first order reasons for removal of the weapons. First, security can be easily improved on all NATO bases in order to safeguard the weapons. Perimeter security is not an insurmountable obstacle. Second, Germany's budgetary concerns seem to be more geared towards hedging; the government is waiting to see, if in fact

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[13] Speech by Dutch Foreign Minister Maxime Verhagen, "Launch Meeting Marking the Creation of Four New PhD Positions in the Field of Non-Proliferation," Faculty Club of Erasmus University, Rotterdam, March 16, 2010

[14] "Germany Opens Pandora's Box," Centre for European Reform: Miller, Robertson and Schake http://www.cer.org.uk/pdf/bn_pandora_final_8feb10.pdf

[15] "US Nuclear Weapons Site in Europe Breached," Hans Kristensen, FAS blog, http://www.fas.org/blog/ssp/2010/02/kleinebrogel.php#more-2510

[16] "USAF Report: 'Most' Nuclear Weapon Sites In Europe Do Not Meet US Security Requirements," Hans Kristensen, FAS blog, http://www.fas.org/blog/ssp/2008/06/usaf-report-%E2%80%9Cmost%E2%80%9D-nuclear-weapon-sites-in-europe-do-not-meet-us-security-requirements.php

[17] Discussions with European NATO member country officials at the Project on Nuclear Issues Fall Conference in Aldermaston, UK. September 2010.

NATO's nuclear force exist when its time to make its planes nuclear capable. In any case, this is also a technical issue which can be solved easily and comparatively cheaply. If Germany was threatened by Russia and concluded these weapons would dramatically improve security, no one would raise objections over cost. Yet both of these incidents and others do suggest that Belgium, German and the Netherlands do not ascribe high value to the NATO's nuclear force and are generally neutral to negative in their views on keeping them for the long term.

One reason for decreased interest in NATO's nuclear force is that the three countries mentioned have significantly altered their perception of the Russian threat. They no longer believe that Russia is a threat that warrants the deployment of tactical nuclear forces in NATO. Furthermore, other anecdotal evidence, such as the hiring of Gerhard Schroeder, former Chancellor of Germany, by Gazprom, a Russian state-controlled energy company eliciting little backlash (aside from calls of corruption) in German media, suggests that these countries no longer fear Russia. This is despite the fact that Gazprom holds the controlling share in the pipeline project effectively making a former German head of state an employee of the Russian government.[18] It's easy to imagine this not being the case in a country like Poland or other former Soviet republics, or even the United States. This is merely to suggest that Germany sees Russia as an economic opportunity, not a threat. These reasons, in turn, are the drivers of decreased support for NATO's nuclear sharing agreement and its nuclear mission.

Baltic and Central European Member States: Return to the 1960's

Unlike Germany, Belgium, the Netherland and others, the Baltic and Central European States perceive greater threat from Russia. As they do not have as long of an institutional relationship with NATO, many look for and take very seriously, the security assurances provided by NATO and most importantly, the United States.[19] The missile defense plan put in place under President Bush and ultimately altered by the Obama administration is an example of how important security assurances are to Poland and others. The missile defenses imagined by the Bush administration were aimed at defending against missile threats from Iran with a small number of weapons, not an overwhelming attack by Russia. As Poland and the Czech Republic would most likely not be targets of an Iranian nuclear attack, one must ask why these countries saw it in their interest to host missile defense installations, knowing that it would upset their large neighbor to the east. Most importantly, this is an effort to have American and NATO forces stationed on their soil to act as a trip wire in the event of Russian aggression. The assumption is that a potential aggressor (namely Russia) would think more seriously about attacking a state with American troops stationed than one without them. The reset policy with Russia which began at the beginning of the Obama administration worries these states as they see U.S.-Russian rapprochement as a zero sum game in which they lose. Tactical nuclear weapons represent an important symbol of the credibility of Article V to these countries.

The Russian war games discussed previously, further solidified these states' views that, in fact, Russia is a threat. The 2008 South Ossetia war was another example of Russian solidified Central European and Baltic States' views. While these countries would agree that there is little chance of a large scale, Fulda Gap-type invasion, they do worry about a small scale territory grab, possibly in the name of protecting Russian citizens from the aggressed country. For these reasons and others, the Baltic and Central European states are in near agreement that

[18] "Schroeder Accepts Pipeline Job" Washington Post, December 10, 2005
http://www.washingtonpost.com/wp-dyn/content/article/2005/12/09/AR2005120901755.html
[19] "Germany Opens Pandora's Box," Centre for European Reform: Miller, Robertson and Schake
http://www.cer.org.uk/pdf/bn_pandora_final_8feb10.pdf

the logic of 1967 and Gallois still holds; the United States must link itself to Europe in a concrete way and tactical nuclear weapons embody that link. For the reasons mentioned, the Central European and Baltic states tend to be universally against the removal of NATO's nuclear force and/or changes to doctrine.[20] There have been some indications that this is not an ideological point. Some Baltic and Central European have voiced interest in finding ways to bolster the alliance's, Article V commitments, without using nuclear weapons. As they are concerned about the security, number and posture of Russia's tactical nuclear arsenal, they are most likely in favor of a negotiated agreement limiting Russian weapons. In this context, it is likely they would support further reductions to the NATO mission under the right circumstances with key conditions.

Turkey

The Turkish government's views on NATO's nuclear force are unclear. Yet, there are many indications that Turkey is in favor of sustaining the status quo on tactical nuclear deployments. Given their position straddling Europe and the Middle East, it is clear why Turkey is not fond of talking openly about NATO's nuclear force. As it strives for strong relations with Iran and Middle Eastern states, a constant reminder that Turkey hosts US nuclear weapons on bases in Turkey is not in Turkey's interest. Furthermore, Turkey has made clear that as part of its "zero problems with neighbors" policy, it intends on strengthening relations with U.S. adversaries, Iran and Syria, among others. One manifestation of this is in Turkey's efforts to keep Iran from being directly named as the threat for which NATO's new missile defenses will be deployed.[21] This policy also manifests itself with regard to tactical nuclear weapons. Turkey, in the event of a removal of tactical nuclear weapons from other NATO members, Germany, Holland and Belgium, would be left to defend keeping the weapons with Italy (or without as Italy may agree to remove them as well). This has important ramifications on its relationships with Iran and Syria, as they would perceive a full throated defense of NATO's nuclear policy as an indication that they are viewed by Turkey, ostensibly a partner, as a threat. Turkey, while not publicly declaring its concerns, is most definitely threatened by the Iranian nuclear program. Yet, it strives to be an interlocutor between the West and Iran in the hopes of coming to a negotiated settlement.

Another reason many argue that it is wise to leave NATO's nuclear policy as is, is the worry that any change could lead to Turkey developing a nuclear program, especially if Iran's program continues to progress. In this sense, Jessica Varnum who recently wrote an article on Turkey and Proliferation correctly notes, "Turkey is both an obvious and a counterintuitive choice for a nuclear proliferation forecasting study."[22] Two factors she notes that would have positive impetus for Turkey to proliferate are: the credibility of NATO's security guarantees and a failure of Turkey to accede to the EU.[23] Regardless of whether or not a removal of tactical nuclear weapons from Turkey is in reality a weakening of NATO's security guarantee, it is the perception of the Turkish government that matters in deciding whether to proliferate. As the removal of tactical nuclear weapons and deteriorating relations with the EU are not impossible to fathom, it would be in NATO's interest to tread softly as Turkey, unlike the Baltic and Central

[20] Steven Pifer, et al. *U.S. Nuclear and Extended Deterrence: Considerations and Challenges*. 1 Vol. Washington, D.C.: The Brookings Institution, 2010 p.25

[21]*NATO's New Strategic Concept and Missile Defence*, Patel Avnish, RUSI online http://www.rusi.org/analysis/commentary/ref:C4CD023AD5314E/

[22] Mukhatzhanova, Gaukhar, and William C. Potter. *Forecasting Nuclear Proliferation in the 21st Century*. Vol 2, Stanford, Calif.: Stanford Security Studies/Stanford University Press, p. 229

[23] Mukhatzhanova, Gaukhar, and William C. Potter. *Forecasting Nuclear Proliferation in the 21st Century*. Vol 2, Stanford, Calif.: Stanford Security Studies/Stanford University Press. Pp. 251-252

European nations, has many options in assessing its potential strategic partners. This is not to say that Turkey is in danger of leaving NATO in the short term; certainly the U.S.-Turkey and NATO-Turkey relationships has weathered very serious disagreements with few long term consequences thus far. Yet, a nuclear Iran could dramatically alter the strategic calculus of the Turkish government, especially in the event of a broader proliferation cascade occurring in the Middle East in the wake of a successful Iranian nuclear program. The perception of the importance of NATO's tactical nuclear force undoubtedly factors into Turkey's position regarding of the Iranian threat.

For these reasons, Turkey's views should be considered most carefully. Turkey sits atop a very different geopolitical and identity condition than other member states. Its freedom to choose differing options is unparalleled among NATO members. Indeed, Turkey values its strategic relationship with the United States and the benefits of prestige that the weapons bring. Turkey, as its economy and stature in the world community grow, will only become more important to take its views into account. Turkey should be considered the lynchpin of any decision to remove NATO's nuclear force.

Arguments for the Status Quo: Maintaining NATO's Tactical Nuclear Force

Many in the United States and Europe see the debate over the removal of NATO's tactical nuclear forces as emblematic of the decreasing importance, loss of relevance and weakening cohesion of NATO. Furthermore, they argue, that the United States engagement and focus on the Middle East and Asia is an inexorable shift that is likely to increase. At the same time, European defense budgets are declining to the point where even Britain launched a public debate to consider dropping its nuclear deterrent for budgetary reasons. They fear that the nuclear sharing agreement is the "glue" holding the alliance together and without it, the Alliance would begin to erode precipitously. A change in the status quo would weigh heavily on NATO members' Article V commitments and for some, cast doubt on the credibility of US and other countries' commitments to the Alliance.

Many in favor of the status quo see the removal debate as an example of the European nations clamoring for the benefits of NATO without incurring the costs. The costs, in this case, are both financial and security-related. Not one country has advocated for both the removal of both the weapons *and* the U.S. nuclear umbrella. Therefore, it is clear, they want to continue to enjoy the benefits of the United States' linking its security with Europe but are not necessarily interested in bearing their share of the burden. Some have even argued that US popular support for NATO could decrease without a nuclear sharing posture in effect.[24] While some arguments put forth by those in favor of the status quo are legitimate, it seems this argument is tenuous. In discussing this research with those knowledgeable about international affairs but not specifically nuclear weapons, it was clear that few are aware of the current NATO force posture. Others claim that NATO must not give up a "bargaining chip" in the form of the 200-400 weapons deployed in NATO. This argument has little foundation as it is not NATO's tactical nuclear arsenal which drives Russian's tactical nuclear force posture. Of course, the two are linked, but Russia's overriding concern is NATO's conventional force. Therefore, the benefits of this bargaining chip are most likely overstated.

The strongest argument for keeping the status quo is spelled out in the 2010 Strategic Concept where it links the removal or reduction of U.S. forces with the repositioning or

[24] Off the record conversation with a former Defense Department official who was intimately involved in NATO and nuclear issues

dismantlement of Russian tactical nuclear forces. While the weapons currently deployed in Europe are of no military value, they do provide an increased level of assurance to states that feel threatened by Russia's large arsenal. This differs from the bargaining chip argument. The assumptions guiding this argument have not changed from the Cold War and track closely with Gallois' ideas. Although, it begs the question: would the US and/or NATO consider ever using nuclear weapons in the event of Russian aggression against, for example, a small piece of territory in Latvia? Proponents of the status quo would argue it may not even matter. The force's existence and the credibility it brings make such a situation less likely than it would otherwise be. These arguments show that those in favor of the status quo are focused on members' and potential adversaries' perceptions of the weapons and their benefit, than the use or capabilities of the weapons.

Arguments for Removal of NATO's Nuclear Forces

President Obama's Prague speech, calling for the elimination of nuclear weapons around the world, has affected the debate over the new Strategic Concept. This idea manifests itself quite clearly in the second key objective of the nuclear posture review: "Reducing the role of U.S. nuclear weapons in U.S. national security strategy."[25] From there, critics of NATO's nuclear forces see NATO's nuclear forces as an opportunity to demonstrate the United States and NATO's commitment to this objective. As the weapons are of little military value, if any, relative to the United States' strategic assets, many argue that it is in fact in line with America's nuclear posture to remove them. Second, many European countries, some of whom have ascribed to a vision of a nuclear free world before the Prague speech, see their removal as an opportunity to move toward the President's goal of a world free of nuclear weapons.

In addition to the President's call for a nuclear free world, those in favor of removal argued the removal demonstrates to non-nuclear weapon states party to the Non-Proliferation Treaty that NATO members are fulfilling their commitments to move toward disarmament. This argument was especially salient in the lead up to the NPT Review Conference as political pressure on nuclear weapons states to demonstrate their commitment to disarmament grew. While a removal of tactical nuclear weapons from Europe would certainly benefit the nuclear weapons states' standing among non-nuclear, non-NATO member states, the argument became less prominent after the NPT Review Conference of 2010 concluded successfully.

More broadly, opponents of the current posture argue that nuclear sharing embodies Cold War thinking that should have retired two decades ago. Threats from Russia and other countries, they argue, are not credible and it would never be in NATO's interest to escalate to nuclear weapons, if indeed, conflict did occur. Furthermore, they reject the political implications of the weapons' removal: the predictions of the deterioration of alliance cohesion are overstated at best and emblematic of NATO's larger problem of reliance on nuclear weapons for cohesion at worst. Indeed, without the removal of the weapons, dangerous rifts may open up within the alliance as countries like Germany move to unilaterally remove the weapons from their territory.[26] Opponents of the status quo focus on the diminished threats, anachronistic nature of NATO's posture and the potential non-proliferation benefits in making their case for removal.

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[25] Nuclear Posture Review 2010, page 2.
http://www.defense.gov/npr/docs/2010%20Nuclear%20Posture%20Review%20Report.pdf

[26] Meier, Oliver, and Paul Ingram. "A Nuclear Posture Review for NATO | Arms Control Association."Web. RefGrab-It. 12/4/2010 <http://www.armscontrol.org/act/2010_10/Meier-Ingram>.

Looking Ahead: Restructuring NATO's Nuclear Forces and Russia

Two key challenges emerge from the tactical nuclear weapons debate: updating and reorienting NATO's posture to reflect the current environment and reassuring allies with different concerns and threat perceptions that NATO's Article V and the United States' extended deterrent is still credible. Deciding the best way forward is to achieve an agreement with Russia which limits its tactical nuclear arsenal, is of great concern. These challenges are intertwined and more deeply, depend on conventional forces and are in many ways more complicated than previous successful arms control initiatives. In addition, as discussed earlier, the diversity of threat perceptions of Russia among alliance members is arguably greater that at any time in the past. This is not to say that the alliance's perceptions of Russia during the Cold War were monolithic, yet the uneven economic and political engagement (and dependency) with Russia among members creates an obstacle to achieving consensus on security issues in NATO as Russia figures most heavily. At the same time, however, maintaining status quo could lead to a crisis in the event of a successful move by one member state hosting nuclear forces on their territory.

While NATO has drastically reduced its nuclear forces in response to changes in the European security environment over the last decade, these changes have not gone far enough. In some ways, the policy has been "less of the same," which is to say that, not unlike the debate over tactical nuclear forces during the Strategic Concept Review, numbers of warheads have been the focus. The debate surrounding the removal of NATO's nuclear force is an important one that was not adequately resolved with the November, 2010 summit but it is not the only issue. NATO's Strategic Concept is a good start, but it is clear that new ideas about conventional and nuclear force posture are needed in order to reflect the concerns of and realities facing old and new members of NATO. Doing so may prompt ideas that lessen member's differences on the tactical nuclear weapons question. One worry is the potential for domestic politics to again affect NATO's nuclear debate. If a political party in one of the more anti-nuclear states, such as has happened in Belgium, is ever successful in achieving a ban on nuclear weapons on their territory, they could provoke a crisis with regards to NATO's nuclear policy. Surely, this is not the correct way in which NATO should go about devising its defense policies. In this vein, it may make sense to consider consolidating all of NATO's nuclear forces in two countries which tend to be more pro-nuclear: Italy and Turkey. This consolidation would ease the pressure from Germany, Belgium and others to remove all nuclear weapons while a more mature debate would be able to take place. Whether an official review of NATO nuclear, similar to the Nuclear Posture Review outside of the High Level Group, it is necessary in an open question, yet it is clear that the current policy does not reflect anything close to consensus. The language in the Strategic Concept surrounding nuclear weapons, as discussed above, is deliberately vague. Consolidation would also lessen the cost of securing the weapons and lead to fewer targets for terrorism and the potential for embarrassing incidents.

NATO's tactical nuclear weapons are universally tied to terms such as, "alliance cohesion" and "Article V commitments," among states that would like to see the weapons remain. It is clear that tactical nuclear weapons remain a potent symbol of NATO's, and specifically the United States', commitment to member states' security. This does not mean tactical nuclear weapons are the optimal way of ensuring cohesion. In fact, it is likely that other, conventional options, could assure members concerned in a more efficient manner. While NATO may be constrained in its options by joint declarations with Russia that limiting the scope of its deployments in former Soviet Republics, this does not mean it is devoid of other options. Reviewing these options, in the context of the CFE treaty, may yield important innovations in policy that can benefit and strengthen the alliance.

Last, negotiating an agreement or agreements with Russia with respect to tactical nuclear weapons should be a top priority in a post-New START context. While they are no panacea for NATO's security, such an agreement does have the opportunity to mend differences and bring greater consensus with regards to the question of tactical nuclear weapons and improve security and relations vis-à-vis Russia. A first step of consolidation on both sides with the beginnings of a verification regime could be a strong start. Data exchanges are an important consideration. It seems unlikely that an elimination of tactical nuclear weapons will be possible in the near term with Russia as its declining conventional strength is the main justification for its arsenal. Creating a context where this point is less salient will be difficult but it is still very important. This suggests that the CFE treaty would be another place in which to begin. All of these options on the table with regards to tactical nuclear weapons are fraught with problems and may limit the success of NATO to mitigate the threat of Russia's large and unwieldy tactical nuclear arsenal. All approaches must take into account the new, lower threat realities of today as the only path to reducing the Russian arsenal relies on convincing Russia that it should not be threatened by NATO. If NATO continues to signal its worries about the Russian threat, this will be more difficult. NATO to convince Russia that it should not feel threatened. The Strategic Concept of 2010 was a good start, but much more work is required to achieve a safer Europe, free of the threats posed by tactical nuclear weapons.

Seeing Deterrence through the Lens of Conflict Resolution

Mark Jansson[1]

The role and potential uses of deterrence in contemporary security strategy remain points of considerable academic interest. Given the diversity of contexts that deterrence will operate in and the increasing importance of maintaining productive relationships among states to address current international security challenges, it is useful to explore the effects that deterrence might have on other aspects of strategic engagement and problem solving. The field of conflict resolution, which sees relationships as key to problem solving, therefore provides a useful lens through which to view deterrence and nuclear deterrence. This brief glimpse at deterrence in the context of conflict resolution and highlights a number of challenges to finding the appropriate role for deterrence in the current international security environment and to reconciling nuclear deterrence with key nonproliferation objectives.

Introduction

Deterrence dominates the thinking and writing on nuclear issues. Nuclear weapons have become so strongly associated with the concept of deterrence that the industry habit of referring to a nuclear arsenal as a nuclear "deterrent" has persisted, even as the relationship between nuclear weapons to achieving some of the new goals for deterrence has become murkier and the salience of other political, legal and technical means of achieving the effect of deterrence has grown. Scholars have recently sought to recast the role of nuclear weapons and deterrence in a post-Cold War context and with particular emphasis on understanding the role of deterrence in preventing acts of terrorism and nuclear terrorism. This has led to more sophisticated thinking on how deterrence can improve security by reassessing what we are trying to deter and how we might go about doing it. Jeffrey Knopf, in a recent synthesis and review of the recent scholarship, refers to the new thinking as the "fourth wave" of deterrence literature.[2] This new scholarship has helped bring the concept of deterrence into relief against a contemporary backdrop. Some authors have explored more assertive approaches to deterrence and sought to identify new areas of application by broadening the target-base for retaliatory threats. Others have taken a dramatically different tack and explored varieties of deterrence that aim to diminish the motivation for carrying out acts of aggression by targeting its root justification or ideology.

The literature has done well to advance thinking on how deterrence might be applicable to addressing the threat posed by non-state and sub-state actors, but it has generally taken a threat-centric approach and devised new ways of using deterrence to address those threats. This is a useful approach for thought experiments. However, when it comes to translating the results

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[2] Jeffrey Knopf, "The Fourth Wave in Deterrence Research," *Contemporary Security Policy* 31, no.1 (April 2010): 1-33

of the experiment into policy recommendations, it can lead to overprescribing deterrence to the point at which it may become counterproductive, or, as the case of "deterrence by reframing" illustrates, articulating strategies in terms of deterrence that, ultimately, are better explained in other ways. Moreover, as Knopf concludes, the fourth wave could offer more if it becomes more specific and devoted more attention to defining boundaries for deterrence, in particular to the issue of what actions should be deterred.[3] However, the issue is actually more complex than that, and the reason is because deterrence does not exist in a vacuum. And while it is commonly acknowledged that deterrence is but one tool in a foreign policy toolkit, the analogy itself obscures the challenge of understanding how the tools are supposed to work together in addressing security challenges. In fact, the debate about whether, as a matter of U.S. declaratory policy, deterrence should be stated as the "sole" or "fundamental" role of nuclear weapons, begs a number of questions about what exactly we intend to do with deterrence. To that end, thinking in terms of a broader problem solving strategy can help begin to answer some of these questions regarding appropriate boundaries for deterrence. As an alternative to deriving deterrence needs from perceived threats, making the relationship between parties the focal point – in other words, taking a relationship-centric approach – can provide a helpful complementary perspective. Although this will not provide definitive answers to the question of what should be deterred and why, it may at least provoke the right kinds of questions as a step along the way.

This approach would seem appropriate because, today, deterrence must find its place within a foreign policy that must sustain fairly complex and multilayered relationships with other states, many of which are simultaneously cooperative and competitive with the United States as well as with one another. These relationships are not only variegated in nature, they will also change over time. To say that deterrence plays less or more of a "role" in international security does not go very far in elucidating exactly how this aspect of national security policy relates to others. The toolkit metaphor is similarly unhelpful, as it misleadingly implies that security challenges exist in a passive state – that is, to be worked on as if they are detached from thinking and responsive human beings. But relations between states are not so mechanical and they are never unidirectional. Furthermore, there are relatively few international security problems that one state can address singlehandedly on the strength of its sheer size and power. Grand strategies designed to deal with the monolithic threat emerging out of a global ideological standoff between two superpowers have given way to not-so-grand strategies to deal with the problems of regional competition for critical resources, transnational crime and terrorism, resource distribution, and building effective governance institutions and strengthening the rule of law. With the ideological polarization of the Cold War a full twenty years in the past, with global distributions of power continuing to even out, and with capability of just a few relatively resource-deprived individuals to pose urgent international security challenges, building fruitful relationships among states to tackle a wide range of problems is becoming an increasingly important, and increasingly complex, affair.

Foreign policy approaches geared toward pragmatic problem solving would be well-suited to this new environment. Looking beyond traditional international relations theories for new perspectives on how conflicts develop would therefore seem to be an appropriate step towards orienting a foreign policy that emphasizes problem solving.[4] It can also help answer questions related to how deterrence and nuclear deterrence fits into a foreign policy designed to deal with today's challenges. Indeed, contemporary goals for deterrence are diverse. They include, but are not limited to: deterring actions by states that are near-peers but not necessarily

[3] Jeffrey Knopf, "The Fourth Wave in Deterrence Research," 27

[4] See John Burton, "Conflict Resolution as a Political Philosophy," in *Conflict resolution theory and practice: Integration and Application,* ed. Dennis J.D. Sandole and Hugo van der Merwe (New York: Manchester University Press, 1993): 55-64.

enemies; deterring actions by states that are smaller, weaker and controlled by eccentric authoritarians; and deterring actions by terrorists within states that are actually considered friendly and within others that are decidedly unfriendly. Efforts to "assure" allies of their security can be added to that list, as specific objectives in this regard are derived in-part from perceptions of how well deterrence works or, more accurately in some cases, might work. There is a great deal of variance among these deterrence goals and the role of nuclear weapons in achieving these goals is not entirely clear in many cases. Although the 2010 Nuclear Posture Review report stated – four times, in fact – that the United States would only consider the use of nuclear weapons in "extreme circumstances" to defend "vital interests," it did not go very far in defining what the United States would regard as "extreme" or "vital."[5] Instead, these terms were explained only through reference to what kinds of weapons (nuclear, chemical, and biological) pose threats that could potentially be met with nuclear force. However, the historical use of nuclear weapons as equalizers that compensate for *conventional* imbalances suggests that questions about when, what and how to deter ought not be reduced solely to matter of what types of weapons adversaries hold or harbor intentions of acquiring. A lot depends on states' perceptions of others' intentions, and these perceptions are derived from the nature of the relationships among them.

The field of conflict resolution, which studies the dynamics of relationships in order to understand causes of conflict, can therefore provide a useful perspective on how deterrence fits into an international security landscape like the one we have today, in which deterrence goals vary and relationships among states are fluid and often determined by context. Simply presuming that deterrence of any kind is inherently complementary to other aspects of statecraft simply because we imagine it as such would be uncritical. On the other hand, assuming that there is no role for deterrence, or even nuclear deterrence, would be equally doctrinaire and equally unhelpful. This paper will therefore briefly introduce conflict resolution as a field of study and practice, then use the lens of conflict resolution to make a few observations about what role deterrence can play in a broader problem-solving framework, and conclude by highlighting a few dilemmas specific to nuclear deterrence.

A Primer on Conflict Resolution

By way of introduction, conflict resolution is an academic discipline and a field of practice. As an academic discipline, it is interdisciplinary by nature, drawing largely from political science but also from other social sciences. It takes conflict as the subject of study and seeks to develop theories to explain the emergence and dynamics of various conflict types – from the interpersonal to the international – in order to develop more sophisticated analyses and problem-solving recommendations than what can be achieved by treating conflict as a mere phenomenon that occurs when certain conditions are met, as can be the tendency for other political science disciplines that seek to understand and predict a broader array of state behaviors. To some, conflict resolution represents a response to the shortcomings of idealist and realist theories of international relations. John Burton, for example, rejects realism on the grounds that it lacks explanatory power when it comes to conflict, arguing that "what was termed 'political realism' was realistic only in the limited sense that it was practice . . . failures, such as revolutions and wars, could not be explained except by failure to employ sufficient power." Idealism, though more useful in his view, is similarly lacking a theoretical explanation of conflict.[6] Although conflict resolution provides no unified theory of conflict and thus struggles

[5] Office of the Secretary of Defense, *Nuclear Posture Review Report*, April 2010, viii, ix, 16, 17
[6] Burton, "Conflict Resolution as a Political Philosophy,"57

as much as other social science disciplines in building predictive power, it nonetheless offers some perspective on the emergence, escalation and persistence of conflict, as well as its psychological dimensions.

The reality, however, is that conflict resolution theories have not, and likely will not, supplant realism or other international relations theories anytime soon. Rather, to the extent that conflict resolution theory and concepts play a role, they will likely be complementary to insights from international relations and comparative politics. Indeed, the degree to which conflict resolution should be mainstreamed or absorbed into other disciplines is the subject of some debate. Many of the distinguishing characteristics are indeed quite subtle and are perhaps best expressed in terms of degrees of emphasis on certain ideas or in the way in which certain aspects of conflict are accounted for. Nevertheless, to set the tone for what follows, a few of its distinguishing attributes are worth mentioning, namely: (1) its acceptance of conflict as a natural and often healthy part of a broader process of change; (2) its concerted efforts to account for the effects of power imbalances; (3) its emphasis on developing non-zero sum solutions to problems; and (4) its focus on root causes and interest in transforming overall relationships between parties. Of course, none of these features by themselves differentiate the conflict resolution perspective from others in any qualitative sense; these are by-and-large differences in degree of concern or appreciation. They are, however, significant enough to make the lens of conflict resolution a useful complement to other ways of viewing international conflict. More to the point, this means that ideas from the field of conflict resolution can be potentially valuable assets in understanding how deterrence, and nuclear deterrence, can play a role in a foreign policy oriented for problem solving.

Contextualizing Deterrence within a Conflict Resolution Framework

The question remains as to what conflict resolution has to offer in terms of perspective on deterrence. So what follows attempts to help illustrate how deterrence fits into a problem solving framework by placing it into a model that depicts asymmetric conflict escalation. Selecting an asymmetric model makes sense, as the conflicts of most interest to the nuclear community, if not all conflicts involving the U.S. military, could fairly be described as asymmetric in nature. This visual aims to provide a frame of reference to begin to further explore the effects and implications of efforts to deter threats – that is, beyond the issue of whether or not deterrence of a particular action was actually achieved. To that end, the following model, though intuitive, adds some context.

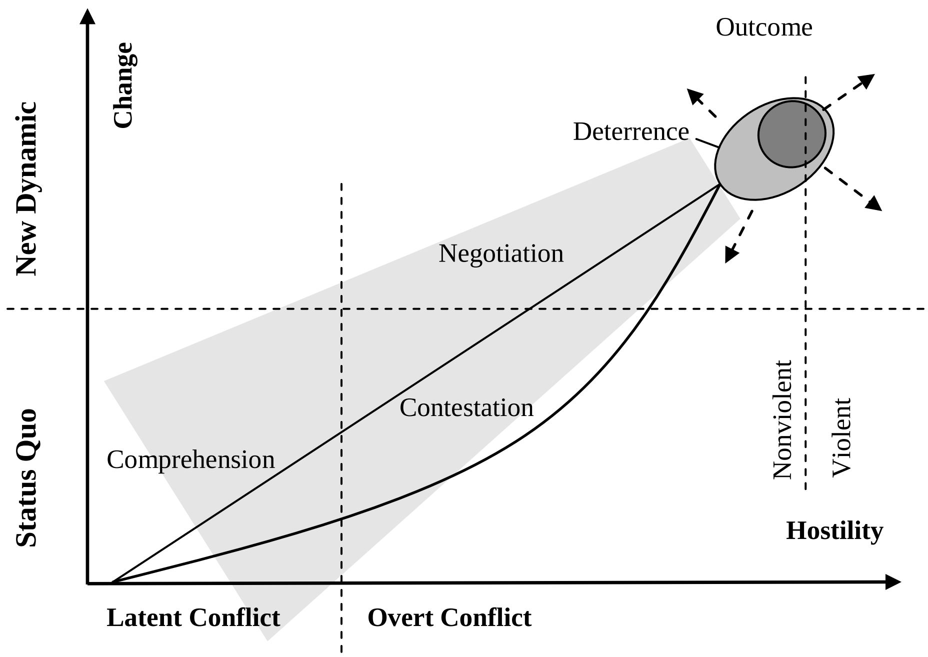

Figure 1: Adaptation of Curle's asymmetric conflict escalation model.

This model, adapted from one originally developed by Adam Curle, depicts the evolution of conflict from its beginnings as latent frustration to its resolution (or not) post-conflict, with the *x* axis capturing the degree of hostility and the *y* axis capturing the degree of change to the status quo.[7] The trajectory of the conflict is represented by the diagonal line that cuts across the various stages of change and, as a hypothetical alternative, by the curved one just beneath it, which illustrates how the ability of a more powerful party may be put to use to frustrate attempts to bring about change to the status quo. According to Curle, conflict is ultimately rooted in the initial comprehension of the weaker party that the status quo is problematic for them. In the event that the aggrieved party or parties decide to contest the status quo, pursuits will lead to a confrontation and eventually some form of negotiation. This negotiation may be pursued in earnest, or, more ominously, consist of little more than repeated position statements and recriminations. Whatever form the negotiating process takes, if it fails to produce a change to the status quo that is sufficiently agreeable to both sides, then violence emerges as the next logical step – that is, unless one or both parties are deterred from attacking. The role of deterrence is therefore represented by the gray oval and, within it, the dark gray oval, which represents the role of nuclear deterrence in preventing the most extreme forms of violence. Finally, the gray area surrounding the line of trajectory narrows, which narrows as the relationship becomes more hostile, reflects the observation that problem management options become increasingly limited as conflict increases in intensity, as efforts to sustain peaceful relations give way to de-escalation tactics and, eventually, war limitation efforts.[8]

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[7] Adam Curle, *Making* Peace (London: Tavistock, 1971). Curle's model was originally designed to depict how relationships characterized by asymmetries of power can become more symmetric through a process of contestation of conflict. It was simpler and did not involve the role of deterrence, let alone as a pivot point towards violent or nonviolent outcomes.

[8] This is adapted from the "hour glass" model used to depict narrowing peacemaking capacity and alternatives during conflict escalation. See Oliver Ramsbothan, Tom Woodhouse and Hugh Miall, *Contemporary Conflict Resolution*, (Cambridge, MA: Polity Press, 1995): 12

This is a simple and neatly theorized representation of how conflicts progress from their psychological beginnings in the consciousness of change-minded individuals to their potentially violent conclusions. Unfortunately, reality is not nearly that simple. To begin with, the trajectory of conflict escalation is unlikely to be as linear as the straight diagonal line suggests, especially when power differentials exist. Indeed, it is more likely that the trajectory is depressed, at least in the beginning, with little change occurring for as long as the more powerful party can stave it off, after which time an event resulting in a more rapid escalation may result. Alternatively, the impetus for challenging the status quo could disappear altogether for a variety of reasons. The depiction is nonetheless helpful, as it illustrates that deterrence can indeed play a pivotal role in managing conflict. Just as importantly, however, it shows that conflicts go through considerable evolution before deterrence enters the picture as a tactical response. The dilemma for deterrence, especially nuclear deterrence, is that the timeline for preparing for scenarios in which nuclear threats are relevant overlaps considerably with the earlier stages of conflict escalation in which there may not necessarily be a need or a role for deterrence – be it nuclear or otherwise. How efforts to deter foreseeable yet still hypothetical problems affect efforts to deal with current ones is, to a large extent, a matter of perception – and perception, of course, is fundamentally linked to psychology.

Psychological Aspects of Conflict and Deterrence

From a conflict resolution standpoint, understanding how individuals receive, process and interpret information is vitally important to understanding conflict itself. Biases that undermine objectivity must be understood, as these can have a profound influence on decision making at crucial moments during conflict and, moreover, on how parties perceive one another, their stakes in the conflict, and prospects for finding a solution. Previous literature on nuclear deterrence has explored psychological factors that influence political leaders' decision making under different scenarios involving real or potential conflict.[9]

However, it is important to take a step back from crisis scenarios and think about psychology and deterrence with respect to the development of relationships between states over time. In that regard, it was observed long ago that perception is often skewed when people make 'rule of thumb' judgments based on incomplete information in ways that can affect the overall trajectory of relationships between parties and thus the effects of deterring threats. The work of Daniel Kahneman and Amos Tversky on heuristics revealed several biases that tend to undermine objectivity. For instance, the availability of an image – that is, the ease with which it can be conjured up and visualized – influences how likely people are to believe that it will occur. Moreover, an image or scenario will be deemed more probable if it is apparently representative of a wider set of known or believed characteristics.[10] Working together, these heuristic biases may either accentuate or mediate the effects of deterrence on broader problem-solving efforts. On one hand, these biases may actually amplify the credibility of deterring threats beyond what would be objectively justified, as one party may become over-convinced of the capacity and willingness of the other to follow through on threats to defeat or respond to acts of aggression. Such cognitive quirks therefore can work to make deterrence threats more potent. On the other

[9] See Robert Jervis, Richard Lebow and Janice Gross Stein, *Psychology and Deterrence*, (Baltimore: Johns Hopkins, 1986)

[10] Daniel Kahneman and Amos Tversky, "Judgment under Uncertainty: Heuristics and Biases," *Science* 185, no. 4157 (Sep. 27, 1974): pp. 1124-1131. http://www.math.mcgill.ca/vetta/CS764.dir/judgement.pdf. They also identified an *affect* heuristic, which describes the way positive associations make with a choice seem objectively beneficial, whereas negative associations make it seem riskier.

hand, taking a step back to get a broader view of the relationship between parties, these biases can also accentuate threat perceptions and reinforce enemy images in ways that undermine the ability to develop problem solving approaches that address core issues, identify non-zero sum solutions and, ultimately, make resorting to deterrence seem more necessary than it actually is. Furthermore, there are other psychological phenomena that can lead to the persistence of hostility and thus undermine problem solving. For example, a general *confirmation bias,* which causes individuals to ignore information that conflicts with their pre-existing beliefs about others and overvalue information that confirms those beliefs, and the *fundamental attribution error*, which describes the tendency to believe that another's actions are better-explained by their innate personal characteristics than by situational factors.[11] Moreover, recent findings in the field of evolutionary psychology have revealed another layer of complexity, as they point to the conclusion that the variations exist in how the human brain deals with risk are actually influenced on a very fundamental level by environment, emotions, and certain physical traits that are unique to individuals. The upshot from this research is that the problem of potential mismatches in risk calculations and tactical mistakes among leaders at the crisis stage of conflict is *by nature* irresolvable.[12]

Whether or not all of this necessarily makes deterrence, or nuclear deterrence for that matter, not worth trying is, of course, another matter. Indeed, these biases can stymie even the most thoughtfully-conceived problem solving approaches, even those that are designed to be as cooperative and non-threatening as possible. In fact, one might suggest that once conflict arises, the difficulty inherent in altering perceptions points to the conclusion that establishing red lines is better done sooner rather than later. If nothing else, establishing red lines early may cap the ambitions of an adversary. Conversely, it is arguable that this kind of thinking is exactly the problem, as making threats for the sake of deterrence prematurely can solidify perceptions of innate and immutable hostility – a perception that does not auger well for creative problem solving while deterrent threats maintain the status quo. Actions taken with the intent to deter can signal to a party that the other lacks either confidence or a sincere interest in addressing current and future problems through other means. A "rush to deter" can therefore give the appearance that one or both parties have effectively resigned themselves to disagreement and an antagonistic relationship for the foreseeable future. This could potentially, though perhaps not necessarily, undermine the credibility of cooperative problem-solving gestures and, ultimately, their effectiveness. In this way, an over-emphasis on deterrence may enfeeble diplomacy and other problem-solving methods.

Although it is fair to point out that making "credible" threats (or simply demonstrating the ability to make threats credible) for the sake of deterrence probably does not do much to help convince others of a state's commitment to solving problems without force or confidence in its ability to do so, it does not necessarily follow that the idea of deterrence is therefore itself the problem. Indeed, to the extent that it allows a party involved in a dispute to feel assured that they can prevent the other from taking action that could dramatically undermine their position (if not dominate them altogether), deterrence can engender some degree of poise, which may in-turn open up more problem solving options than what might otherwise be the case. More fundamentally, the causes of conflicts go beyond the observation of one party that the other has an interest in deterring them from something someday. The main point is that – regardless of

[11] Dean Pruitt and Sung Hee Kim, *Social Conflict: Escalation, Stalemate and Settlement (Third Edition)* (New York: McGraw Hill, 1994), 158-160. See also Teresa Hayden and Walter Mischel, "Maintaining trait consistency in the resolution of behavioral inconsistency: The wolf in sheep's clothing? *Journal of Personality* 44, (1976): 109-132.

[12] Bradley Thayer, "Thinking About Nuclear Deterrence Theory: Why Evolutionary Psychology Undermines its Rational Actor Assumptions," *Comparative Strategy* 26 (2007): 311-323

whether deterrence is employed sooner or later, or with ambitious or reserved goals in mind – the effects of deterrence go beyond whether or not a given act of aggression is carried out to encompass other effects on parties involved and inform the narratives that evolve on both sides. Indeed, there is still room for more for more research to explore how actions undertaken to deter certain threats affect perceptions of the overall relationship over time. This again raises the question of what the boundaries of deterrence should be in terms of its mode of application and its goals.

Finding Boundaries

As Knopf noted, there is a preference in the United States for exploring forms of "unidirectional" deterrence vis-á-vis rogue states and terrorist – that is, aiming to assure that others are deterred from taking certain actions while the United States is not.[13] The realization of "unidirectional" deterrence would thus guarantee unencumbered freedom of action for the United States without fear of reprisal. Although this may seem intuitively appealing and even appropriate for dealing with terrorists, it is probably not realistic to expect that this can be achieved, let alone sustained. Moreover, at its extreme, structuring the environment to suit the interests of one party in such a way that others have no choice but to conform or be penalized, though it may impose a new and improved status quo, does not constitute problem solving method per se.

Along these lines, it is therefore important to distinguish two forms of achieving what is referred to as "deterrence by denial." This concept is commonly understood as an alternative to "deterrence by threat of punishment." Whereas the latter seeks to produce the effect of deterrence by threatening a consequence for an action if it is carried out, the former seeks to achieve the same effect by making the other doubt that certain acts of aggression will even be successful in achieving their envisioned effects. However, there are subtle but significant differences between denying a party the advantages of carrying out an attack by: (a) demonstrating the ability to withstand the attack, or (b) demonstrating the ability to prevent the other from successfully executing the attack at all. The operational prescriptions corresponding to these two approaches are indeed distinct: developing resiliency capabilities are required for the first; developing countermeasures to defeat attacks are required for the second.

There is an understandable appeal of pursuing both forms of deterrence by denial, especially the ability to deny benefits by defeating an attack, as this promises political leadership the most reassurance. However, to the extent that assuredness in one's ability to deter certain acts that would have unacceptable effects can engender composure among leaders that aids other efforts to address root causes of problems, it would seem to be most helpful if that assuredness was shared. The effort to deny benefits by deploying capabilities to defeat attacks, when pursued to its logical extent, would seem to induce the risk of forcing weaker parties to resort to asymmetric responses that will be increasingly hard to prevent through deterrence and, failing that, predict and defeat.[14] Pursuing this version of deterrence can indeed become a highly demanding task to implement and sustain. Furthermore, seeking to prevent contestation altogether by denying another the ability to contest at all makes it difficult to distinguish deterrence by denial from outright dictation of terms. This may not seem like a bad thing at all when dealing with "rogue" states or sub-state actors. However, from a problem-solving perspective, the trouble is that framing the conflict in these terms can exaggerate the threat by

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[13] Knopf, "The Fourth Wave in Deterrence Research," 3

[14] For instance, it's easy to imagine a desperate state such as North Korea going beyond its historical pattern of selling arms to potential terrorists to committing acts of terrorism directly.

prejudging every move taken by the other as an act of defiance. Indeed, many of Iran's responses to pressures from the United States, and even the Iranian regime itself, are often described in exactly this way. While there is no denying the hostility between the United States and Iran, it is not helpful for either side to reduce relations to acts of either compliance or defiance, or, likewise, oppression or surrender. The problems arising out of these oversimplifications are compounded when each apparent act of defiance by one side is automatically interpreted by the other as a demand to find a new way of deterring similar actions in the future, especially if this inference alone serves as the justification for evermore ambitious deterrence efforts down the road. The onset of a cycle of deterrence expansion and failure also risks making bolstering deterrence an end in itself as opposed to a means to a better outcome.

Of course, none of this is not to suggest that striving to deter certain actions necessarily precludes the pursuit other problem-solving approaches, but rather to point out the conceptual and practical problems with thinking of deterrence *as* problem solving. Indeed, pursuing unidirectional deterrence may ultimately limit policy innovation in some cases. Finally, the conflation of deterrence with problem solving is especially problematic when it comes to nuclear deterrence, as contesting the grounds upon which nuclear-level deterrence would be deemed necessary stands as one of the most important challenges to take up in the broader effort to discourage other states from acquiring nuclear arsenals of their own.

Nuclear Weapons and Perceptions of Nuclear Need

In the nuclear realm, there is an added complication arising from the fact that using nuclear weapons for deterrence is in tension with the nonproliferation norms as well as legal obligations under the Non-Proliferation Treaty (NPT) to pursue disarmament. This raises a fundamental question of who may avail themselves of nuclear protection and who may not. While the NPT acknowledges five nuclear weapon states, who are nonetheless still obliged to pursue disarmament, the interest of non-nuclear weapon states in having nuclear protection (either with their own weapons or others') raises difficult issues. At one time, "extended deterrence" arrangements in Europe and East Asia, developed as a means of obviating the perceived need of its allies to develop nuclear weapons to deter attacks from larger powers during the Cold War, constituted a sensible strategy for minimizing the spread of nuclear weapons around the world. Although these arrangements have long outlived the threats that they were originally designed to address, in some cases, new security problems have emerged that arguably justify the need for the United States to continue to offer the benefits of nuclear protection to certain allies. Unfortunately, some of these problems have become increasingly difficult to distinguish from other, perhaps equally compelling, security problems in regions where acquiring nuclear protection – either through states' acquisition of their own weapons or through extended deterrence arrangements – would be more problematic to develop and sustain. The Middle East and East Asia are areas of utmost concern in this regard, as Iran continually falls short in its efforts to demonstrate the peaceful nature of its nuclear program and North Korea continues to build a nuclear arsenal after withdrawing from the NPT. Nonetheless, while the desire for others in each region to want a nuclear counterpoint of their own is understandable intuitively, policy discourse (among government officials and academics alike) that describes this outcome as inevitable can exacerbate the issue by inadvertently planting seeds of nuclear need in the minds of political leaders in both regions. Threats aimed at Iran and North Korea of looming "cascades" of proliferation not only evince a startling lack of confidence and interest in problem solving frameworks in each region, they also imply that acquiring nuclear protection is an appropriate, if not *automatic*, response to the problems posed by a rival with nuclear weapons or even one with latent nuclear capability.

According to Benoít Pelopidas, such determinism is derived partly from a "proliferation narrative" that elevated the very concept of "proliferation" from simile to metaphor, resulting in a skewed perception of the history of nuclear weapons as one of linear and self-begetting spread.[15] More simply put, the proliferation narrative obscures the fact that a state's decision to acquire nuclear weapons is just that – a decision, not a predetermined effect – and these decisions can be influenced. Although the growing interest in nuclear power in the Middle East is often suspected to be a "hedging" response to the prospect of Iranian acquisition of a nuclear weapon, political leaders in the region have maintained that their interest in nuclear power are economic. Of course, as NPT signatories, these leaders would be reluctant say otherwise. Nevertheless, regardless of whether or not the hedging explanation is correct, the fact is that it is largely derived from the deduction that nuclear problems require nuclear answers. In some cases, this might in fact be true. That does not mean, however, that is *necessarily* true. As some have argued, the actual problems that may arise out of Iran's acquisition of nuclear weapons are arguably quite manageable. Instead of militarizing the region through arms sales or implicitly endorsing it with bold talk about the need for deterrence, the region would be better served by the pursuit of treaty-based approaches to reaffirming the inviolability of borders and building forums for regional dispute resolution.[16] Such an approach could also make preoccupations with deterrence in times of crisis a lot less salient in the minds of political leaders in the region as they consider their strategic options. This is obviously a lot easier said than done, and concerns about worst scenarios involving nuclear-armed adversaries will not disappear with the advent of robust conflict management programs built on treaties. Nonetheless, thinking beyond deterrence, choosing words more carefully, and aggressively developing other forums for addressing regional conflicts may pay important dividends as leaders consider the strategic hedging incentive to launching a civilian nuclear program and when they consider the prospect of converting these programs to nuclear weapons programs.

Similarly, the task of "assuring" allies in East Asia is becoming more demanding as time goes by and tensions with nuclear-armed North Korea remain. While the goals of assurance go beyond convincing allies that they do not need a nuclear weapon of their own, it is widely assumed that these arrangements pay nonproliferation dividends. However, it is not entirely clear how nuclear weapons would help South Korea or Japan deal with the challenge posed by North Korea. Despite the overwhelming superiority of the combined United States and South Korean forces, which already include U.S. nuclear weapons, and the repeated affirmations of solidarity between the two countries, problems with North Korean "provocations" remain. Short of South Korean acquisition of a nuclear weapon or redeployment of U.S. nuclear weapons to the peninsula, there are few options left for the United States and South Korea to up the ante. Perhaps it should be unsurprising that some in South Korea continue to raise the prospect of taking one of these two steps. On the other hand, there is an argument to be made that deterrence has already delivered just about all that it can and that deterrence "failures" only underscore that point. From this view, the more pressing need would be to find a way to re-engage North Korea through diplomatic channels to help address its motivations rather than merely trying to threaten greater consequences to change its incentives.

A dual-track approach that aims to address North Korea's motivations for aggression through engagement as well as its incentives as it considers acting upon these motivations through deterrence would seem to make sense. However, two caveats with respect to the

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[15] Benoít Pelopidas, "The Oracles of Proliferation: How Experts Maintain a Biased Historical Reading that Limits Policy Innovation," *Nonproliferation Review* 18, no. 1 (March 2011), 302-303

[16] See Vali Nasr and Ray Takeyh, "The Costs of Containing Iran," *Foreign Affairs* 87, Issue 1 (Jan/Feb 2008): 85-94

deterrence track are worth noting. The first follows from the points made above about the problems associated with solidifying perceptions of hostility. The only thing left to be said in this regard is that, however deserving North Korea may be of retaliation or threats thereof, a bankrupt country with no semblance of political accountability whatsoever likely has more leverage and less to lose in sustaining a cycle of provocations followed by demonstrations of resolve. The second caveat, and more to the point here, is that threatening a regional arms race in order to compel North Korea to give up its nuclear weapons program seems to have already created an echo chamber in which the benefits of others acquiring a nuclear counterpoint are simply assumed. Again, while there is no-doubt some attractiveness to this logic, it does not need to be the logic that is embraced. In fact, insofar as preventing the spread of nuclear weapons and fulfilling NPT commitments remains a policy goal of the United States and its allies, there are strong reasons to resist this logic and approach the issue another way.

The pressure in both regions is likely to increase for as long as nuclear problems with Iran and North Korea persist. As this occurs, rhetoric that proclaims the inevitable spread of nuclear weapons through a process of chain reaction may offer some marginal deterrence benefits by devaluing the advantages that adversaries' nuclear arsenals (real or prospective) will provide. However, it can also be counterproductive insofar as it equates deterrence to problem solving, as this would scuttle important discussions pertaining to what tangible security benefits nuclear protection would actually provide while at the same time increasing the risk of creating a self-fulfilling proliferation prophecy. This is by no means a call for deliberate naiveté about the potential spread of nuclear weapons, but rather to suggest caution in framing security issues in such a way that may provide a justification for this result by presuming is inevitability. Thinking beyond deterrence and taking a broader view of problem solving would help avoid this trap. Moreover, regardless of how the security issues are framed or described, from a nonproliferation standpoint, it is critical to maintain an aggressive and enduring commitment to developing problem-solving approaches in each region that deal with the concrete security issues that may be affected by the acquisition of nuclear weapons by one or more states. Absent that, the logic of deterrence and appeal of nuclear weapons acquisition will be more likely to dominate the political calculus regionally, and at the possible expense of other diplomatic efforts – not to mention the cause of preventing the spread of nuclear weapons.

Conclusion

The foregoing discussion obviously does not tell the whole story about deterrence, let alone the role of nuclear weapons in deterrence, but it does draw attention to the importance of pursuing the full range of problem solving approaches and thinking more critically about how (and when) deterrence fits in. Limitations of deterrence notwithstanding, there are still plenty of reasons to be skeptical about relying on skillful diplomacy and well-intentioned international forums to prevent, manage and solve problems among states. Although this look at deterrence has been deliberately critical, there is no denying that maintaining the ability to hold parties accountable for their actions and thereby deter those actions that are deemed unacceptable makes sense. And while certain forms of contestation may be acceptable and even helpful over the long term, others are clearly not, and therefore ought to be deterred.

However, this brief glimpse at deterrence through the lens of conflict resolution suggests that it is important to observe the limitations of deterrence in being able to solve problems and the potential for unintended consequences by emphasizing deterrence too much. Deterrence may not necessarily complement these other methods and overemphasizing the importance of deterrence is not necessarily consequence-free. While the nuclear policy community's focus on deterrence is understandable given the close historical association of nuclear weapons with this role, it is important for nonproliferation advocates to think beyond deterrence capability in making a compelling case for why states do not need nuclear weapons to provide for their security. Likewise, assertions by nuclear weapon states that their arsenals are used every day for deterrence probably overstate both the role of deterrence and the role of nuclear weapons in providing it. And although determining the appropriate boundaries for deterrence is a complex task that will not lead to any definitive answers that satisfy everyone, viewing deterrence through the lens of conflict resolution can help policymakers begin to ask better questions in terms of where, when and how deterrence fits into problem solving plans. This by no means suggests that all conflicts are amenable to resolution through peaceful or non-threatening means, but rather that, from a conflict resolution perspective, a judicious approach to pursuing and even talking about deterrence is a preferable one.