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**PROGRAM ON NUCLEAR POLICY ALTERNATIVES**

**PROGRESS REPORT, July 1999 - June 2000**

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## SUMMARY

During the past year, our activities have focused primarily on the following goals:

- Down-sizing Russia's nuclear-weapons-production establishment in a way that reduces the danger of Russian nuclear materials and technology going onto the black market
- Strengthening the security of nuclear weapons and materials in Russia
- Converting or shutting down Russia's three remaining operation plutonium production reactors
- Ending the production of fissile material for weapons worldwide
- Taking U.S. and Russian nuclear missiles off hair-trigger alert
- Blocking deployment of a provocative and ineffective national-missile defense
- Dealing with the objections raised to the Comprehensive Test Ban Treaty
- Designing a more proliferation-resistant nuclear fuel cycle
- Raising the level of the nuclear-policy debate in South Asia
- Clarifying the hazard from depleted uranium munitions

We also hosted Chinese, Indian, and Pakistani physicists and a South Korean nuclear engineer for post-doctoral training and research and continued to edit the international journal, *Science & Global Security*.

The Program on Nuclear Policy Alternatives is co-directed by Harold A. Feiveson and Frank von Hippel. During 1999-2000, its other researchers were: **Oleg Bukharin**, Research Staff Physicist; **Jungmin Kang**, Research Associate, South Korean nuclear engineer; **Zia Mian**, Research Staff Physicist from Pakistan; **Robert Nelson**, Research Staff Physicist (joined our group in June 2000); **M.V. Ramana**, Research Associate from India; **Sharon Weiner**, Research Associate; **Zhang Hui**, Chinese physicist and SSRC/MacArthur Peace and International Security Fellow; **Abdul Nayyar**, Visiting Professor of Physics from Quaid-e-Azam University, Pakistan (summers 1999 and 2000); **R. Rajaraman**, Visiting Professor of Physics from Jawaharlal Nehru University, India (summer 2000); **Joshua Handler**, PhD student, Woodrow Wilson School; and **Kenneth Luongo**, Visiting Research Collaborator and Director of the Russian-American Nuclear Security Advisory Council (RANSAC).

## I. POLICY RESEARCH AND ADVOCACY

### **Down-sizing Russia's nuclear-weapons-production complex**

Eight years after the breakup of the Soviet Union, scientists and workers in some of Russia's ten fenced cities, the core of the former Soviet Union's vast nuclear weapons complex, are in deep economic distress. This distress increases the danger of nuclear-weapons experts selling nuclear materials and knowledge on the black market.

The U.S. has mounted a number of programs to reduce these dangers. A commercial agreement to buy 30 tons of surplus Russian weapons uranium annually and have it blended down to the low-enrichment levels used in nuclear power-reactor fuel is providing income to some of the nuclear cities. The U.S. Department of Energy has mounted a major program to strengthen the security of Russian nuclear materials. And the U.S., in collaboration with the European Community and Japan, has funded a program to pay key Russian weapons scientists to carry out non-weapons R&D projects.

These projects have been effective palliatives, but the only long-term solution will be for Russia to drastically down-size its nuclear complex. The Russian government is doing so but is afraid to simply lay off large numbers of employees in its closed nuclear cities if they are not able to find new jobs. In 1998, therefore, the U.S. launched the "Nuclear Cities Initiative (NCI)," headquartered within the Department of Energy (DoE), designed to create jobs for excess weapons workers in Russia's closed nuclear cities. This program was proposed by our program, in collaboration with the Russian-American Nuclear Security Advisory Council (RANSAC).<sup>1</sup>

The NCI has not received Congressional or high-level Administration support, however. As a result, instead of increasing its funding in fiscal year 2000, Congress cut its funding from \$12.5 million to \$7.5 million.

PNPA therefore organized and hosted an international conference, "Helping Russia Downsize its Nuclear Weapons Complex" (March 14-15, 2000), to lay the basis for a redesign of the NCI. The conference was made possible by a grant from the JJJ Foundation, which also made it possible to hire Sharon Weiner as a post doctoral researcher to work full-time on this problem.

In addition to organizing the conference, Weiner researched and wrote a detailed newsletter about activities in Russia's Nuclear Cities (*Nuclear Cities News*). This brought together for the first time the available information on U.S. activities in Russia's closed Nuclear Cities and established a common reference point for policy analysis. The newsletter was widely welcomed and material from it is now being used by governmental and non-governmental organizations as well as academic researchers. Weiner is currently working on turning the newsletter into a database that can be accessed through the web.

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<sup>1</sup> "Retooling Russia's Nuclear Cities" by Oleg Bukharin, Matthew Bunn, Jill Cetina, Ken Luongo and Frank von Hippel, *Bulletin of the Atomic Scientists* 54, September/October 1998, pp. 44-50.

The participants in the conference included scientists from Russia's nuclear cities and their counterparts from the U.S. national laboratories; officials from the Russian and U.S. executive branches; U.S. Congressional staff; program officers from interested U.S. private foundations; European scientists interested in creating an EU NCI; U.S. academic and NGO experts; and journalists. A report containing the conclusions we drew from the conference has been written and translated into Russian.<sup>2</sup>

Preparations for the Conference helped crystallize a new approach to the problem of down-sizing the Russian nuclear complex. Thanks to the leadership of Senator Pete Domenici, this approach has been embodied in a bill, *The Nuclear Weapons Complex Conversion Act of 2000*.<sup>3</sup> This bill provides substantially-increased funding in fiscal year 2001 to help Russia down-size its nuclear complex, and a continuing high level of funding thereafter if the Russian Ministry of Atomic Energy (MinAtom) provides "verifiable milestones" for the downsizing effort. At the Conference, PNPA and RANSAC agreed with MinAtom First Deputy Minister Lev Ryabev on a joint workshop which was held in Obninsk in late June to start the process of identifying the "verifiable milestones."

A key related problem, which has not been sufficiently studied by nonproliferation experts outside of the Russian government, is how to restructure and consolidate nuclear-weapons production activities in Russia. MinAtom's current down-sizing program is based on assumptions of relatively large stockpiles and high levels of funding. In reality, Russia's strategic weapons delivery capacity is expected to continue to decline and funding is likely to remain scarce. Bukharin has therefore conducted an analysis of MinAtom's down-sizing options. He proposes a long-term strategy that emphasizes:

- Synchronization of the complex's downsizing with nuclear warhead stockpile reductions;
- Rapid demilitarization and environmental cleanup of as many facilities as possible to facilitate defense conversion; and
- Clear separation of defense and non-defense activities.<sup>3</sup>

He has also published a comparative analysis of U.S. and Russian complex consolidation activities in the Russian-language journal, *Yaderny Kontrol*.<sup>4</sup>

Bukharin is also the principal author of the NRDC report *New Perspectives on Russia's Ten Secret Cities*, which provides an up-to-date overview of the closed nuclear cities and their

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<sup>2</sup> Oleg Bukharin, Harold Feiveson, Frank von Hippel, Sharon Weiner, Matthew Bunn, William Hoehn and Kenneth Luongo, *Helping Russia Downsize its Nuclear Complex: Focus on the Closed Nuclear Cities* (Princeton University, June 2000).

<sup>3</sup> Oleg Bukharin *Downsizing of Russia's Nuclear Warhead Production Infrastructure*, PU/CEES Report No. 323, 23 p.; presented at the Princeton Conference "Helping Russia Down-Size Its Nuclear Complex" (March 14-15, 2000).

<sup>4</sup> Oleg Bukharin "Consolidation of the U.S. and Russian Nuclear Warhead Production Complexes after the Cold War," *Yaderny Kontrol*, No. 5, September-October 1999, p. 43-56.

past and present missions.<sup>5</sup> The report is based to a considerable extent on his analysis of declassified Corona satellite imagery.

Finally, Bukharin has analyzed the human resources situation in the Russian weapons complex.<sup>6</sup> He finds that while in the near term, large personnel cuts are needed; in the longer term retirements, a continuing outflow of young specialists and an absence of new high-quality hires could undermine Russia's nuclear weapons-competence.

## **Securing Russia's nuclear materials**

Although important progress has been made, the security of Russia's huge inventories of HEU and plutonium still remains inadequate. Unfortunately, the U.S. Department of Energy's assistance program is becoming less effective, and its spirit of partnership is wearing thin. Bukharin, Luongo, and Matthew Bunn of Harvard University have undertaken a critical review and recommend a series of steps designed to reinvigorate the partnership and increase the program's effectiveness.<sup>7</sup>

One significant omission in the program is performance testing of security upgrades at nuclear facilities in Russia. Realistic testing is critically important, as the performance of a system in the real world is almost always different from its performance on paper. Achieving a fully effective security system typically requires repeated testing, fixing of vulnerabilities revealed by the tests, testing again, and fixing again. Based on his research and personal observations of U.S. Nuclear Regulatory Commission performance tests, Bukharin has written a Russian-language article on performance testing programs in *Yaderny Kontrol*.<sup>8</sup> A more technical version of this article has been submitted to *the Journal of Nuclear Material Management*. Specific proposals on how to establish a cooperative U.S.-Russian program on Materials Protection, Control and Accounting (MPC&A) performance testing are included in the Bukharin-Bunn-Luongo report, *Renewing the Partnership*.

## **Ending Russia's production of weapon-grade plutonium**

In December 1993, while working in the White House Office of Science and Technology Policy, von Hippel proposed a joint U.S.-Russian effort to shut down three Russian dual-purpose production reactors that remain in operation because they supply by-product heat and electricity to regional populations. This proposal became a formal U.S.-Russian project by agreement between Vice President Gore and Prime Minister Chernomyrdin. Later, however, the Department of Defense (DoD), which had been given responsibility for management of the project, concluded that replacement energy sources would be too costly. It therefore decided to

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<sup>5</sup> O.Bukharin, T.Cochran, R.S.Norris *New Perspectives on Russia's Ten Secret Cities*, NRDC Nuclear Weapons Databook, NRDC, Washington, DC, October 1999.

<sup>6</sup> Oleg Bukharin "Stewards and Custodians: Tomorrow's Crisis for the Russian Nuclear Weapons Complex?," *The Nonproliferation Review*, Fall 1999, pp. 128-138.

<sup>7</sup> O.Bukharin, K.Luongo, M.Bunn *Renewing the Partnership: Recommendations for Accelerated Action to Secure Nuclear Material in the Former Soviet Union*, RANSAC, [forthcoming].

<sup>8</sup> Oleg Bukharin "Physical Protection Effectiveness: Lessons of U.S. NRC Special Programs," *Yaderny Kontrol*, No. 2, March-April 2000, pp. 67-80.

adopt a proposal from the Pacific Northwest National Laboratory (PNNL) to convert the reactors to a fuel that could be stored and therefore would not require the separation of plutonium.

von Hippel became involved again in October 1997 when he learned that the U.S. had accepted a Russian proposal that the new fuel be weapon-grade uranium – a cure in many ways worse than the disease. The production of 1.5 metric tons of weapon-grade plutonium per year would be ended but 4 tons of weapon-grade uranium (WgU) would be imbedded each year in 200,000 small fuel elements. Less than one percent of this material would be enough for a terrorist nuclear weapon.

The U.S. government had been persuaded to adopt the HEU option on the basis of a PNNL conclusion that converting to a fuel containing non-weapons-usable low-enriched uranium (LEU) would be prohibitively costly. von Hippel's review of this analysis raised enough doubts, however, that the Department of Energy (DoE) and State Department decided to launch a parallel program to develop an alternative low-enriched uranium (LEU) fuel. The DoD argued that a shift to LEU fuel would delay the project but von Hippel discovered and brought to the Administration's that the DoD was ignoring serious safety issues that would, in any case, delay the conversion program for several years.

In December 1999, the Russian Ministry of Atomic Energy informed the U.S. government that because of cost increases and delays in the project, it would like to reopen the idea of shutting the reactors and replacing them with coal- and oil-fired boilers and co-generation stations. As part of an effort to keep the conversion option alive, the U.S. and Russian contractors for the conversion project have agreed to shift to low-enriched uranium.

In the meantime, the DoD has launched a study of the reactor-replacement option. Because the DoD study was not to include an examination of the potential for energy-efficiency improvements, von Hippel initiated a W. Alton Jones Foundation-funded study from the Moscow Center for Energy Efficiency to fill this gap. Subsequently, the DoD provided supplemental funding to extend the study.

## **Ending the production of fissile material for weapons worldwide**

During the late 1980s, our work was largely responsible for a revival of international interest in the negotiation of a worldwide ban on the production of plutonium and highly-enriched uranium for weapons. Negotiations on a Fissile Material Cutoff Treaty (FMCT) have been delayed since 1993, however, by an impasse between the weapons states and the “non-aligned” states, who insisted that the negotiations must be coupled to negotiations on total nuclear disarmament.

Even if this impasse is resolved, negotiation of an FMCT could take years. In the interim, there should be a production moratorium to forestall any further buildup in the nuclear stockpiles. The U.S., Russia, Britain, and France have already announced that they have ended their production of fissile material for nuclear weapons; and China has indicated privately that it is not producing. What remains, therefore, is to persuade Israel, India, and Pakistan to join the production moratorium and China to make a formal, public commitment.

During the past two years, Zhang Hui and von Hippel have undertaken a major research project to examine how confidence in a moratorium could be increased by the interpretation of commercial satellite images of shutdown nuclear-materials-production facilities. They have been using commercial images from Landsat 5 and the new Space Imaging IKONOS satellite as well as de-classified U.S. 1967-72 satellite photographs of older enrichment and reprocessing plants and plutonium-production reactors. They have found a number of indicators that can be used to determine whether a major heat-producing facility is operating. These include vapor plumes from cooling towers and elevated temperatures (visible to infrared sensors) of the vast roofs of gaseous diffusion uranium-enrichment plants. A summary of these findings is being published in *Science & Global Security*.<sup>9</sup>

Zhang Hui, Ramana and Mian recently published an op-ed in *The Hindu* arguing that India and Pakistan should institute a fissile material production moratorium and use commercial satellite imagery to increase their confidence that the other side had indeed stopped production. They also argued that such an initiative could help put international pressure on the nuclear-weapon states to deal more urgently with the reduction of their vast stockpiles of nuclear weapons and fissile material.<sup>10</sup>

### **Raising the level of South Asia's nuclear-policy debate**

Zia Mian and M.V. Ramana continue to focus primarily on ways to contain South Asia's nuclear arms race. They were joined in summer studies by two senior South Asian physicists: Professor A.H. Nayyar of Pakistan (1998-2000) and Prof. R. Rajaraman from India (2000).

In June 1999, Ramana published a comprehensive review of the health and the environmental impacts of underground nuclear tests in *The Annual Survey of the Environment*—published every year by *The Hindu*, a national Indian newspaper. An edited version was subsequently published in *The News*, a leading Pakistani newspaper. This review has inspired an independent baseline survey of the inhabitants of several villages close to the Indian nuclear test site in Pokharan.

Ramana's *Bombing Bombay? Effects of Nuclear Weapons and a Case Study of a Hypothetical Explosion* was published in 1999 by the International Physicians for the Prevention of Nuclear War and widely distributed in India. Ramana gave presentations on the subject in many cities in India. Several prominent newspapers reported on these presentations.

In August 1999, India released a Draft Nuclear Doctrine. Despite a proclaimed commitment to "minimum credible deterrence," the doctrine was based on ideas developed by the U.S. and Russia as they built up their arsenals to obscene levels. Ramana pointed out in *The Hindu* that these plans would commit India to huge expenditures and a nuclear arms race that would only foster insecurity.<sup>11</sup> A nationwide organization, Indian Scientists Against Nuclear Weapons, held a press conference and released a statement citing Ramana's critique.

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<sup>9</sup> Hui Zhang and Frank von Hippel, "Using Commercial Imaging Satellites to Detect the Operation of Plutonium-Production Reactors and Gaseous-Diffusion Plants," *Science & Global Security* (in press).

<sup>10</sup> Zia Mian, M. V. Ramana and Hui Zhang, "Ending the N-race," *The Hindu*, 25 May 2000.

<sup>11</sup> M. V. Ramana, "A Recipe for Disaster," *The Hindu* September 9, 1999.

Ever since the Indian nuclear tests of May 1998, seismologists and other analysts have questioned the officially announced yields. Last November, the Indian Department of Atomic Energy published some partial results from its radiochemical analysis of samples from underground rock contaminated by the test. Ramana pointed out several problems with the analysis and explained why the seismological data implies that the official numbers are exaggerated.<sup>12</sup> A longer technical analysis is in preparation for submission to *Science and Global Security*.

In 1999, Ramana was awarded a postdoctoral “international collaborative research” fellowship by the SSRC-MacArthur Program on International Peace and Security to study the role of scientists in the Indian nuclear weapons debate. Srirupa Roy of New York University was also awarded a fellowship to study societal understandings of the bomb. The two therefore joined to organize a one-day workshop on Nuclear Understandings: Science, Society, and the Bomb in South Asia in Dhaka, Bangladesh on February 17, 2000. The workshop brought together Indian and Pakistani academics and activists, and people from varied metropolitan and non-metropolitan locations in South Asia, to discuss different “non-nuclear” underpinnings and implications of the nuclear crisis. It was followed by a larger peace conference involving over 150 people from 14 different countries, mostly from the region, including Zia Mian and Ramana. An edited volume of papers from the workshop will be published in 2001.

Together with Rammanohar Reddy, a journalist in Chennai, India, Ramana is also in the process of editing a volume of essays critically analyzing different aspects of India’s nuclear policy. Contributors to the volume include Admiral Ramdas, retired head of the Indian navy; Amulya Reddy, the well-known energy analyst; and Jean Dreze, the renowned economist. Ramana’s chapter for the book will cover the role of scientists in the Indian nuclear weapons program and in manufacturing support for it. The book is to be published in 2000 by Orient Longman (India).

During the summer of 1999, Mian and Nayyar examined the safety issues and potential consequences of an accident at a nuclear power plant, which has just been built near Chashma, Pakistan but has not yet operated commercially.<sup>13</sup> Their study, which was reprinted by a leading environmental policy think tank in Islamabad—the Sustainable Development Policy Institute (SDPI),<sup>14</sup> has triggered a major debate over nuclear safety in Pakistan and has led to efforts within Pakistan’s government to create a more independent nuclear regulatory agency.

The Chashma study identified a number of safety concerns, including possible earthquake hazards at the site; the reliability of the Chinese design; and the quality of the Chinese manufactured components. An additional concern follows from the 1998 accident that shut down for a year the prototype reactor near Qinshan, China. The Chinese eventually contracted a U.S. nuclear engineering company to assess the problem and make repairs. Similar assistance would not be available to Pakistan because it is not a party to the Nonproliferation Treaty.

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<sup>12</sup> M. V. Ramana, “The Question of Nuclear Yield,” *Frontline* January 21, 2000.

<sup>13</sup> *Pakistan’s Chasma Nuclear Power Plant: A Preliminary Study of Some Safety Issues and Estimates of the Consequences of a Severe Accident* (Princeton/CEES Report 321, December 1999).

<sup>14</sup> Zia Mian and A.H. Nayyar, *Pakistan’s Chasma Nuclear Power Plant: A Preliminary Study of Some Safety Issues and Estimates of the Consequences of a Severe Accident*, SDPI Monograph No. 11, 1999.

Pakistan's Nuclear Regulatory Board is far from being an independent watchdog body, even though it is officially described as one. The Chairman of the Pakistan Atomic Energy Commission (PAEC), which operates all nuclear facilities in the country, also holds the office of Chairman of the Nuclear Regulatory Board, and there is no provision for either a separate budget or staff.

Using the Mian-Nayyar technical study as a basis, Mian wrote two articles on Chashma in *The News*, the quality morning newspaper of Islamabad, describing the safety issues and proposing an independent review of Chashma before it is allowed to operate.<sup>15</sup> Subsequently, Professor Nayyar presented this work at a seminar organized by the SDPI. A large number of senior PAEC officials attended. The other speaker at the seminar was the Deputy Manager of the Chashma nuclear power plant.

This was the first public debate in which PAEC has participated, and it was covered by Pakistan's leading newspapers.<sup>16</sup> *The News on Sunday* later published a full-page summary of Mian and Nayyar's work on Chashma, including their estimate of 12,000 - 23,000 possible cancer deaths following a severe accident.<sup>17</sup> Mian was asked to write an op-ed by *The News* on the anniversary of the Chernobyl nuclear accident, in which he suggested Pakistan consider stockpiling potassium iodide for distribution to children in the event of a nuclear accident as prophylaxis for thyroid cancer.<sup>18</sup>

Following these articles and reports, a number of Pakistani NGOs and NGO networks became involved. The Advocacy and Development Network, a group of leading Pakistani NGOs working on sustainable development, has taken a public position calling for a halt to further work on Chashma pending an independent study of its safety.<sup>19</sup>

Given the public interest, PAEC agreed to let Professor Nayyar see some of the official safety documents relating to Chashma. Subsequently, the Federal Minister for the Environment invited Professor Nayyar, senior officials from PAEC, and a number of officials from the Ministry of Environment to discuss the matter. Mian and Nayyar were asked to prepare a memo for the Minister about their concerns. They hope to participate in the review of proposed legislation to meet Pakistan's commitment under the 1994 Vienna Convention on Nuclear safety "...to ensure an effective separation between the functions of the regulatory body and those of any other body or organization concerned with the promotion or utilization of nuclear energy."

These developments have begun what may be a more enduring public policy debate in Pakistan about the need for openness and accountability in its nuclear-energy program. SDPI has

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<sup>15</sup> Zia Mian, "Nuclear Dangers of Another Kind", *The News on Sunday*, Islamabad, 8 August, 1999 "Almost too Late," *The News*, Islamabad, 17 December 1999.

<sup>16</sup> "Accident May be Disastrous: Chashma Reactor Not Safe, Says Expert", *Dawn*, Karachi, 21 December 1999; "Chashma Power Plant Built on Seismic Fault", *The Nation*, Lahore, 21 December 1999, "Nuclear Regulatory Board Should be Made Independent", *The News*, Islamabad, 21 December 1999; "CHASNUPP - A Potential Disaster Waiting to Happen", *The Friday Times*, Lahore, 31 December 1999.

<sup>17</sup> Zia Mian, and A.H. Nayyar, "Potential Risks and Consequences of an Accident at the Chashma Nuclear Power Plant", *The News on Sunday*, 23 January, 2000.

<sup>18</sup> Zia Mian, "Chernobyl's Children", *The News*, 30 April 2000.

<sup>19</sup> ADN demands suspension of work at Chashma reactor, *News Network International*, Tuesday 4th April, 2000

published a short report by Mian on the problems of Pakistan's only other nuclear power reactor, the thirty-year old Canadian-designed-and-built KANUPP plant near Karachi.<sup>20</sup> The increased interest in the health and environmental effects of Pakistan's nuclear energy and weapons programs led *The News on Sunday* to reprint two of Mian's 1995 essays on these issues.<sup>21</sup>

Mian also contributed an article on the history of nuclear-weapon accidents that was carried by both *The News on Sunday*<sup>22</sup> in Pakistan and *The Hindu*.<sup>23</sup> Both articles were accompanied by the Greenpeace list of accidents involving weapons of the U.S. and former Soviet Union. These issues are currently being explored in more detail in a study with Professor Rajaraman and M.V. Ramana on the possible health and environmental effects of nuclear-weapon accidents in South Asia.

## **De-alerting U.S. and Russian nuclear missiles**

It is reckless for the U.S. and Russia to insist on keeping their own—and thereby each others'—nuclear missiles on launch-on-warning alert. However, the missile commands on both sides are wedded to this posture because of a commitment to “counterforce” targeting. As a result, the U.S. and Russian strategic forces are each others' “time urgent” targets.

Feiveson and von Hippel have continued to work with Bruce Blair of the Brookings Institution on efforts to put the de-alerting of nuclear weapons on the policy agenda. These included an article by Feiveson and Blair, “How to Lengthen the Nuclear Fuse,” in the March 2000 issue of the widely-read journal of the Institute of Electrical and Electronics Engineers, *IEEE Spectrum*,<sup>24</sup> and a *Washington Post* op-ed by von Hippel and Blair.<sup>25</sup>

Some Russian military analysts have claimed that de-alerting measures involving the storage of missile warheads would be impossible for Russia because of the unavailability of adequate storage. Very little has been known outside Russia about Russia's nuclear weapons storage complex. Josh Handler, utilizing declassified U.S. satellite imagery and U.S. Cold War intelligence information, as well as recent Russian publications, has therefore pieced together the first unclassified analysis of this complex.<sup>26</sup> This analysis will be further refined in the coming year as a result of a grant from the Ploughshares Foundation to purchase new 1-meter resolution commercial satellite imagery of Russian nuclear weapons storage sites.

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<sup>20</sup> Zia Mian, *Some Issues Associated with Pakistan's Karachi Nuclear Power Plant (KANUPP)*, SDPI Working Paper Series No. 51, 2000.

<sup>21</sup> Zia Mian, “Impregnable Nuclear Deterrence or Incalculable Human Tragedy?”, *The News on Sunday*, 12 March 2000, and “How Badly Do The People of Pakistan need Nuclear Security?”, *The News on Sunday*, 26 March 2000.

<sup>22</sup> Zia Mian, “Risking It All”, *The News on Sunday*, 16 April 2000.

<sup>23</sup> Zia Mian, “There will Be No Second Time”, *The Hindu*, 2 April 2000.

<sup>24</sup> Harold Feiveson and Bruce Blair, “How to Lengthen the Nuclear Fuse,” *IEEE Spectrum*, March 2000.

<sup>25</sup> Frank von Hippel and Bruce Blair, “A Longer Nuclear Fuse,” *Washington Post* op-ed, June 6, 2000.

<sup>26</sup> Joshua Handler, “Lifting the Lid on Russia's Nuclear Weapons Storage,” *Jane's Intelligence Review*, August 1999; Joshua Handler, “U.S.-Russian Efforts to Improve Russian WPC&A: Shutting the Barn Door Before the Horse has Left?”, *Proceedings of the INMM/Carnegie Endowment Special Seminar “Russian Nuclear Security Programs and Prospects”* Hyatt Capitol Hill, Washington, DC, 26 April 2000.

## National-missile defense

Like most arms controllers, we have been outraged by the irresponsibility of both the Clinton Administration and the Congressional Republican leadership who have been relentlessly advocating deployment of a “thin” missile defense. Our role has thus far been a supportive of those who have done most of the heavy technical analysis in this area (Richard Garwin, Lisbeth Gronlund, George Lewis, Ted Postol, and David Wright). In December 1999, we published a summary critique in the *Washington Post* and *International Herald Tribune*.<sup>27</sup>

## The Comprehensive Test Ban Treaty

Along with Sidney Drell, Steve Fetter, Richard Garwin, Ray Kidder, Christopher Paine and others, we have worked for many years to deal with the objections raised by the nuclear-weapons labs to the Comprehensive Test Ban Treaty (CTBT). Following the ambush of the CTBT by the Senate Republican leadership, abetted by the laboratory directors, it is necessary to recommit ourselves to this task.

Just before the Senate vote in October, von Hippel recruited Ray Kidder, a retired Livermore weapons physicist, and Lynn Sykes, a leading seismologist, to write a joint Oped, “False Fears About a Test Ban,” in the *Washington Post*.<sup>28</sup>

After the Senate vote, von Hippel was asked by the State Department’s Arms Control and Nonproliferation Advisory Board to give his views on what should be done to prepare for the next ratification opportunity. He called for a study of four issues to put the arguments of the opponents into perspective:<sup>29</sup>

- 1) The role of the Stockpile Stewardship program in assuring warhead reliability;
- 2) Detection thresholds of the international monitoring system;
- 3) What various countries could accomplish testing up to those thresholds; and
- 4) The cost/benefit ratios for specific warhead safety improvements.

He urged such a study in discussions with senior officials of the National Academy of Sciences (NAS) and with State Department officials working with General Shalikashvili, the President’s special advisor on the future of the CTBT. Subsequently General Shalikashvili asked the NAS to carry out such a study and report back to the U.S. Government by January 2001.

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<sup>27</sup> Phillip Bleek and Frank von Hippel, “Missile defense -- A dangerous move,” *Washington Post*, “Outlook” Section, Sunday, December 12, 1999, page B09 (reprinted in the *International Herald Tribune*, Dec. 23, 1999, p. 8 as “A Missile Defense System Isn’t What America Needs.”)

<sup>28</sup> Ray Kidder, Lynn Sykes and Frank von Hippel, “False Fears About a Test Ban” by *Washington Post*, Outlook Section, Sunday, October 10, 1999; Page B07.

<sup>29</sup> Frank von Hippel, “The need for a report that clarifies and puts into perspective the technical arguments against the CTBT,” presentation to the State Department’s Arms Control and Nonproliferation Advisory Board, Dec. 2, 1999.

Currently von Hippel is working with Henry Kelly, the new President of the Federation of American Scientists, to develop a major FAS effort to help educate the public and the Senate on the answers to these questions.

### **Proliferation-resistant nuclear fuel cycles**

To date, the standard nuclear fuel cycle involves low-enriched uranium fuel. Some countries store the spent fuel. Others reprocess it chemically to recover and recycle the contained plutonium and uranium. Over the past 25 years our group has published multiple influential critiques of the reprocessing option. Our major concern has been the relative ease with which separated plutonium could be made into nuclear explosives. In addition, we have shown that the “mixed oxide” fuel in which plutonium is recycled is many times more costly than new low-enriched-uranium fuel.

Recently there has been a revival of interest in mixing thorium with uranium in fresh fuel. This results in a great reduction in plutonium production because the thorium replaces much of the  $U^{238}$  from which the plutonium is bred. Neutron capture in thorium results instead in the breeding of  $U^{233}$  which is a better fuel than plutonium in current-generation reactors. For example, Jungmin Kang found that almost 20 percent more energy can be generated from the same amount of  $U^{235}$  in a uranium-thorium mixture than in low-enriched uranium.<sup>30</sup> Enough  $U^{238}$  remains in the mix to “denature” the  $U^{233}$  for weapons use without isotope-separation. In contrast, plutonium can be separated from uranium by relatively simple chemical processing.

Relatively pure  $U^{233}$  could be superior plutonium for nuclear-weapons use.<sup>31</sup> However, an additional uranium isotope,  $U^{232}$ , is produced along with  $U^{233}$  that decays to an isotope which emits a very penetrating gamma ray. If the  $U^{232}$  level were high enough, it could generate serious radiation hazards for those attempting to use  $U^{233}$  in weapons. Kang and von Hippel undertook a thorough examination of the determinants of  $U^{232}$  contamination in  $U^{233}$ .<sup>32</sup>

An article by Feiveson, “Diversion-Resistant Criteria for Nuclear Power,” done for a conference at Stanford at the end of June 2000, gives a comprehensive overview of new proliferation-resistance concepts now being considered within the U.S. Its central conclusions are that it will be possible to achieve improvements in making “once-through” (no-reprocessing) nuclear-power fuel cycles somewhat more resistant to the diversion of fissile material by terrorist groups. Improving proliferation resistance to national efforts to acquire nuclear weapons would be far more difficult, however. It would require countries to give up sovereignty either by concentrating nuclear power in large internationally-controlled sites or by creating a regime in

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<sup>30</sup> Jungmin Kang, “Proliferation Resistance of Spent Thorium-Uranium Fuel” (Annual meeting of the American Nuclear Society, San Diego, June 2000). More neutrons are released per fission of  $U^{233}$  than per fission of  $Pu^{239}$ . Hence more  $U^{233}$  is “bred” in the fuel and more energy can be extracted from it.

<sup>31</sup>  $U^{233}$  combines the best weapons properties of both plutonium and  $U^{235}$ . Like plutonium, it has a small critical mass. Like  $U^{235}$  it has a very low spontaneous-neutron emission rate and could therefore be used in a very simple Hiroshima “gun-type” assembly design.

<sup>32</sup> Jungmin Kang and Frank von Hippel, “ $U^{232}$  and the Proliferation-resistance of  $U^{233}$  in Spent Fuel” (submitted to *Science & Global Security*).

which any country attempting to defect from a non-proliferation regime could be forcibly prevented from doing so—as Iraq was.

### **The hazard from depleted uranium munitions**

Following reports about “Gulf War Syndrome” (chronic illnesses affecting many U.S. soldiers returning from that war) and reports of increased cancer rates in Southern Iraq, a number of individuals and groups have suggested that U.S. use of depleted uranium (DU) in anti-tank munitions might be part of the cause. Attention was focused on the issue again as a result of the use of DU-munitions by NATO aircraft in Yugoslavia. The International Action Center, a New York City based NGO, twice published an inflammatory collection of articles under the title, *Metal of Dishonor: How the Pentagon Radiates Soldiers and Civilians with DU Weapons*. U.S. government contractors have published more soothing reports. The result was considerable confusion in the peace community. Steve Fetter (of the University of Maryland) and von Hippel therefore undertook to make their own independent estimates of the hazards.

They concluded that apart from the interiors of vehicles destroyed with DU munitions, the health risks are relatively low. Indeed, the radiation doses appear to be low except to soldiers with shards of DU imbedded in them. However, the health risks due to the heavy-metal toxicity of uranium inhaled and ingested by soldiers in direct unprotected contact with vehicles struck with DU munitions or with areas contaminated by nearby burning DU munitions could be significant. Unfortunately, a large fraction of the hundreds of thousands of U.S. soldiers involved in the Gulf War and subsequently stationed in the Gulf region may have climbed upon and inside U.S. or Iraqi tanks struck by DU munitions. Despite Army regulations, no timely measurements of actual quantities of uranium inhaled or ingested by any U.S. soldiers appear to have been made. Fetter and von Hippel proposed that contaminated vehicles and penetrator fragments be buried as low-level radioactive waste.<sup>33</sup>

### **Fostering compliance with arms-control agreements**

Feiveson and Mian (with the assistance of Jacqueline Shire) are carrying out, under the joint auspices of Princeton’s Center of International Studies (CIS) and the NYU Law School, a study of compliance gaps in arms control agreements and ways in which enforcement of such agreements could be enhanced. A first draft of their study, “Some Issues in Compliance: Arms Control and Disarmament,” was given at a conference in Princeton on February 18-19, 2000.

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<sup>33</sup> Steve Fetter and Frank N. von Hippel, “The Hazard Posed by Depleted Uranium Munitions,” *Science & Global Security* 8 (2000), pp. 125-161; and “When the dust settles: Depleted uranium is not the radioactive nightmare some say but it is still a dangerously toxic heavy metal,” *Bulletin of the Atomic Scientists* 55, Nov.-Dec. 1999, pp. 42-45, ([bullatomsci.org/issues/1999/nd99/nd99toc](http://bullatomsci.org/issues/1999/nd99/nd99toc)); see also, letter to the editor and the authors’ response, “The DU dispute continues,” Jan/Feb. 1999 issue, pp. 4-5.

The work has so far focused on three large issues. The first is captured by a story Noam Chomsky attributes to St. Augustine. A captured pirate was brought before the Emperor Alexander the Great: “How dare you molest the sea?” asked Alexander. “How dare you molest the whole world,” replied the pirate, and continued, “Because I do it with a little ship only, I am called a thief; you, doing it with a great navy, are called an emperor.” In our study, we have tried to understand compliance issues not only with regard to “rogue states” that might wish to acquire weapons of mass destruction but also with respect to the nuclear weapon states—especially the U.S.

A second issue is to sort out when compliance is essentially a question of “regime management,” as opposed to coercion through the use of force or sanctions. For example, in the bilateral U.S.-Russian arms control treaties, non-compliance has mostly resulted from ambiguities of treaty language and a lack of transparency. Compliance has focused on resolving the various ambiguities through high-level technical discussions between the parties, not on the use of force or sanctions.

The third large issue is to examine ways to improve compliance of the “pirates.” Here we have examined in some detail the cases of North Korea and Iraq and new ideas to strengthen compliance, such as “smart sanctions,” development of more effective procedures for the authorization of force in the Security Council, and the criminalization of certain activities. We have also sought to understand the circumstances in which a country’s acquisition of weapons of mass destruction would call for an international response even where the country has not subscribed to a treaty banning such weapons or has withdrawn using proper procedures.

## **II. STRENGTHENING THE INTERNATIONAL COMMUNITY OF INDEPENDENT, TECHNICALLY-TRAINED NON-PROLIFERATION EXPERTS**

### **Arms Control Centers in Russia and China**

Over the past several years, we have helped educate independent scientists in other countries, many of whom collaborate and brainstorm with us on solutions to the nuclear weapons-related problems discussed above. This interaction has both strengthened our own research and fostered independent Russian and Chinese nuclear arms control and nonproliferation centers.

**MITP Center for Arms Control, Energy, and Environment Studies.** We work particularly closely with Anatoli Diakov, Director of the Center for Arms Control, Energy, and Environment Studies at the Moscow Institute of Physics and Technology. Diakov spent the first half of 1992 and three months during the spring of 1997 with our group. He has also been an invaluable collaborator in Moscow, working as an interlocutor with Russia's nuclear establishment on issues of nuclear arms reduction and conversion.

**Four new nonproliferation centers in Russia.** Emboldened by the success of Diakov's Center, we encouraged likely scientists at each of four Russian nuclear laboratories to develop proposals for nonproliferation centers:

- The Federal Laboratory of Experimental Physics at Sarov and of Technical Physics at Snezhinsk. These laboratories are the Russian counterparts of the U.S. nuclear-weapons design laboratories at Los Alamos and Livermore.
- The Kurchatov Institute of Atomic Energy in Moscow and the Institute of Physics and Power Engineering (IPPE) in Obninsk. These are Russia's two leading nuclear-reactor-design laboratories.

During the fall of 1998, pairs of technical experts from each of the two nuclear-weapons design centers visited Princeton and developed funding proposals that were submitted both to the U.S. Department of Energy (DoE) and U.S. foundations.

The Sarov nonproliferation center is directed by Yuri Yudin, a young physicist who has attended two of the Summer Symposia organized annually by Lisbeth Gronlund, George Lewis, and David Wright to recruit young scientists to careers in arms control. For their first years, the DoE's Nuclear Cities Initiative has funded a number of projects at the Sarov center at a level of \$300,000 and a project at Snezhinsk center at \$100,000. Broader proposals were funded at a level of almost \$100,000 at each center by the W. Alton Jones, John Merck, and Ploughshares Foundations. The W. Alton Jones Foundation has also provided startup funding for the centers at the Kurchatov Institute and IPPE.

The foundation grants have gone through the Moscow multi-national International Science and Technology Center (ISTC). This has resulted in about a year of delay. RANSAC has taken the responsibility for being the "partner" organization required by ISTC for pass-

through funding. Our program has committed to organizing advice and peer review for the new Centers. von Hippel plans to spend two weeks at the Sarov center in September.

We believe that all the centers have the potential for success. Both the IPPE and Kurchatov Centers have experienced and sophisticated leaders. The IPPE center has launched a serious research program, even though it still has not received its first year of funding. The Sarov Center is led by Yuri Yudin, who is deeply committed to its success. At Snezhinsk, however, the leadership has been uncertain and our communications have mostly been about bureaucratic matters.

**Fudan Program on Arms Control and Regional Security.** We are interacting less strongly with the Arms Control and Regional Security Program created by Professor Shen Dingli at Fudan University in Shanghai after his two-year post-doctoral training fellowship with us during 1989-91. However, his program has become a key host for U.S.-Chinese and international meetings on arms control. At the end of June, for example, Feiveson attended a workshop organized by Shen and the Union of Concerned Scientists on arms-control “transparency.”

**Li Bin and Zhang Hui.** We have supported the development of the arms-control research program at the Beijing Institute of Applied Physics and Computational Mathematics (IAPCM) ever since we helped found it in 1986. Li Bin, its first Ph.D. graduate, spent a year each during 1994-6 doing post-doctoral training at MIT and then Princeton as an SSRC/MacArthur Peace and International Security post-doctoral fellow. He returned to become Director of the IAPCM arms-control program. In 1997, Zhang Hui, the second Ph.D. to be produced by the IAPCM arms-control program, joined our group for two years to work on issues related to the verification of a ban on the production of fissile material for nuclear weapons.

In 1999, Li Bin struck out on his own and established China’s first independent arms control program. Margaret Spanel of Princeton and the Ploughshares Fund provided the necessary startup funding. In his first year as an independent sounding board and organizer of discussions between governmental and non-governmental analysts, Li Bin has already had a large impact on the Beijing arms-control community.

Zhang Hui was the second arms-control Ph.D. to be produced by IAPCM and came to our program in August 1997 for post-doctoral training. In September 1999, with the situation at IAPCM not clearly welcoming, he joined the Kennedy School’s arms-control program for further post-doctoral work. We have continued to collaborate with him from a distance.

### **Post-doctoral Training and Foreign Visitors**

In addition to Zhang Hui, we have had several other foreign scientists in our group this past year. These include two physicist-activists: Zia Mian, a Pakistan-U.K. dual citizen; M.V. Ramana, from India; and Jungmin Kang, a South Korean nuclear engineer. Our other post-doctoral researcher, Sharon Weiner, is an American political scientist whose expertise is in the

bureaucratic politics of national security policy. Weiner is currently researching a book on energy, state and defense regarding nonproliferation and Russia's Nuclear Cities.

Encouraged by the success of Professor Abdul Nayyar's research visits in 1998 and 1999, we have developed, with funding from the Carnegie Corporation, a formal program for hosting senior South Asian physicists interested in nuclear arms control. This summer (2000) we have with us in addition to Professor Nayyar, Prof. R. Rajaraman, a Professor of Theoretical Physics at Jawaharlal Nehru University, India.

## Graduate Students

**Joshua Handler.** We have only one PhD student, Joshua Handler. The purpose of his thesis is to understand why the U.S. and Russia failed to move further with nuclear disarmament during the decade following the Cold War. Handler spent the fall in Moscow researching the Russian side of the story but had to call his visit short when the FSB (the Russian counterpart of the FBI) decided that he might have contributed to the collection or publication of defense information that Russia did not want to be made public.<sup>34</sup> This seems to have stemmed from the fact that he was sharing an office at the Russian Academy of Sciences Institute of USA and Canada Studies with Igor Sutyagin, who, in October 1999, was jailed by the FSB for providing information to foreigners. Sutyagin was also one of the contributors to a Russian nuclear-weapons databook published by Diakov's Center. The unsold copies of the databook were confiscated, along with the hard drives of the computers which contained databook material. Eight months after his arrest, Sutyagin languishes in jail without being charged. This affair appears to be part of a pattern of cracking down on Russian researchers who cooperate with Western analysts.<sup>35</sup>

Handler advises western and Russian environmental groups addressing the environmental, social, and political problems arising from the operation and decommissioning of nuclear-powered vessels. He is currently helping to organize a legal conference on the implications for civil liberties in Russia of the trial of Alexander Nikitin, who co-authored under the auspices of a Norwegian environmental group, Bellona, a research report on the radioactive waste problems created by the Soviet/Russian nuclear navy. The conference is sponsored by Bellona and the New York University School of Law and will take place at the NYU Law School in October 2000. Handler has also helped the Portsmouth-Severodvinsk Connection, an organization created by the citizens of two centers of nuclear shipbuilding and repair, Portsmouth, NH, and Severodvinsk, Russia, to continue with their citizen-to-citizen exchanges.<sup>36</sup>

## Science & Global Security

Feiveson continues as the editor of *Science & Global Security*. The purpose of the journal is to publish articles that provide detailed peer-reviewed technical material and analyses

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<sup>34</sup> Joshua Handler, "Under Suspicion," *IEEE Spectrum*, March 2000.

<sup>35</sup> Joshua Handler, "The Nikitin Affair: An Acquittal at Last?" *Bulletin of the Atomic Scientists*, March/April 2000.

<sup>36</sup> Additional publications by Handler are cited in the discussion on de-alerting above.

that can be relied upon by other scholars investigating problems of global security. During 1999-2000, the journal published technical articles on a range of topics including:

- The number of Iraqi Scud missiles intercepted by Patriot missiles during the Gulf War;
- Danger of spent fuel repositories becoming “plutonium mines”;
- Technical challenges of ballistic-missile interception and a method for modeling the effectiveness of a ballistic-missile interception system;
- Environmental hazard from weapons using depleted uranium;
- Amount of plutonium that could have been produced by North Korea’s research reactor, and
- Use of commercial satellites to verify aspects of a moratorium on fissile material production.<sup>37</sup>

*Science & Global Security* continues to foster the professional development and accreditation of a new generation of independent technically trained arms control and nonproliferation experts. It is translated and published in Russian by a group under Drs. Oleg Prilutsky and Stanislav Rodionov of the Moscow Space Research Institute. Under the initiative of Li Bin, we are also exploring the possibility of a Chinese version.

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<sup>37</sup> *Science & Global Security*, Table of Contents, Vol. 8.

## APPENDIX A. PERSONNEL

The Program on Nuclear Policy Alternatives is co-directed by Harold Feiveson and Frank von Hippel.

**Harold A. Feiveson** (Senior Research Policy Scientist) is the editor of *Science and Global Security*, and a senior lecturer in both Princeton's Woodrow Wilson School for Public and International Affairs and the Princeton Environmental Institute.

**Frank N. von Hippel** (Professor of Public and International Affairs) is a physicist and elected chairman of the Federation of American Scientists.

**Oleg Bukharin** (Research Staff) completed his Physics PhD at the Moscow Institute of Physics and Technology (MIPT) in September 1990 and then spent 1990-1 in Princeton taking courses related to arms control, nonproliferation and international security. During the next year he served as the Acting Director of MIPT's Center for Arms Control, Energy and Environmental Studies during the absence in Princeton of the Director, Anatoli Diakov. Bukharin was awarded an SSRC/MacArthur Peace and International Security fellowship and returned to Princeton for additional post-doctoral work in October 1992. He joined our research staff in July 1995.

**Joshua Handler** (PhD Student) came to Princeton in September 1996 after eight years with Greenpeace as a Disarmament Campaign Coordinator, where his final responsibility was leading Greenpeace's campaign for the Comprehensive Test Ban Treaty. He is an expert on issues relating to the military side of U.S. and Russian nuclear weapons programs and nuclear-powered ships. He spent the fall of 1999 in Russia.

**Jungmin Kang** (Research Associate) joined our group in the summer of 1998 as a Visiting Student. His work with us resulted in him being awarded a PhD in Nuclear Engineering from Tokyo University in July 1999. While here, Kang has completed articles on South Korea's options for storage of its spent nuclear fuel and an examination of a once-through uranium-thorium fuel cycle as an alternative to plutonium recycle. He is also writing a history of South Korea's nuclear and weapons programs.

**Ken Luongo** (Visiting Research Collaborator) joined our group in 1997. From 1994-7 he was Director of the Department of Energy's Office of Arms Control and Nonproliferation and built up the U.S. assistance program to improve nuclear-materials security across the former Soviet Union. He is currently the Executive Director of the "Russian-American Nuclear Security Advisory Council," an organization which fosters U.S.-Russian cooperative-security initiatives. Our joint work has focused especially on the Nuclear Cities Initiative.

**Zia Mian** (Research Staff) received his PhD in Physics from Britain's University of Newcastle upon Tyne in 1991 and stayed there for an additional two years as a post-doctoral researcher. He spent 1993-6 in Pakistan as a Visiting Research Fellow at the Sustainable Development Policy Institute in Islamabad, contributing, as a weekly columnist for *The News* and editor of *Pakistan's Atomic Bomb and the Search for Security* (1995), to the development of Pakistan's debate over nuclear power and nuclear weapons policy. During 1996-7, he was a Research Fellow at the Union of Concerned Scientists Cambridge office. He joined our group in

September 1997. He continues to contribute to Pakistan's nuclear-weapons debate via e-mail and newspaper columns while writing a book on the history of Pakistan's nuclear-energy program.

**Abdul Nayyar** (Visiting Research Scholar) is a Professor of Physics at the Quaid-i-Azam University in Islamabad, Pakistan. He has spent the summers of 1998-2000 with us. During the summer of 1999, he and Zia Mian co-authored an examination of the safety problems of a new nuclear power plant that has been built in Pakistan by China. This work has inspired a major public debate in Pakistan and a rethinking within Pakistan's government of how it deals with nuclear safety.

**Robert Nelson** (Research Staff) got his PhD in Astrophysics in Cornell in 1991. For two years starting in 1998 he was a member of the research staff of Princeton University's Department of Astrophysics. In June 2000 he decided to join our group, bringing with him a research/teaching post-doctoral fellowship from Princeton University's Council on Science and Technology.

**Ramamurti Rajaraman** (Visiting Research Scholar) is a Professor of Theoretical Physics at Jawaharlal Nehru University, India. He has participated in India's nuclear debate and now wants to analyze alternative policies. He spent approximately two months with us during the summer of 2000, launching his own arms-control research program.

**M.V. Ramana** (Research Associate), a citizen of India, obtained his Ph.D. in Physics from Boston University in 1994. He joined us in the fall of 1998 after spending a year and a half at MIT as an SSRC-MacArthur International Peace and Security postdoctoral fellow. He contributes to India's nuclear debate with articles, edited books and by organizing a South Asian workshop of activist analysts while researching a technical history and assessment of India's nuclear program.

**Sharon Weiner** (Research Associate) received a PhD in Security Studies from M.I.T. in 1998 after working as a staffer for the House Armed Services Committee in the late 1980s. She joined our group in June 1999. She has been working full time on activities associated with the future of Russia's closed cities.

**Zhang Hui** (SSRC/MacArthur International Peace and Security Post-doctoral Fellow) came to Princeton in the fall of 1997 after receiving his PhD in Arms Control Physics from the Beijing Institute of Applied Physics and Computational Mathematics. He spent two years with us carrying out path-breaking research on verification issues relating to a global ban on the production of fissile materials for nuclear weapons. In September 1999, he joined the arms-control research program at Harvard's Kennedy School.

## APPENDIX B. ABSTRACTS OF PUBLICATIONS AND REPORTS (January 1, 1999- June 30, 2000)

OLEG BUKHARIN

**“Stewards and Custodians: Tomorrow’s Crisis for the Russian Nuclear Weapons Complex?”** *Nonproliferation Review*, Fall 1999, pp. 128-138.

ABSTRACT. At present, large personnel cuts are needed to bring the Russian nuclear weapons complex in line with reduced defense requirements and limited budgets. In the longer term, however, retirements, a continuing outflow of young specialists, and an absence of new high-quality hires could disrupt the continuity of Russia’s nuclear weapons competence, undermine stability of the complex and, eventually, jeopardize its core missions.

**“Consolidation of the U.S. and Russian Nuclear Warhead Production Complexes after the Cold War,”** *Yaderny Kontrol*, No. 5, September-October 1999, p. 43-56 (in Russian).

The United States has made measurable progress in reducing the size of its nuclear weapons production infrastructure after the Cold War. Russia has finally developed official plans for downsizing its complex. The article provides a comparative analysis of the nuclear weapons production infrastructures and national approaches to maintaining nuclear arsenals after the Cold War in the two countries. In particular, the article discusses such critical nuclear weapons activities as nuclear weapons R&D and non-nuclear testing, production of tritium, and warhead dismantlement and remanufacturing.

***New Perspectives on Russia’s Ten Secret Cities***, NRDC, Washington, DC, October 1999 (with T.Cochran and R.S.Norris)

ABSTRACT. The core of the Russian nuclear weapons complex is composed of ten closed nuclear cities. This complex researched, developed, tested, and produced Russia’s nuclear weapons. Five years ago, the authors of this report published a book describing in some detail what was known at the time (T.Cochran, R.S.Norris, and O.Bukharin *Making the Russian Bomb: From Stalin to Yeltsin*, Boulder,CO: Westview Press, 1994). Based on new information, this report revises and updates some of the information presented in the earlier work. Among the useful new sources is the declassified 1967-72 Corona satellite imagery that has become available to researchers. The report uses selected imagery and other information to provide new perspectives on the past and present activities conducted in the closed cities.

**“Defense Conversion And Business Development In Trekhgornyy (Zlatoust-36),”** *Nuclear Cities News*, Volume 1, December 1999.

ABSTRACT. Trekhgornyy, formerly Zlatoust-36, is probably the most secretive of Russia’s ten closed nuclear cities. It was established in 1955 as a site of the Device-Building Plant, one of Russia’s four serial nuclear warhead assembly and disassembly facilities. Located in the Chelyabinsk region in the Urals, Trekhgornyy has a population of approximately 33,000.

According to Minatom’s reconfiguration plans, the Device-Building Plant will be one of two Russia’s remaining operational serial warhead production facilities. Its defense work, however, is expected to decline considerably. According to the facility’s program of restructuring and conversion, which was approved in March 1999, the number of defense-program personnel is to decrease from 5766 in 1997 to 2800 in 2001. Approximately 2500 new jobs will have to be created by 2001 to compensate for defense order reductions. To meet this target, the plant is developing manufacturing capacities to produce instrumentation and control equipment for nuclear power plants, electrical equipment, and back-up power sources.

In part due to efforts by Trekhgorny's mayor (N.A.Lubenets) and facility's director (A.V.Dolinin) defense conversion at Trekhgorny has already begun. The Device-Building Plant is producing bathtubs, car trunks, and polyethylene pipes. One of plant's major projects is the reconditioning of Czech-made tram cars for the Moscow government. Other businesses, for example, a shoe factory, have opened in the city as well. Perhaps the most ambitious and unusual project is the construction of a large ski resort which is expected to provide 2500 new jobs.

**“Minding Russia's Nuclear Store,”** *IEEE Spectrum*, March 2000, pp. 44-50 (with D.Mosher and T.Perry)

ABSTRACT. Russia's thousands of metric tons of bomb-grade uranium and plutonium and hundreds of thousands of displaced nuclear workers represent a proliferation risk that is impossible to ignore. The United States and Russia are cooperating on a broad range of programs designed to reduce the threat of proliferation. Success has been spotty. The United States should devote more political and financial resources to reducing this threat.

**“Physical Protection Effectiveness: Lessons of U.S. NRC Special Programs,”** *Yaderny Kontrol*, No. 2, March-April 2000, pp. 67-80.

ABSTRACT. The United States is working cooperatively with Russia to improve nuclear material protection, control and accounting (MPC&A) at tens of sites of the Russian nuclear complex. MPC&A upgrades have been completed at over 25 sites in Russia and other former Soviet republics. These upgrades have improved the deterrence and protective capabilities of the nuclear security systems against relatively low-level threats. However, they could be ineffective against a determined, knowledgeable and resourceful adversary. There is also a concern that, in the absence of a fully developed safeguards culture and an effective regulatory oversight, newly improved security systems might be not sustainable over time. The U.S. experience suggests that these problems cannot be addressed successfully without an effective program of performance testing. This report reviews the physical protection performance testing program developed by the U.S. Nuclear Regulatory Commission (NRC). It then seeks to outline a cooperative U.S.-Russian approach to establish a performance testing capability within Russia's nuclear complex.

***Downsizing Russia's Nuclear Warhead Production Infrastructure***, PU/CEES Report No. 323, May 2000, 23 p.

ABSTRACT. The Russian nuclear weapons complex remains oversized and still configured for the Cold War. The downsizing of the complex is inevitable. A rational approach to the task of consolidating nuclear weapons activities is phased downsizing that is synchronized with nuclear stockpile reductions. The alternative is its continuing decay that could undermine the complex's core missions, heighten the risk of proliferation, increase the possibility of a major accident, and hinder economic development and defense conversion. Based on public information about Russia's weapons complex, this report discusses its nuclear-weapons missions and associated infrastructure requirements, reviews the conversion efforts of the complex to date, and outlines a long-term strategy for restructuring and consolidation of Russia's nuclear warhead production infrastructure.

***Helping Russia Downsize its Nuclear Complex: Focus on the Closed Nuclear Cities***, A Report of an International Conference held at Princeton University, March 14-15, 2000 (by Oleg Bukharin, Harold Feiveson, Frank von Hippel and Sharon Weiner; Matthew Bunn; William Hoehn and Kenneth Luongo, June 2000).

EXECUTIVE SUMMARY. Russia is struggling both to keep its nuclear-weapons complex from collapsing and to down-size it to an affordable size that is appropriate to its post-Cold War security requirements. Production of highly-enriched uranium and plutonium for weapons have ended but the Russian Ministry of Atomic Energy (MinAtom) would like to shut two of four warhead-assembly plants, one of two fissile-component-production facilities and shrink its remaining nuclear-weapons facilities and their staffs. It hopes by 2005 to reduce the current number of nuclear-weapon workers by half.

The rate of implementation of these plans is limited by lack of funds. The federal budget for Russia's nuclear-weapons facilities is one seventh of what it was ten years ago and the average weapons worker gets a salary of only \$56 per month. It will take additional funds to clean out excess facilities to make them available for non-weapons projects, to help create civilian jobs for excess weapons workers, and to allow older workers to retire with dignity.

The U.S. is playing an important role in helping stabilize the Russian complex and in securing the experts and nuclear materials that could find their way into the black market if the level of desperation were to reach the breaking point. Income from the "HEU [highly-enriched uranium] deal," under which the U.S. is buying over a period of 20 years 500 tons of excess weapons uranium, after it has been blended down to low enrichment for use in reactor fuel, is helping Russia's enrichment and plutonium-production complex transition to civilian work. The Department of Energy's Materials Protection, Control and Accounting (MPC&A) program is helping to strengthen the security of Russia's huge stockpile of weapon-useable uranium and plutonium. The Department of Defense is building a secure storage facility for some of Russia's excess weapons plutonium and is co-funding the conversion or replacement of three plutonium-production reactors which are still operating to produce heat to local populations. The International Science and Technology Center is providing non-weapons work and salaries to key scientists in Russia's weapons-design institute.

It is generally recognized, however, that U.S. assistance has *not* yet been effective in facilitating the downsizing of Russia's nuclear-weapons design, fabrication and assembly complex. In particular, the U.S. Nuclear Cities Initiative, which was established in 1998 within the Department of Energy to help facilitate the transition of the ten "nuclear cities" that house the core of the complex, has made too slow a start and has been funded at too small a scale. Princeton University therefore hosted a conference on "Helping Russia Downsize its Nuclear Complex" on March 14-15, 2000 to understand better the obstacles to down-sizing and share ideas as to how the international community can provide more effective assistance.

At the conference Lev Ryabev, First Deputy Minister of MinAtom, outlined the plan that the Ministry had developed over the past two years to downsize the complex and create jobs for the 50 percent of the weapons workers who it would make redundant. He estimated that each of these two tasks would cost about \$500 million. It was agreed subsequently that there would be a followup workshop in Moscow at the end of June at which experts from seven of Russia's ten nuclear cities would provide more data about the downsizing and conversion plans. (MinAtom excluded as "too sensitive" participation from the three nuclear cities which specialize in nuclear-warhead assembly and disassembly.)

Senator Domenici, who plays a key role in the appropriations process for U.S. nuclear programs, sent a message to the Conference in which he said that he would support a greatly enlarged Nuclear Cities Initiative if Russia would establish "verifiable milestones" for its downsizing program. Subsequently, on May 1, 2000, Senator Domenici submitted the "Nuclear Weapons Complex Conversion Act of 2000" to the Senate Armed Services Committee for consideration as an amendment to the FY 2001 Defense Authorization Act. Plans with such downsizing milestones are being developed by three of Russia's nuclear cities (Sarov, Snezhinsk and Zheleznogorsk) in cooperation with senior officials from three U.S. nuclear labs (Los Alamos, Livermore and Sandia respectively).

It was generally agreed that new business ventures will not provide jobs rapidly enough to absorb the excess weapons workers. Until Russia's tax system is rationalized and legal protections for investments are strengthened, both foreign and domestic investment will continue to be low. Indeed, even in the U.S. where conditions for investment are much better, when major nuclear-weapons facilities were shut down, the vacuum was filled with a huge cleanup program (currently running at about \$6 billion per year) and a major new nonproliferation programs, including the MPC&A program and other technical assistance programs in Russia. Russia cannot afford such programs but salaries are so low in Russia that the U.S. and other industrialized countries could employ a considerable number of excess Russian weapons personnel if they contracted a few percent of their cleanup and nonproliferation R&D funds at the Russian nuclear facilities. In fact, small initiatives of this type have been launched.

Energy efficiency was also identified as a major opportunity for employment. As energy prices have climbed to world market levels, energy has become a major expense for the nuclear cities and facilities as it is for the rest of Russia. The low energy efficiency of Russia's infrastructure creates opportunities for high rates of return in terms of saved energy costs on well-design investments. Indeed, the World Bank is making major loans for energy-efficiency upgrades in Russia. This effort should be extended to the nuclear cities, starting with the establishment of analytical centers that could develop the necessary investment proposals.

A perennial complaint about the U.S. assistance effort in Russia is that it is not coordinated. Each agency develops its own program with little consideration of overlaps and possible synergisms with other programs. Stronger Presidential backed coordination could result in much more “bang for the buck. Such coordination could start with the development of a Presidential Decision Directive on the objectives and organization of U.S. programs.

Finally, other possible sources of funding for conversion were canvassed, including additional or accelerated sales of blended down excess Russian HEU, lowered barriers in other industrialized countries to imports of Russian natural uranium and enrichment work, storage of foreign spent fuel, a “debt for security” swap, the stripping of additional  $U^{235}$  from U.S. depleted uranium.

## HAROLD FEIVESON

### **Proliferation-Resistant Nuclear Power in a Greenhouse-Constrained World**

Proceedings, Global 99: International Conference on Future Nuclear Power Systems, American Nuclear Society, Jackson Hole, Wyoming, August 29-September 3, 1999.

**ABSTRACT.** Nuclear power could play a role in combating the greenhouse problem. But it faces several challenges:

- First if energy demand worldwide rises slowly, especially in the developing countries, nuclear power will also grow slowly and will not have a large impact in reducing carbon emissions. On the other hand, if energy use worldwide grows rapidly, nuclear will be only a small part of the energy mix for several decades since it starts out as a relatively small fraction of energy supply.
- Second, nuclear could have a role beyond the electricity sector only if it is used to produce hydrogen. But if there is a large use of hydrogen in the next century, it is likely that sequestration will then become a strong, and perhaps preferred, competitor to nuclear as a de-carbonization strategy.
- Finally, for nuclear power to be a significant contributor to combating the greenhouse problem, it will have to grow ten-fold at least, which will only be possible if nuclear power is made significantly proliferation resistant. The challenges to doing so are daunting. But, as noted, the real impact of nuclear power on global warming will be after the middle of the next century if alternative de-carbonization strategies are not developed. Therefore, there is time to develop nuclear power along fresh lines.
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### **Comment on “Confronting the Paradox in Plutonium Policies,” by Luther Carter and Thomas Pigford, *Issues in Science and Technology*, Winter 1999-2000.**

This is an excellent and wise article. In particular, I find the following points advanced by the authors of critical importance: (1) that the U.S. and Russia expedite their disposition of separated weapons-grade plutonium; (2) that all the countries with advanced nuclear power programs move to establish a global system for spent fuel storage and disposal; and (3) that the nuclear industries in France, Britain, and Russia halt all civil fuel reprocessing.

Of these, the third point is certainly the most controversial and the one that will require the most wrenching change in policy by significant parts of the nuclear industry in Europe and elsewhere. But the authors’ central argument is, in my view, compelling: notably, that the separation, storage, and recycling of civil plutonium pose unnecessary risks of diversion to weapons purposes; the risks are unnecessary because the reprocessing of spent fuel offers no real benefits for waste disposal, nor has the recycling of plutonium in MOx fuel in light water reactors any real economic merit. To this reason, I would add one other. An end to civilian reprocessing would simplify markedly the articulation and verification of a treaty banning the production of fissile material for weapons – an often-stated objective of disarmament negotiations over the past several years. With civil reprocessing on-going, such a treaty would ban any *unsafeguarded* production of plutonium (and highly enriched uranium) but, of necessity, allow *safeguarded* production, vastly complicating verification arrangements.

One prescription of the authors I am more ambivalent about. This is to give priority to disposition of the separated civil plutonium, especially if this is done through the MOx route. Such a MOx program would put into widespread commercial or commercial-like operation the transport and use of separated civil plutonium. At the end of the disposition program, the plutonium would certainly be in a safer configuration (that is, in spent fuel) than at present. But while the program is in progress, risks of diversion might be heightened particularly compared to continued storage at Sellafield and La Hague, where the plutonium (I imagine) is under strong security. This may not be true of the civil plutonium in Russia, however; and here a program of disposition looks more urgent and more attractive. Also, to tie up most reactors in the burning of the civil plutonium could slow substantially the use of reactors to burn weapons plutonium, a more important task.

The alternative route of disposition of civil plutonium that the authors discuss – immobilization – would not have these drawbacks, at least to the same degree. One reason that the MOx option has received most attention in the disposition of weapons plutonium is that the Russians have generally objected to immobilization, partly on the grounds that immobilization would not convert weapon-grade plutonium to reactor-grade as would happen by burning the plutonium in a reactor. This criticism, at least, would be moot for the disposition of civil plutonium.

**Closing the Compliance Gap: A Review of the Literature** (with Jacqueline Shire) Prepared for Workshop on International Law and Organization, Center for the Study of International Organization, NYU Law School and the Woodrow Wilson School, Princeton University, February 18-19, 2000.

**Some Issues in Compliance: Arms Control and Disarmament** (with Zia Mian) Prepared for Workshop on International Law and Organization, Center for the Study of International Organization, NYU Law School and the Woodrow Wilson School, Princeton University, February 18-19, 2000.

**Plutonium Politics**, Forum, *Issues in Science and Technology*, Spring 2000

**How to Lengthen the Nuclear Fuse**, *IEEE Spectrum*, (with Bruce Blair), March 2000.

ABSTRACT. A decade after the end of the Cold War, the U.S. and Russia are still maintaining nuclear weapons on hair-trigger alert aimed at each other's nuclear forces and cities. There are a straightforward set of actions that the U.S. and Russia could take, many of these through reciprocated unilateral initiatives, to achieve the stand-down from alert.

**Build a Missile Shield?** Letters, New York Times, May 3, 2000

In the document that American negotiators presented to the Russians regarding amendments to the AntiBallistic Missile Treaty (front page, April 28), the United States seeks to reassure Russia that Moscow could make "an annihilating counterattack," even after a surprise American first strike, as long as it "keeps its strategic arsenal on constant alert."

What an argument! To pave the way for deployment of a ballistic missile defense system, which among other purposes, is meant to guard against accidental launching of a few Russian missiles, the United States encourages Russia to keep between 1000-2000 strategic warheads on constant alert.

This is foolish. It is also an implicit admission that deployment of even a limited national ballistic missile defense system will make it far more difficult to reduce numbers of strategic weapons and the hair-trigger alert of the forces.

### **Helping Russia Downsize its Nuclear Complex: Focus on Closed Nuclear Cities**

A Report of an International Conference held at Princeton University, March 14-15, 2000 (with Oleg Bukharin, Frank von Hippel and Sharon Weiner; Matthew Bunn; William Hoehn and Kenneth Luongo), June 2000 (see Bukharin for Summary)

**Diversion-Resistance Criteria for Nuclear Power**, Workshop on “Does Nuclear Power Have a Role in Climate Mitigation”, Center for International Security and Cooperation, Stanford University, Stanford, June 22-23, 2000

ABSTRACT. There is no quarrel that we should work hard on designing nuclear technologies and fuel cycles that are strongly proliferation resistant to terrorists and sub-national group, and there is prospect that this can be done. Proliferation resistance for nations seems a much longer shot. The best hope is that nuclear power could be restricted to large, centralized energy parks under international control. But this implies that nations give up sovereignty over their energy system. The alternative is that nuclear power remains under national control but that the international system evolves so that any country seeking to defect from an overall non-proliferation regime (precipitously, or by exercising rights of withdrawal embedded in the NPT) could be prevented from doing so.

### **JOSHUA HANDLER**

**“Lifting the Lid on Russia’s Nuclear Weapons Storage,”** *Jane’s Intelligence Review*, August 1999.

ABSTRACT: For the first time in an unclassified publication, information is presented about the history of the Russian nuclear-weapons-storage complex and the current locations of its storage facilities. The article concludes that given what we now know about the Russian nuclear weapons storage system, efforts to improve the security of Russian nuclear weapons through the Cooperative Threat Reduction (CTR) program may have a good chance of success if these efforts receive adequate funding in the coming years.

**“Under Suspicion,”** *IEEE Spectrum*, March 2000

ABSTRACT: Describes the search and seizure of Handler’s research materials by the FSB in October 1999. Makes a broader analysis of the situation in Russia in regards to international collaboration and academic freedom during the last few years. Concludes that worsening Russian-western relations and Putin’s ascendancy may have made collaboration more complicated than in the early days of glasnost.

**“The Nikitin Affair: An Acquittal at Last?”** *Bulletin of the Atomic Scientists*, March/April 2000

ABSTRACT: Discusses the trial and the December 1999 acquittal of Alexander Nikitin, the retired Russian Navy captain, accused of espionage for his work on the Russian naval nuclear waste and submarine decommissioning problem. Concludes the acquittal was an unexpected victory for Nikitin, the Russian judicial system and the rule of law, particularly since it happened between the rigged Duma elections and presidential transfer of power and in the context of the FSB and official harassment of numerous Russian environmentalists. Implications for the future are ambiguous, however, due to the uncertainty of Putin’s commitment to civil liberties.

**“U.S.-Russian Efforts to Improve Russian WPC&A: Shutting the Barn Door Before the Horse has Left?”** *INMM/Carnegie Endowment Special Seminar “Russian Nuclear Security Programs and Prospects,”* Hyatt Capitol Hill, Washington, DC, 26 April 2000

ABSTRACT: Describes current social and economic problems at Russian nuclear-weapons-storage complex. Outlines important reasons for continuing cooperation with Russia to improve security of Russian nuclear weapons storage. Discusses some of the current problems in the U.S. CTR's Weapons, Protection, Control and Accounting assistance to Russia. Observes that the U.S. also had similar problems with its weapons storage in the 1960s and 1970s. Concludes that today security of nuclear weapons is Russia's problem but tomorrow it could again be a problem for the U.S., or for the U.K., France, India, Pakistan or Israel. This problem will remain as long as large stockpiles of nuclear weapons exist.

**“Russian Nuclear Warhead Storage Capacity and Dealerting Measures,”** *Proceedings of a Workshop Organized by the Free University of Berlin, Russian Pugwash Committee, and the Business and Innovation Center of Obninsk, Moscow-Obninsk, 12-17 June 2000.*

ABSTRACT: Western analysts have proposed de-alerting of strategic nuclear missiles, which could include the removal of nuclear weapons from deployed ICBMs and, in some cases, SLBMs. In addition, the U.S. has proposed under START II that missiles scheduled for destruction should be deactivated by 2004 by removal of their warheads. Some Russian military experts have argued that de-alerting in such a way is impossible because Russia does not have enough capacity to store the nuclear warheads. An analysis of the capacity of Russia's nuclear-weapon storage complex and its nuclear weapons dismantlement rate indicates, however, that, by 2003, the warheads from de-alerted or de-activated missiles could be accommodated. Thus de-alerting and deactivation measures involving warhead removal are feasible.

**“Russia's Nuclear and Strategic Forces in 2008-2013,”** *Proceedings of the VIII International Castiglioncello Conference, New Challenges in the Spread of Weapons of Mass Destruction, Castiglioncello, Italy, 23-26 September 2000.*

ABSTRACT: Updating research first published in 1995-96 by Handler, the current status and future prospects of the Russia's nuclear forces are analyzed. Due to economic constraints, Russia is likely to have a much smaller strategic force than permitted under START II or even START III. Concludes there is a strong Russian interest in further nuclear disarmament steps that perhaps could possibly include tactical nuclear weapons as well.

**JUNGMIN KANG**

**$U^{232}$  and the Proliferation-resistance of  $U^{233}$  in Spent Fuel** (with Frank von Hippel) submitted to *Science & Global Security*, 2000.

ABSTRACT. The factors influencing the level of  $U^{232}$  contamination in  $U^{233}$  are examined for heavy-water-moderated, light-water-moderated and liquid-metal cooled fast breeder reactors fueled with natural or low-enriched uranium and containing thorium mixed with the uranium or in separate target channels.  $U^{232}$  decays with a 69-year half-life through 1.9-year half-life  $Th^{228}$  to  $Tl^{208}$  which upon decay emits a 2.6 MeV gamma ray.

We find that pressurized light-water-reactors fueled with LEU-thorium fuel at high burnup (72 MWd/kg) produce  $U^{232}$  with  $U^{232}$  contamination levels of about 1 percent. At this contamination level a 5 kg sphere of  $U^{233}$  would satisfy the IAEA's standard for self-protection (100 rems/hr at 1 meter). The associated plutonium contains more than 15 percent of the undesirable heat-generating 88-year half-life isotope  $Pu^{238}$ .

It is also practical, however, to produce  $U^{233}$  containing only a few ppm of  $U^{232}$  in a heavy-water reactors if the thorium is segregated in “target” channels. The dose rate from a 5-kg solid sphere of  $U^{233}$  containing 5 ppm  $U^{232}$  could be reduced by a further factor of 20, to about 2 mrem/hr, with a close-fitting lead sphere weighing about 100 kg. Thus the proliferation resistance of thorium fuel cycles depends very much upon how they are implemented.

**Proliferation Resistance of Spent Thorium-Uranium Dioxide Fuel**, Proceedings, American Nuclear Society 2000 Annual Meeting, San Diego, CA, USA, June 4-8, 2000.

ABSTRACT. This study analyzes whether spent thorium-uranium dioxide fuel poses a significantly lower risk for nuclear weapon proliferation than spent uranium-dioxide fuel. The focus is on the radiation barrier to diversion and on the isotopic composition of the weapons-usable component of the spent fuel.

**Proliferation Resistance and Energy Security Advantages of a Thorium-Uranium Dioxide Once-Through Fuel Cycle for Light Water Reactors** Prepared for International Conference on Probabilistic Safety Assessment and Management PSAM 5, November 27- December 1, 2000, Osaka, Japan (with Tatsujiro Suzuki)

ABSTRACT. Recently, there has been a revival of interest in thorium in the U.S. and Western Europe because it can be used to increase the achievable burnups in light-water-reactors operating on a once-through fuel cycle and also reduce the quantity of weapons-usable transuranic elements in radioactive waste. Five successive neutron captures are required before  $Np^{237}$  is produced from  $Th^{232}$  whereas a single neutron capture on  $U^{238}$  produces  $Pu^{239}$  (see Fig. 1). Proposals have therefore been brought forward for light-water-reactor fuel cycles in which thorium largely replaces  $U^{238}$ .

This study analyzes whether spent light water reactor (LWR) thorium-uranium dioxide fuel poses a significantly lower risk for nuclear weapon proliferation than spent uranium-dioxide fuel, based on the isotopic composition of the contained uranium and plutonium. We also analyze the contribution that thorium-uranium dioxide fuel could make to energy security in uranium-import-dependent countries with large nuclear capacities such as Japan and South Korea.

**ZIA MIAN**

**“Defended to Death,” *The News On Sunday*, 29 August 1999**

India and Pakistan are governed by madmen. The prime ministers are mad, the generals, scientists, civil servants all mad. The proof of their madness is their paranoid obsession with security and nuclear weapons. What, after all, could be more insane than two desperately poor countries, struggling to feed, educate, and house their people spending scarce resources on preparing to murder millions of innocent people, then glorying in their capability and willingness to commit such a monstrous deed. More disturbing still is that while these madmen and their obsessions may mean the death of us, we do next to nothing about them. Perhaps the people, governed by lunatics for so long, have also quietly gone mad, to protect themselves from the consequences of understanding what is happening to them.

These thoughts have been brought on by India’s recently released nuclear doctrine, and the expectation that the madmen in Islamabad will follow those in Delhi and move a step closer to deploying their nuclear weapons, and a step closer to using them.

The Indian nuclear doctrine contains no surprises. It is what anyone should have expected from India's National Security Advisory Board, given that it is a nest of nuclear hawks. Asked to produce a doctrine, no one should have expected reason from them. Each was bound to try to out do the others, and none would relish being found wanting in patriotism or hard-headedness. Then there is the lure of history. The nuclear tests were about science and technology, and the scientists took the credit. As strategic thinkers, the National Security Board will take credit for having made the plan for how India's weapons are to be used. For some of them, this report is the culmination of decades of writing and arguing for India to have nuclear weapons; it reflects their hopes, dreams, fantasies, of a nuclear India.

Given how nationalistic these men are, how committed to a kind of independence at any cost, one is reminded, ironically, of Lord Macaulay's famous 1835 Minute on Education. Writing about British rule in India, he said the aim should be to create "a class of persons Indian in blood and colour, but English in taste and opinions, in morals and intellect." The British succeeded to the extent that a hundred or so years later it was anglicised Indians like Nehru and Jinnah who took over from them. American strategic thinkers, who preside like demented gods over their own nuclear weapons, can boast they have had the same effect in even less time. Despite all their differences, and animosities, within fifty years of inventing nuclear weapons, destroying Hiroshima and Nagasaki, and then claiming that nuclear weapons were for defence, the U.S. nuclear weapons complex has successfully created enclaves of Indians, and Pakistanis, who have exactly their nuclear "morals" and "intellect."

The tone and content of India's nuclear doctrine carries the stamp of the hardest of the hardest liners and their global fears and ambitions. The doctrine declares that "the very existence of offensive doctrine pertaining to the first use of nuclear weapons and the insistence of some nuclear weapons states on the legitimacy of their use even against non-nuclear weapon countries constitute a threat to peace, stability and sovereignty of states." It is this threat, the doctrine declares, that India's nuclear weapons are supposed to protect against. But the countries which have said they will use nuclear weapons first are the U.S., UK, France, Russia, and Pakistan. China has a policy of no-first-use. Israel has never said what it would do, but no doubt will use nuclear weapons whenever it feels like it. It is also the U.S., in particular, and its NATO allies, who have indicated policies of using nuclear weapons against non-nuclear weapons states.

The fixation on the U.S. is part of an established pattern. Indian hawks have always had global pretensions. For years, members of the National Security Advisory Board have justified Indian nuclear weapons with reference to the inequities of the international system and U.S. threats to India during the 1972 war with Pakistan. One member of the Board, Bharat Karnad, wrote last year that India's nuclear weapons should be aimed at "detering an over-reaching and punitive minded United States leading the Western combine of nations".

With this in mind, the doctrine is blunt, India's nuclear forces are aimed at "convincing any potential aggressor that... India ... shall inflict damage unacceptable to the aggressor". Worst case analysis, the kind of thing that nuclear hawks love, would suggest that India has to build a nuclear force able to retaliate against the U.S., even after a massive U.S. attack on India. This may seem absurd. The USSR tried it and ended up building over 30,000 nuclear weapons. How could India possibly manage it?

One way to try would be to follow the Chinese example. Following its first nuclear test in 1964, China is estimated to now have about 400 nuclear warheads. They are on aircraft, missiles, some artillery shells, and a few at sea. The majority are spread over about 20 locations, including some hidden in caves in mountainous regions, in the hope that they would survive an attack and could be used to retaliate - and kill even more people. China has about 20 missiles able to hit the U.S., each has a single warhead of 4,000-5,000 kt, (a hundred times more destructive than the hydrogen bomb India claimed to have tested, and a few hundred times more destructive than the simple atom bombs Pakistan claimed it tested).

It seems Indian hawks are hoping for something like a Chinese style arsenal which is to be developed over a long period of time. The doctrine describes a triad, with warheads on planes, missiles and at sea. Bharat Karnad has talked of 350-400 nuclear warheads and a cost of at least 700 billion rupees over the next thirty years as meeting the aims of the doctrine. It is certain to cost more, take longer, and be more difficult.

What does the Indian doctrine mean for Pakistan? There are enough madmen in Pakistan who will demand that, no matter what, we must do what India does. If India has a nuclear doctrine with operational nuclear forces we must have one also. We must have the planes, the missiles, the nuclear weapons at sea. They will say this for all the usual reasons - it satisfies their hate for India, feeds their ambition to father another bomb or a missile, guarantees them and their institutions even more money, and gives them more power. In previous situations they have prevailed. If they prevail again the arms race will enter an even more tortuous lap.

All the elements are there. Last May, Indian weapons scientists claimed that they had tested a Hydrogen bomb. Last week the head of India's nuclear program claimed not only that India could build a neutron bomb (an advanced kind of hydrogen bomb that generates a higher than usual amount of radiation), but that they could design and build bombs of "any type or size." Soon after the May tests last year, the managers of Pakistan's nuclear weapons program talked of being able to build a Hydrogen bomb, should they be asked, and provided they were given enough money. Now, it is said, Pakistan can build a neutron bomb also - although this verges on the unbelievable since Pakistan has not yet tested a simple hydrogen bomb.

The missiles too are being lined up. In April, Abdul Kalam, the head of India's missile programme said that the Agni-II, a 2,000-3,000 km range, was "operationally ready" for deployment with a nuclear warhead. In his independence day speech, India's prime minister announced that "AGNI-2 has been tested... and will be integrated into our defence arsenal." India's space launcher successfully launched three satellites from one rocket, and could be converted into an intercontinental ballistic missile with multiple warheads, given enough time and money. There is no doubt Pakistan's missile men will say that they too can achieve this, if they are given enough money.

There is no end to the madness. There is talk of an Indian anti-ballistic missile system that will shoot down incoming missiles. Bhabha Atomic Research Centre even claims it is building a device (called Kali-5000) that can be used as a beam weapon which "when aimed at enemy missiles and aircraft, will cripple their electronic systems and computer chips and bring them down." No doubt Pakistan's scientists will claim they can match that too - given enough money.

This is certainly the response from Pakistan that India's hawks hope for. In early July, the Hindustan Times ran a report "What Should We Do With Pakistan?" The first answer was "smash them." But it was not with nuclear weapons. General V.R. Raghavan (former Director General of Military Operations) said "Till now, we've borne heavy costs. Now we must impose costs." A former Foreign Secretary urged "We must hurt them in every single way..." Brahma Chellaney, a member of the National Security Advisory Board, went further: "Hit them when they least expect, ideologically, strategically and economically, with military force being only a small slice of the offensive." The Hindustan Times reported him as calling for economic warfare.

The clearest of all was K. Subrahmanyam, the guru of India's nuclear hawks and head of the National Security Advisory Board. He answered the question of what to do about Pakistan by saying "The perfect war is subjugation of the adversary without going to battle. If India raises its defence expenditure to 3 per cent of GDP from the present 2.3, Pakistan will try to match it and go broke. This was how the U.S. under Reagan precipitated the Soviet collapse." His plan is simple. Pakistan will be incited into an arms race that it is bound to lose. It will, in effect, defend itself to death. Unless there is war.

The alternative is to put the madness of the bomb behind us. To give it up while there is time, before the bomb's hateful machinery and its demented mechanics take complete control of life and death.

**"Nuclear dangers of another kind,"** *The News on Sunday*, 17 December 1999

**"Chashma - Almost too late,"** *The News*, 17 December, 1999

***Pakistan's Chashma Nuclear Power Plant: A Preliminary Study of Some Safety Issues and Estimates of the Consequences of a Severe Accident*** (with Abdul Nayyar), Princeton/CEES Report 321, December 1999.

ABSTRACT [of CEES Report 321]: The Chashma nuclear power plant in Pakistan is expected to begin producing power in March, 2000. Public information about the reactor is limited, but an analysis of available data suggests there may be grounds for concern about the safety of the reactor. Some of these concerns are outlined here and the effects of a severe reactor accident estimated.

The first concern about Chashma is the location of the reactor. The reactor is sited in an area that studies have shown to be seismically active and possibly able to generate a magnitude 7.0 - 7.5 earthquake. The reactor's site on the banks of the Indus River may increase the risk of an accident because the water-rich sandy soil there may be susceptible to liquefaction in response to an earthquake.

The second concern is the safety of the reactor design. Originally designed by the China National Nuclear Corporation as a replica of China's first indigenous reactor, Qinshan-1, the history of Chashma suggests that the design has been subject to repeated changes. Not all the suggestions made for improving the safety of the reactor appear to have been incorporated. The limited Chinese experience in reactor design and the changes that have been made may combine to make the behavior of the system as a whole less predictable and less reliable, and so less safe. The July 1998 accident at Qinshan-1 and China's subsequent resort to Western help to assess and repair the problem have exposed some aspects of the poor initial design. Unlike China, Pakistan would not have access to Western help to deal with them.

Also, unlike the prototype Qinshan-1 reactor, restrictions on the supply of nuclear technology to Pakistan have meant that Chashma's reactor pressure vessel, coolant pumps and control system, among other key systems, have been built in China. China's lack of experience with setting the requirements for such components and quality control during manufacturing may increase the risk of structural failures and equipment malfunction. This risk is compounded by the institutional inexperience of the Pakistan Atomic Energy Commission which has been limited to one power reactor that is among the worst performing in the world.

The methodology described in the 1975 American Physical Society "Study On Light Water Reactor Safety" is used to consider the consequences of a severe accident at Chashma. Assumptions about the release of radionuclides from the reactor's core to the atmosphere are combined with a simple model for the atmospheric transport and deposition of a radioactive aerosol to derive estimates of the radiation dose to people at distances of up to 300 km from the reactor.

The radiation doses resulting from inhalation of the aerosol, cloudshine from the passing cloud and contamination of the soil are estimated as causing, given the present population density, 12,000 - 23,000 cancer deaths, and perhaps three times as many cancer cases. The model suggests over 8,000 child deaths from thyroid cancer. Poverty, poor health care and other factors associated with underdevelopment would tend to increase this estimate.

Radioactive contamination of the ground would make it necessary to evacuate the population out to a distance of about 70 km from the reactor for a limited period, and perhaps permanently displace people living within about 30 km. Agricultural activity in these and perhaps larger areas would be affected.

Radioactive contamination of the Indus river could be caused by deposition of the released aerosol and by groundwater leaching radionuclides from the core mass remaining after meltdown. These slow processes acting over decades could be speeded up by the presence of earthquake faults close to the site, which may create channels for the contaminated water to reach deep into the groundwater as well as migrate horizontally up to 100 km.

The issues raised by Chashma are sufficiently important that the reactor should not be allowed to begin operation until these issues have been effectively addressed. At a minimum, operation of the reactor should not be allowed to begin until there has been a full, open, and independent expert review of the entire project, its possible public health and environmental impacts, and a study of all the alternatives that could meet the energy-production goal of Chashma.

**“Some Issues in Compliance: Arms Control and Disarmament”** (with Harold Feiveson). Prepared for Workshop on International Law and Organization, Center for the Study of International Organization, NYU Law School and the Woodrow Wilson School, Princeton University, February 18-19, 2000.

**“There will be no second time,”** by Zia Mian, *The Hindu*, 2 April 2000, and as **“Risking It All”** in *The News on Sunday*, 16 April 2000.

South Asia’s nuclear hawks have a pretty dismal record. First, they claimed that simply having a ‘nuclear option’ would be a convincing deterrent. This belief, that being able to build the bomb would be enough and there would never be any need to actually test it, was exploded in May of 1998. Having tested their bombs, they claimed that there would be peace between India and Pakistan -- cold, bitter and squalid, but still recognisably peace. Kargil put paid to that. Now the same set of do-it-yourself nuclear strategists are thinking out loud about how to manage and to use these weapons. Failure here will make their past mistakes seem small.

To understand the perils of command and control of nuclear weapons, there are few better people to ask than General Lee Butler, who until 1994 was the Commander in Chief of United States Strategic Command and had daily charge of thousands of nuclear weapons. In January of this year, he wrote about what he had seen in a lifetime of dealing with nuclear weapons: “The capacity for human and mechanical failure, and for human misunderstandings, was limitless. I have seen bombers crash during exercises designed to replicate, but which were inevitably far less stressful than, the actual conditions of nuclear war. I have seen human error lead to missiles exploding in their silos. I have read the circumstances of submarines going to the bottom of the sea laden with nuclear missiles and warheads because of mechanical flaws and human errors.”

If they deploy nuclear weapons, Pakistan and India will risk accidents caused by ‘human and mechanical failure’ and ‘human misunderstandings’. There are instances enough in both countries of accidents involving the very institutions that may have responsibility for these weapons. One need look no further than the accident record of the Indian and Pakistani airforce, which as the most high-tech of the armed services are the most familiar with having to handle complex systems. Moreover, given how few tests there have been of ballistic missiles by both countries, planes are still the most likely way they would try to deliver their nuclear weapons. The record is fateful. India’s Defence Minister George Fernandes informed Parliament in December 1998 that 79 fighter planes had been lost in accidents since April 1994. Most of these were because of technical defects or human error. About Pakistan, Air Marshal (retired) Ayaz Ahmad Khan writing in *Defence Journal* in August 1998, describes in stark terms that “in spite of the best efforts of PAF technicians and engineers, fighter aircraft have started falling out of the sky”. The cause of his concern were the 11 major PAF accidents between January 1997 and August 1998. A month later there was a crash between two C-130s at Chaklala air base.

There are no reports (yet) of accidents involving ballistic missiles in South Asia. The missile builders would try to keep them secret anyway. But experience elsewhere suggests accidents are certainly possible. For instance, in 1960, the U.S. BOMARC missile was in ‘ready storage condition’, which meant it was able to be launched at short notice. There was an explosion and a fire involving the missile’s fuel tanks. The nuclear warhead was destroyed in the fire, but fortunately did not explode. The safety devices built into the nuclear warhead worked. This was not an untested missile. It had received eight years of development and testing before it was deployed. The accident happened in the first year of deployment. The missile was liquid-fuelled, like Ghauri and India’s Prithvi.

This was by no means the only accident involving missiles. The U.S. Air Force has revealed that in a period of four years, between 1975 and 1979, there were 125 accidents at their missiles sites. There were a further ten from March 1979 to September 1980. There were other accidents. There always are.

## **“Chernobyl’s children,” *The News on Sunday*, 30 April 2000**

On 26 April 1986, mistakes by nuclear engineers led to an accident at the Chernobyl nuclear power station, in Ukraine in the former Soviet Union. The uranium fuel of the reactor became so hot that it started to melt and there was an uncontrollable release of radioactivity to the atmosphere. A one kilometer high cloud of smoke and intensely radioactive gas and dust was released. The wind spread this radioactivity across Northern and Southern Europe, and as far as Canada, Japan and the United States.

Fourteen years later, the scale and extent of the human suffering caused by the accident are still becoming evident. Perhaps the greatest and most unexpected suffering was that unleashed on the children living in the areas closest to the reactor, in particular the children of Belarus, Ukraine and Russia. In 1999, the World Health Organisation reported that “The geographical extent of ground contamination [by radioactive iodine] following the Chernobyl accident had not been anticipated... Now it is clear that a population of roughly 2.3 million children living in southern Belarus, northern Ukraine and the most easterly regions of the Russian Federation was exposed to significant amounts of radioactive iodine.”

Radioactive iodine causes thyroid cancer in children who breathe it in. The thyroid gland, located below the Adam’s apple in the neck, uses iodine to produce hormones that help regulate the pulse, blood pressure, and body temperature and it is particularly important in child development. Thyroid cancer can be fatal if not treated. In the most affected areas in Belarus the incidence of childhood thyroid cancer is now more than 100 and in some places 200 times the rate prior to the accident. According to the World Health Organisation, the increase in thyroid cancer has been found as far as 500 km from the Chernobyl reactor.

This and other evidence has led the World Health Organisation to recommend that all school age children should have immediate access to potassium iodide in the event of a nuclear accident, irrespective of distance from a nuclear facility. The more or less harmless potassium iodide acts to block radioactive iodine from reaching the thyroid. Britain has already decided to stock potassium iodide in schools, police stations and other locations near nuclear power plants. France has a similar program. This is a policy that all countries with nuclear reactors should adopt. It is particularly important in a country like Pakistan, where almost half the population is under the age of fifteen.

Closer to Chernobyl, the radioactive contamination was so great that everyone living within thirty kilometres was evacuated and may never be allowed to return. One concern is that the remaining half-melted mass of uranium fuel may slowly contaminate drinking water in the area and render it unsafe perhaps for the next one hundred years. The radiation would have spread much further if it had been allowed to get into the rivers. This was prevented by building giant underwater dams across the rivers. These and other emergency measures needed the labour of hundreds of thousands of workers, many of whom were exposed to radioactivity. The death rate among these exposed emergency workers is reported to be double the national average.

Chernobyl remains undeniably the worst nuclear accident to date. But there have been others. Most recently, on 30 September, 1999 a nuclear facility at Tokaimura, in Japan, had an accident which released radiation and exposed over 400 workers and people living in the surrounding community. The cause, again, was human not mechanical. Nuclear technicians - who were supposed to know what they were doing - cut corners and made a mistake.

The third worst nuclear accident was at Three Mile Island, in the United States, on March 28, 1979. A U.S. Presidential Commission set up to look into that accident concluded that when it came to nuclear safety “the fundamental problems are people related” and it is not just the technology. This realisation forced the Presidential Commission to admit that, despite its wide-ranging and detailed proposals to improve nuclear safety, “We have not found a magic formula that would guarantee that there will be no serious future nuclear accidents.”

There is significance in the fact that the three worst nuclear industry accidents in the world so far have all been in technologically advanced countries which have made enormous investments in nuclear science, technology and nuclear energy. It suggests a very important lesson. Nuclear technology does not tolerate error. And it is one of humanity’s oldest pieces of wisdom that people, even the best trained and the smartest, make mistakes. For those countries which have nuclear facilities but have not yet had a nuclear accident it may only be a matter of time and luck. Building and operating more nuclear reactors only serves to increase the risk. This is however the last thing that atomic energy commissions around the world can accept.

**“The Pakistani Record on Nuclear Disarmament,”** commissioned by Greenpeace International as part of a series on the international nuclear disarmament process for distribution to Member States to NPT Review Conference, April/May 2000

**ABSTRACT:** In May 1998 Pakistan tested nuclear weapons and declared a moratorium on further testing. Its current nuclear weapons capabilities are limited to simple first generation uranium fission weapons, with estimated yields comparable to the weapons used against Hiroshima and Nagasaki. It may not be capable of developing low yield tactical weapons, high yield boosted-fission weapons or two-stage thermonuclear weapons without further nuclear tests.

Pakistan’s current arsenal may amount to several tens of weapons, or equivalent fissile material. In addition to uranium enrichment it has begun to produce plutonium for nuclear weapons, but its overall production capacity may be sufficient only to add a few weapons each year. It has rejected a moratorium on fissile material.

Pakistan’s nuclear weapons delivery systems are its U.S. made aircraft or the 30 or so 300 km range missiles reportedly procured from China. Pakistan has tested various liquid and solid fuelled missiles, with ranges reported up to 2000 km. These tests have been limited to single flights and would not seem adequate to permit the missiles to be deployed as reliable military systems. Pakistan has not yet deployed its nuclear weapons, although it has recently announced a National Command Authority with responsibility for command and control.

Information on nuclear doctrine is limited. There are indications Pakistan would use nuclear weapons if during the course of a conventional military conflict key infrastructure or territory was threatened. The targets are likely to be Indian cities. Pakistan has refused Indian offers of a treaty of no first use of nuclear weapons.

Pakistan’s policy makers are struggling to reconcile their nuclear ambitions with the demands of the international community to sign the Comprehensive Test Ban Treaty, stop producing fissile material for nuclear weapons, and to not deploy these weapons. No agreement has been reached on any of these issues.

As part of its long standing policy to “keep the nuclear option open” and “keep up with India” Pakistan has proposed a “Strategic Restraint Regime” for South Asia. This would ban further nuclear tests, operation deployment of nuclear weapons, anti-ballistic missile systems, space based military capabilities, and restrict the purchase and development of advanced conventional weapons. It also seeks agreement on a balance in fissile materials stockpiles. India has so far refused to discuss such issues bilaterally.

Pakistan is not likely to renounce nuclear weapons in the absence of Indian moves towards nuclear disarmament. India has, in turn, linked its policies to those of the other nuclear weapons states.

**“Ending the n-race”** (with M. V. Ramana and Hui Zhang), *The Hindu*, 25 May 2000

After their nuclear tests in May 1998, the Governments of India and Pakistan sought to placate international criticism by announcing that they did not intend conducting more tests and promising to control nuclear technology exports. They have also not yet deployed nuclear weapons. But, India and Pakistan have continued building up stocks of plutonium and highly-enriched uranium for nuclear weapons in a fissile material race with profound economic, environmental and health consequences for their people. Stopping this race would benefit both countries. Using newly available commercial satellite images they could verify a production freeze independently with considerable confidence.

In December 1999, India’s Minister of State for Atomic Energy announced plans to construct a new plutonium production reactor comparable to its 100 MW Dhruva plant. The older 40 MW CIRUS reactor (which produced the plutonium for the 1974 nuclear test) is currently being refurbished. India’s Rattehalli uranium enrichment plant is likely to be used only to produce fuel for the planned nuclear submarine, and is of less immediate concern. Pakistan, for its part, has recently completed its 40 MW reactor at Khushab and continues operating its older Kahuta uranium enrichment facility.

India and Pakistan would be better off if they stopped the production of fissile material for weapons purposes. However, the atmosphere of mistrust and tension between India and Pakistan, resulting from the May 1998 tests and the subsequent Kargil war, makes even starting talks a problem. Their limited nuclear weapons capabilities also put a premium on keeping secret the scale and operational characteristics of their facilities, severely restricting if not eliminating possible on-site inspections to assess compliance with any agreement. Rather than try to resolve these difficulties straight away, both India and Pakistan could follow the example of the other nuclear states and unilaterally declare a moratorium.

In parallel, India and Pakistan could call on the nuclear weapon states (the U.S., Russia, the U.K., France and China) to formalise their existing moratoria on fissile material production and, along with Israel (the only other nuclear weapon state), start negotiations on reducing existing fissile material stockpiles. This initiative could, in turn, help free up the global Fissile Material Cut-off Treaty (FMCT) that has been stuck at the Conference on Disarmament in Geneva. The nuclear weapon states refuse to discuss their stockpiles in that forum and most non-nuclear weapon states insist that stocks must be addressed if the FMCT is to have any disarmament value.

By instituting a moratorium, Pakistan and India would do more than limit the health, environmental and economic consequences of large-scale fissile material production. Pakistan could prevent the escalation of an arms race that it can ill-afford, and would certainly lose - by an ever-increasing margin - if India were to build and operate its planned new reactor. Indian hardline concerns would be addressed by a Chinese normal commitment to not resume fissile material production as a response to U.S. deployment of ballistic missile defence systems. India would also be able to engage with the other nuclear weapons states to reduce their nuclear stockpiles, thereby limiting the requirements on the size of its own prospective arsenal, and shape a disarmament agenda that it has long been claiming to support.

Unlike the other nuclear weapon states, India and Pakistan lack the capability to independently assess whether the others (and especially each other) were keeping their word. The U.S. and its allies, and Russia, use various forms of high-tech spying, including satellite imagery to closely monitor each other and everyone else. However, recent developments in commercial satellite imaging, notably the IKONOS satellite owned by Space Imaging Inc., make it possible for anyone to buy pictures showing structures on the ground about one meter in size.

While less capable than military satellites, commercial images are now sufficient to detect nuclear facilities and, often, to assess whether they are operating. For example, analysis of IKONOS pictures released by the Federation of American Scientists (available on the internet at [www.fas.org](http://www.fas.org)) suggests the presence of water vapour emerging from the large cooling towers used to remove the heat generated by the operation of Pakistan's 40 MW Khushab reactor. This telltale sign is the first independent confirmation that Khushab is in fact operational. Under an agreement to cease fissile material production, which would require shutting down the Khushab reactor, evidence of water vapour plumes would be a give-away. Thus, by independently obtain images of each other's key nuclear facilities that are very revealing, India and Pakistan can gain confidence in a declared moratorium. They could, of course, gain even more confidence if they were to allow for some monitoring within the country.

Similarly, the images of India's CIRUS and Dhruva, the two reactors that are used to produce weapon-grade plutonium and part of a larger complex near Mumbai, suggest characteristic patterns forming as warm water carrying heat from the reactors is discharged into the ocean and begins to mix with seawater. Infrared images from commercial satellites such as Landsat 7 and ASTER, launched last April and December respectively, would enhance the already existing ability to monitor these cooling water traces. Since discharges from both reactors flow into the same body of water, it would not be possible to separately identify which reactor is operating. A fissile material moratorium would require both to be inoperative, and this could be verified. The medical and commercial isotope production at Dhruva, and possibly at Khushab, could be moved to nuclear power reactors in the respective countries. To build confidence that these power reactors are not contributing to the nuclear weapons stockpile, they could be put under international safeguards. At present, both power reactors in Pakistan, and four of the 12 in India are safeguarded.

The shutdown of Pakistan's Kahuta uranium enrichment centrifuge plant would be more difficult for India to verify from current satellite images. One way around this problem would be to look not at the enrichment plant itself but at the facility that produces the uranium hexafluoride gas, which is fed into Kahuta's centrifuges. The production of uranium hexafluoride is an energy intensive, high temperature, chemical and electrochemical process and may be detectable in thermal images. Since Pakistan has no use for uranium hexafluoride other than producing fissile material for nuclear weapons it would be feasible for its production to stop under a moratorium.

Stopping fissile material production in South Asia, like any other arms control or disarmament measure, is a question of political commitment; the technical capability to verify such a commitment is available. A halt now to fissile material production for weapons in South Asia, announced unilaterally and independently verifiable by commercial satellite images, offers an opportunity for Pakistan and India to avoid the long, dangerous, and expensive race that the U.S. and the Soviet Union ran for 40 years.

At the same time, their initiative could help push the nuclear weapons states to deal more urgently with the reduction of the vast stockpiles of nuclear weapons and fissile material they have accumulated. The fissile material gap could be closed by going down rather than up.

## **ABDUL NAYYAR**

**“Pakistan’s Chashma Nuclear Power Plant: A Preliminary Study of Some Safety Issues and Estimates of the Consequences of a Severe Accident”** (with Zia Mian), Princeton/CEES Report 321, December 1999.

ABSTRACT: See Zia Mian

## **M.V. RAMANA**

**“If Bombay was Bombed,”** Pakistan Peace Coalition, *Pakistan-India Nuclear Peace Reader* (Lahore: Mashal, 1999) pp.145-152

The paper briefly describes the effects of a hypothetical Hiroshima sized explosion over the Indian city of Bombay. The number of casualties in this case would range between 160,000 to 866,000 and are caused by the shock wave and nuclear radiation originating from the explosion as well as the firestorms that would be set off. These estimates are quite conservative and there are a number of reasons to expect that the actual numbers would be much higher.

**“Did India Test an H-bomb?”** (with Frank von Hippel), *FAS Public Interest Report*, January-February 1999, p. 8.

ABSTRACT. On May 12, the day after India’s test of a “thermonuclear device,” during an interview on National Public Radio’s evening-news program, “All Things Considered”, one of us (FvH) said that the 10-20 kiloton yield estimated by U.S. seismologists seemed low for a true two-stage device and suggested that India might have tested a “boosted primary,” i.e. a light-weight fission device whose yield was enhanced by the fusion of a few grams of deuterium and tritium, rather than a true two-stage thermonuclear explosive. A few days later, at a press conference on May 17, Dr. R. Chidambaram, chairman of India’s Department of Atomic Energy, stated categorically that India had tested a 43-kiloton thermonuclear bomb with two stages.

In September, U.S. seismologists came out with published analyses in “Science” and “Seismological Review Letters” suggesting that the yield was in the range of 10-15 kilotons. In response, Indian scientists from the Bhabha Atomic Research Center published two papers (<http://www.barc.ernet.in>) claiming that their studies confirmed the initial Indian yield estimate. They argue that U.S. seismologists underestimated the yield of the test because of destructive interference effects with the seismic signals from a simultaneous 15 kiloton test. This analysis has been reviewed and rejected by the U.S. seismologists.

In late November, Mark Hibbs a leading nuclear-industry journalist reported that “analysts at the Z Division of the Lawrence Livermore National Laboratory... based on classified data, have now concluded that the second stage of a two-stage Indian hydrogen bomb device failed to ignite as planned. As a result of the apparent failure, U.S. official sources said, the Indian government is under pressure by the Department of Atomic Energy...to test an H-bomb again.”

This report stimulated us to write an opinion piece for “The Hindu,” one of India’s leading newspapers, arguing that, if the first test failed, it provided India with an opportunity to reconsider its decision join the thermonuclear club. In response, we received a personal communication from Chidambaram through an intermediary rejecting “the outrageous lie that the Department of Atomic Energy has asked for more thermonuclear tests because the May 11 one failed.”

**“Beyond Lahore: From Transparency to Arms Control”** (with Zia Mian), *Economic and Political Weekly*, April 17, 1999

The Lahore meeting between the Prime Ministers of India and Pakistan led to some transparency measures being adopted between India and Pakistan. Beyond these, the participation by India and Pakistan in global arms control measures, such as the Comprehensive Test ban Treaty and the Fissile Material Treaty, are being contemplated. However, these measures themselves do not lead to a significant decrease in the nuclear danger that confronts the people of India and Pakistan in the wake of the nuclear tests of May 1998. A number of possibilities to reduce this danger such as commitments not to deploy nuclear weapons and movement of nuclear-capable missiles away from the border are proposed. Methods of verifying these agreements are also suggested.

**“Disarmament Judo: Using the NPT to make the Nuclear-Weapon States Negotiate the Abolition of Nuclear Weapons”** (with Zia Mian), *Disarmament Diplomacy*, No. 36, April 1999

Though it has been thirty years since the nuclear non-proliferation treaty was negotiated, the nuclear weapon states have not kept up their end of the bargain by getting rid of their nuclear weapons. The non-nuclear weapons, for the most part, have been exemplary in following the treaty. Over the past few years, several important initiatives have been proposed at the United Nations and the Conference on Disarmament to further nuclear disarmament. What has often been lacking is the ability to force the nuclear weapon states to negotiate. This paper proposes one method, using the Amendment clause of the NPT, to get the nuclear weapon states to negotiate disarmament.

**“For a Just Peace: The Anti-Nuclear Movement in India,”** *Social Science Research Council Newsletter*, Vol. 12, May 1999

**“Underground Tests: Ravaging Nature,”** *The Hindu Survey of the Environment* ‘99, June 1999, pp. 7-15

Governments and nuclear establishments the world over have tried to convince their citizens and others that underground nuclear tests pose no risks to their health and the environment. However, even based on the limited amount of data that is available, it has become abundantly clear that this is not the case. There are effects due to releases of radioactivity to both the atmosphere and ground water, as well as some potential problems due to the seismic shock wave arising from the explosion.

Following the nuclear tests by India and Pakistan, a large-scale antinuclear movement has been emerging in both countries. In comparison with the anti-nuclear movement in the US, the Indian movement is likely to be different. This is due to underlying social conditions as well as the markedly distinct political biographies of the activists involved in organizing.

**“Disturbing Questions: The MAPS Heavy Water Leak,”** *Frontline*, Vol. 16, June 4, 1999

On March 26, 1999, somewhere between 4 and 14 tons of heavy water leaked from the Madras Atomic Power Station in Kalpakkam, India. Based on data from previous accidents at the same reactor, this may have led to 1000 to 7000 Curies of radiation being released to the atmosphere. Further, and perhaps more serious, each worker involved in mopping up the spill could have received a radiation dose 6-8 mSv per hour. Since the volume of heavy water that leaked was quite large, workers may have spent several hours, perhaps days, on this operation. This may have led to doses well in excess of regulations.

**“Reinventing the Arms Race,”** *FORUM for Applied Research and Public Policy*, Vol. 14, No. 2, Summer 1999

The United State has committed under the Nuclear Non Proliferation Treaty to complete nuclear disarmament. However, nearly a decade after the end of the cold war and the collapse of the Soviet Union, the U.S. seems to be maintaining its nuclear arsenal for the foreseeable future, at considerable cost. This commitment is demonstrated by actions such as the Science Based Stockpile Stewardship Program, the Presidential Decision Directive 60, building Ballistic Missile Defenses, resuming Tritium Production and not proceeding with the START process. At the same time, international opinion increasingly favors rapid progress towards the abolition of nuclear weapons and several new initiatives have been proposed at the United Nations and the Conference on Disarmament.

**“Bombing Bombay? Effects of Nuclear Weapons and a Case Study of a Hypothetical Explosion,”** International Physicians for the Prevention of Nuclear War Report, July 1999

This report highlights the key effects of a nuclear explosion and describes the methodology for calculating these effects in the case of a nuclear explosion of arbitrary yield. These are then applied to a concrete case involving a hypothetical Hiroshima sized explosion over the Indian city of Bombay. The number of casualties in this case would range between 160,000 to 866,000. A 150 kiloton weapon could cause somewhere between 736,000 and 8,660,000 casualties. These estimates are quite conservative and there are a number of reasons to expect that the actual numbers would be much higher.

**“A Recipe for Disaster,”** *The Hindu* September 9, 1999

On 17 August 1999, the Indian government released a draft version of its nuclear doctrine. Despite a proclaimed commitment to “minimum credible deterrence”, the doctrine is based on ideas developed by the U.S. and Russia as they built up their arsenals to obscene levels. If the plans laid out in the doctrine are embarked upon, they would lead India down a path that promises an arms race and commits the nation to huge expenditures on a system that only furthers insecurity instead of increased security.

Indeed, it is the doctrine that is a recipe for a disaster and needs control. If implemented, it is sure to result in an arms race. Instead of furthering the cause of nuclear disarmament, it only promotes weaponization and leads India closer to the brink of an atomic abyss. Instead of security, it only leads to vulnerability. The time to step back is now. The doctrine must be firmly rejected and the path of weaponization must be reversed. Nuclear weapons must be abolished both from the region and the world. That is the only way to true security.

**“Sweeping Charges: The Cox Report and Nuclear Espionage,”** *Frontline* October 22, 1999

The Cox report received wide media coverage, both in the U.S. and elsewhere, including India. The issues raised by the Chinese official responses, as well as numerous critiques of the Cox report within the U.S., suggest that the Cox report and some of the allegations therein go beyond what was implied by available evidence.

Two questions need to be analysed. First, was China involved in nuclear espionage? Second, does information thus obtained give China a new, substantial capacity to design weapons that it was previously incapable of?

It would not be surprising if China, like most nations with nuclear ambitions, does indulge in nuclear espionage. But to prove it is another matter. Certainly nobody in either country has stepped forward and admitted to spying. Thus, it is difficult to conclude from public reports whether or not China stole classified information. However, it is worth noting that the U.S. itself obtained information about China's nuclear programs through spying.

With regard to the second question, it is important to remember that China has worked on nuclear weapons for decades. Based on evidence of the advanced nature of China's nuclear programs has led some American critics of the Cox report to point out that Beijing, even if it did spy, has made major breakthroughs on its own.

In the final analysis, the Cox report and the brouhaha surrounding it says more about the current climate in the U.S. than it does about China. It comes at a time when high levels of military expenditure and exorbitant, technically ineffective programs such as Ballistic Missile Defense are sought to be rationalised by invoking threats of irrational "rogue nations". Alongside this is the bogey of a new peril from terrorism, based on a presumption that there are "others" who are unethical and fundamentally opposed to the U.S. Feeding indirectly on such images, the Cox report's allegations about espionage adds to the sense of the U.S. being under threat, internally and externally.

### **"Organizing in India Against the Bomb," *Vital Signs*, Vol. 12, Issue 2, November 1999**

Following India's nuclear tests of May 1998, a widespread peace and anti-nuclear movement has emerged. In this context, presentations about the effects of nuclear weapons have been useful in raising the awareness about the dangers. One of the ways Indian peace movement has attempted to build wide-ranging democratic opposition to nuclear weapons is to emphasize the economical costs of these programs. One of the issues that anti-nuclear groups in India have to constantly battle is the fact that there are other countries that possess nuclear weapons. Trying to press for a purely regional solution while leaving global nuclear arsenals as they are will simply not work. The task of nuclear disarmament must simultaneously be local and global.

### **"Dangerous Encounters: Nuclear Reactor Accidents," *The Hindu*, November 21, 1999**

Despite accidents like the recent criticality accident in the Tokaimura uranium processing plant in Japan, the Indian nuclear establishment makes statements that confidently claim that no accidents will occur in Indian facilities. The confidence is misplaced because there *have been* several accidents over the course of the India's nuclear history – these include the fire at Narora, multiple heavy water leaks in Kalpakkam, the collapse of the containment at Kaiga and flooding of the pumps in Kakrapar. It was lucky that some of these did not result in major catastrophes.

Compounding the problem of over-confidence is the secrecy and control maintained by the institutions that construct and operate these reactors. This is not limited to India. But, with secrecy written into its mandate through the 1962 Atomic Energy Act – described as draconian even by a former Atomic Energy Chairman – the Department of Atomic Energy has been able to get away with it in a manner that has not been possible in many other countries. In part the secrecy reflects the close connection between nuclear power production and nuclear weapons development. But, it also serves to cover accidents, safety violations and poor performance. Therefore, one important step that needs to be taken to reduce the risk of accidents is to make the nuclear complex much more transparent. Making the Atomic Energy Regulatory Board, currently answerable to the AEC, independent and giving it clout to enforce safety standards would also help.

### **"The Question of Nuclear Yield," *Frontline*, January 21, 2000**

The controversy over the yields for India's May 1998 nuclear weapons tests shows no sign of abating. Faced with continuing scepticism from the international scientific community, India's nuclear weapons scientists have tried again to show that the yields they announced after the tests should be taken seriously. The evidence presented this time is the radioactivity of samples extracted from the sites after the tests [*Frontline*, 10 December 1999]. It shall convince no one since the data provided is seriously incomplete and cannot be used to infer anything about the yield.

The combined yield of the May 13 explosions was so small that it went undetected even by nearby seismic stations, including the ones at Nilore and the Kyrgyz network. On the other hand, both these sites recorded the May 11 explosions very well; for example, the signal-to-noise ratio at Nilore was over a 1000. Seismologists have also used filtering and cross-correlation techniques to search the regional data from Nilore for several hours before and after the announced time of the explosions. Though several signals from small earthquakes in the Hindu Kush region were recorded, no signal consistent with a test was found. Accordingly, they concluded that the seismic magnitude of the May 13 test was at least 500 times smaller than that of the May 11 explosions.

Even allowing for the possibility that the explosions were conducted in a sand dune, as Indian officials have claimed, these seismologists concluded that the tests are likely to have been less than 0.3 kilotons in size. (See Brian Barker *et al*, "Monitoring Nuclear Tests," *Science* Vol. 281, 25 September 1998) This is only about a third of the combined total of 0.8 kilotons claimed by BARC scientists. If these explosions were conducted in a medium similar to that of the May 11 tests, their yield would have been less than 0.1 kilotons.

In conclusion, the *publicly available* evidence so far suggests that the yields of the May 13 tests were much smaller than the announced yields. This would fit the definition of a fizzle, a test whose yield is much smaller than the design value. In the future, BARC should either provide *raw data* that can be independently analysed or stop producing papers that pretend to demonstrate their claims while not measuring up to scientific standards.

### **"Scientists and the Indian Bomb," Anubhav, February 2000**

The nuclear establishment that resulted from the collusion between Homi Bhabha and Jawaharlal Nehru was, from the very inception, secretive. To attempt to understand the reasons for Nehru's support for secrecy in the Indian nuclear establishment, we turn to an early quote of Nehru's dating back to 1946. In a remarkably forthright speech, he said, "As long as the world is constituted as it is, every country will have to devise and use the latest scientific devices for its protection. I have no doubt that India will develop her scientific researches and I hope Indian scientists will use the atomic force for constructive purposes. But if India is threatened she will inevitably try to defend herself by all means at her disposal." A year after the complete destruction of Hiroshima and Nagasaki, the "means" that Nehru alluded to were clear.

The role of the Atomic Energy establishment in pushing for the 1974 test is considerable. Apart from Bhabha, senior scientists like Homi Sethna, Raja Ramanna, P. K. Iyengar and R. Chidambaram played important roles in building up momentum to test. As summarized by George Perkovich, "Whatever Mrs. [Indira] Gandhi's calculus [in conducting the test], the fact remained that conducting the PNE was not her idea. She disposed what others proposed: it was Ramanna, Sethna, Iyengar, Chidambaram, and, before them, Bhabha who made the PNE possible. It was the weaponeers who went to the prime minister seeking sanction. In doing so, they represented a nuclear establishment that had failed to deliver on promises of cheap civilian power and was now facing severe budget cuts." The dominance of the Pokharan team within the Atomic Energy Commission can be deduced from the fact that all the leaders of the test went on to becoming heads of the Atomic Energy Commission.

Since the 1974 test, the nuclear establishment had been developing either the new designs for testing and lobbying with the government to allow them to conduct further tests. At least on one occasion in the early 1980s, Mrs. Indira Gandhi sanctioned a test, only to change her mind. Similarly, in 1995 and 1996, they nearly succeeded in obtaining permission to test. Unlike the 1974 test, now DAE scientists were joined in their lobbying by leaders of the missile program as well.

In 1998, due to a conjunction of several factors, the strategic enclave succeeded in having its way. Soon after the nuclear tests, the Indian Prime Minister Atal Behari Vajpayee publicly celebrated the role of the scientists who designed the weapons and conducted the explosions. Speaking at the Pokharan nuclear test site, Vajpayee built on an old slogan invented during the 1962 Indo-China War: Jai Jawan, Jai Kisan (Hail the Soldier, Hail the Farmer), by adding Jai Vigyan (Hail Science), thus raising science to the level hitherto reserved for those who protect the nation and feed its citizens. Left unsaid in this formulation is what kinds of science he was hailing. But, as must be obvious from the context, it is the kind of science practiced by the strategic enclave that he sought to place on a pedestal. Shortly thereafter, this projection also translated to massive budget increases for these establishments as well as several national awards to these scientists. This new public prominence and attendant political authority of India's

nuclear scientists, in addition to their traditional role as “experts,” is likely to translate into an even greater capability to influence nuclear policy.

**Old Weapons, New Contestants**, *IEEE Spectrum*, March 2000

Reviews of **India’s Nuclear Bomb: The Impact on Global Proliferation** by George Perkovich, University of California Press, Berkeley, 1999

**South Asian Mode of Weaponisation**, *Economic and Political Weekly*, March 11, 2000

and

**Ending the n-race** (with Zia Mian and Zhang Hui), *The Hindu*, May 25, 2000

(abstract under Zia Mian)

## **FRANK VON HIPPEL**

**“Did India Test an H-bomb?”** *FAS Public Interest Report*, January-February 1999, p. 8 (see M.V. Ramana)

**“When the dust settles: Depleted uranium is not the radioactive nightmare some say but it is still a dangerously toxic heavy metal”** *Bulletin of the Atomic Scientists* 55, Nov.-Dec. 1999, pp. 42-45, ([bullatomsci.org/issues/1999/nd99/nd99toc](http://bullatomsci.org/issues/1999/nd99/nd99toc)); see also, letter to the editor and the authors’ response, “The DU dispute continues,” Jan/Feb. 1999 issue, pp. 4-5. (with Steve Fetter)

**Proposed Anti-missile System Could be Neutralized by Air Bags**, letter to the editor, *Princeton Packet*, March 30, 1999.

ABSTRACT. In your March 23 issue, David Evans wrote that Representative Rush Holt’s vote against a national missile defense “lacks common sense.” In fact Holt’s vote was one of the best informed in Congress. He had just received a briefing showing that the Pentagon’s proposed \$10 billion starter anti-missile system could be overwhelmed by a single missile carrying a hundred aluminized air bags. These simple decoys could not be distinguished in space from the true warhead if it too were surrounded by an aluminized bag.

Based on his understanding of the action-reaction dynamics of nuclear arms races, Representative Holt also knew that the missile-defense program could actually prolong the danger to the U.S. from Russia’s missile force. By violating the 1972 U.S.-Russian Treaty Limiting Anti-Ballistic Missile Systems, it will make Russia reluctant to proceed with the all-important START II and START III missile reduction treaties. Finally, it may stimulate China to build up its missile force to ensure that it can deter any future nuclear threats such as those the U.S. made in the 1950s.

In summary Representative Holt’s vote displayed *uncommon* sense.

**“The Stockpile Stewardship Charade”** Invited comment on an article by Greg Mello, Andy Lichterman and Bill Weida, *Issues in Science and Technology*, Spring 1999, pp. 78-85.

ABSTRACT. When the Department of Energy’s Stockpile Stewardship program was designed, there was no significant policy review outside of the Department of Energy. A funding level was set but otherwise the design of the program was left largely to the nuclear-weapons laboratories. The resulting program focuses as much on the preservation of the weapons-design expertise of the nuclear laboratories as on the reliability of the weapons in the “enduring stockpile.” In the view of the weapons labs, these two objectives are inseparable. Mello et al, along with senior weapons experts such as Richard Garwin and Ray Kidder,<sup>38</sup> have argued that they are separable. Sorting out this question deserves serious attention at the policy-making level.

There is also the concern that, if the Program succeeds in producing a much more basic understanding of weapons design, it may make possible the design of new types of nuclear weapons such as pure-fusion weapons. I would draw some comfort if there were a national policy to forbid the nuclear-weapons labs from even *trying* to develop new types of nuclear weapons.

Finally, there is the concern that the interest in the national laboratories in engaging the larger scientific community in research supportive of the program of “science-based” stockpile stewardship may accelerate the spread of advanced nuclear-weapons concepts to other nations. The publication in the open literature of sophisticated thermonuclear implosion codes as a result of the “civilianizing” of inertial-confinement fusion by the U.S. nuclear-weapons design establishment provides a cautionary example.

**“The FMCT and Cuts in Fissile Material Stockpiles,”** *UNIDIR Disarmament Forum 2*, spring 1999, pp. 35-44.

ABSTRACT. Since no nuclear weapon can be made without using at least kilogram quantities of fissile material, a verified ban on new production, a Fissile Material Cutoff Treaty (FMCT), would make up a major portion of the regime required to monitor irreversible nuclear disarmament.

The most fundamental issues that will have to be negotiated will relate to:

- pre-existing stocks of military fissile materials in the nuclear-weapons states (NWS);
- extension into the NWS of the international safeguards regime that monitors civilian nuclear activities in non-nuclear-weapon states parties to the Non-Proliferation Treaty; and
- the separation and stockpiling by some countries of huge quantities of directly weapon-usable plutonium for non-weapons purposes.

The approach proposed here supports an FMCT with comprehensive safeguards on civilian nuclear facilities in all states, complemented by separate commitments from the states with the largest stockpiles of direct weapon-usable materials—civilian as well as military—to greatly reduce these stocks.

**“U.S. Can Begin Cutting its Tritium Needs and Nuclear Arsenal without STARTing,”** letter to the editor, *Physics Today*, May 1999, pp. 11, 13 (with Charles Ferguson)

ABSTRACT. Secretary of Energy Bill Richardson selected, on 22 December 1998, the Tennessee Valley Authority’s Watts Bar and Sequoyah nuclear reactors as preferred tritium production facilities for U.S. nuclear weapons. While we commend Richardson for choosing the least expensive method, the U.S. could reap even greater cost savings by reducing its nuclear arsenal in parallel with Russia’s retirement of obsolete and decrepit systems in its nuclear arsenal. Under START III, the total U.S. arsenal could fall below 3500 warheads if the need for thousands of extra warheads as an upload hedge were abandoned. In those cases, DOE could delay tritium production until after 2025. We believe that under longer-term reduction agreements, involving Russia, China, France, and the UK, the U.S. arsenal could shrink to only about 200 warheads—still more than enough explosive power to destroy any nation. This could make possible a delay in the resumption of tritium production until 2075.

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<sup>38</sup> Ray E. Kidder, “Problems with stockpile stewardship,” *Nature* 386, April 17, 1997, pp. 645-7.

***The Application of Commercial Observation Satellite Imagery for the Verification of Declared and Undeclared Plutonium Production Reactors***, PU/CEES Report No. 319, August 1999, <http://www.princeton.edu/~cees/pdf/reactor.pdf> (with Hui Zhang)

**“False Fears About a Test Ban,”** *Washington Post*, Outlook Section, Sunday, October 10, 1999; Page B07 (with Ray Kidder and Lynn Sykes)

More than 80 percent of the American people want a permanent ban on nuclear weapons tests, and support outside the United States is at least as high. This public support, sustained over 45 years, has powered the movement that persuaded the governments of 154 nations to sign a Comprehensive Test Ban Treaty, now awaiting ratification in the U.S. Senate.

The arguments against the test ban treaty today are the same as those that opponents used to slow its progress for 40 years: the fear that other countries will cheat and be able to reap advantages from small clandestine tests, and the belief that the only way to make sure that a nuclear weapon works is to test it.

The first argument is illustrated by a continuing controversy within the U.S. intelligence community as to whether Russia is conducting small underground nuclear tests on its Arctic test site. There have been repeated leaks, based on spy satellite images, that Russia is continuing to carry out activities on the island of Novaya Zemlya identical to those that used to accompany underground tests. Russian spy satellites are presumably detecting similar activities at the U.S. Nevada test site. The U.S. government says that we are carrying out permitted and essential zero-nuclear-yield (“sub-critical”) tests with plutonium. Russia says it is doing the same.

If the United States and other key countries ratify the test ban and the treaty comes into force, we can request an on-site inspection by the international Test Ban Treaty Organization. Inspectors will be able to go to the site where the suspicious activity took place and drill into the test chamber. If the drilling yields fresh fission products, a cheater will be exposed.

Still there is a possibility that a small nuclear test, carried out secretly away from monitored test sites, might escape detection. But what could be gained from such a test? Very little could be gained below the threshold for the “boosting” of fission explosives. And allegations about Chinese nuclear spying to the contrary, boosting the yield of a fission explosive with the fusion of a small amount of tritium-deuterium gas was the key step in the development of modern compact warheads, a “secret” that has been officially declassified for decades.

Testing boosting requires a nuclear explosion with a power of at least a few hundred tons of TNT, and full boosting gives yields of thousands of tons. This is beyond the level that could plausibly be concealed from U.S. seismic monitoring stations. The detection threshold would be lowered further if the treaty came into force and more seismic stations in other countries could be used.

The United States has done almost no testing for nuclear weapons development below 1,000 tons of TNT, so we can be comfortable with a ban on nuclear tests of all sizes.

What about the reliability argument? Here the most powerful counter would be to make public the statistical record of the remarkable success of U.S. nuclear tests. Nearly all of them were developmental tests. The analyzed classified record shows that since the U.S. nuclear establishment mastered the art of designing boosted thermonuclear weapons more than two decades ago, there have been virtually no failures. Except for tests that were exploring new design concepts or testing sensitivity to extreme environmental conditions, the deviations from theoretically predicted yields were remarkably small.

Given this level of understanding and the availability of non-nuclear means, such as sub-critical tests, to confirm the key properties of nuclear materials, there is no question that U.S. nuclear weapons can be maintained without nuclear testing.

On the surface, the debate over the nuclear test ban is about technical uncertainties. Below the surface, it is about competing priorities. Many test ban opponents care only that the United States be unconstrained in the development of nuclear weapons. If this country resumed testing, however, other countries would as well. They would improve their nuclear weapons much more than we would and the world would be pushed back closer to nuclear weapons use.

**“Missile defense -- A dangerous move,”** *Washington Post*, “Outlook” Section, Sunday, December 12, 1999, page B09 (reprinted in the *International Herald Tribune*, Dec. 23, 1999, p. 8 as “A Missile Defense System Isn’t What America Needs” (with Philipp Bleek)

Like an elephant stampeded by a mouse, the U.S. is being driven toward increased danger by the fear that North Korea or Iran could soon acquire nuclear-armed missiles that could reach the U.S. A U.S. national missile defense system is currently in development and a deployment decision on a “thin” defense against a small number of missiles is scheduled for July 2000.

The desire for both prestige and bargaining leverage may motivate North Korea and Iran to acquire intercontinental ballistic missiles. But these missiles are unlikely vehicles for a deliberate nuclear attack – unless a country wants to commit suicide. The attacker’s identity would be far easier to conceal if a boat or civilian aircraft were used.

It might make sense to invest in a missile defense “just in case” -- if the costs were only monetary. But as Chinese, Russian and West European officials have warned repeatedly and publicly in recent months, U.S. deployment of a national missile defense would have more far-reaching consequences.

China’s military has noticed that the first anti-missile base, proposed for Alaska to intercept a potential future threat from North Korea, is also positioned to shield against China’s small intercontinental missile force. The Chinese government fears that this might give the U.S. more freedom to back Taiwan if that island were to declare independence. China’s response to a deployment decision would likely be to build more nuclear-armed missiles capable of reaching the U.S. This would move the U.S. toward a large-scale missile confrontation with China similar to the one we are finding so difficult to dismantle with Russia.

Russia’s military is already worried about the vulnerability of its land-based missiles to attacks by an expanded NATO equipped with the precision-guided non-nuclear missiles and bombs demonstrated in Iraq and Yugoslavia. This insecurity is compounded by the fact that Russia can no longer afford to keep its ballistic-missile submarines hidden at sea. Russia’s missile generals see the proposed U.S. system as a first step toward construction of a shield against the small retaliatory strike that Russia could mount after a U.S. first strike.

To assure that any U.S. missile defense could be overwhelmed, Russia would keep as many nuclear warheads on hair-trigger, launch-on-warning alert as possible. This would increase the risk of an accidental or unauthorized Russian launch, arguably already the greatest threat to U.S. national survival.

Ironically, standard military worst-case assessments of a U.S. national missile defense by the Russian military could evoke these reactions even if more realistic analyses indicated that the missile defense would be unlikely to even intercept a few warheads. Although a U.S. missile defense could eventually be tuned to work against U.S. target test missiles, few experts believe it would work the first time against foreign missiles equipped with even simple countermeasures.

If the U.S. deployed missile defenses, Chinese and Russian missiles would certainly be equipped with countermeasures. As a result, even a few missiles, launched accidentally or without authorization, could penetrate the system. This simple fact has, in the past, sufficed to convince the U.S. that it would be pointless to deploy missile defenses.

Negotiating a START III agreement with Russia would be a far more effective way to reduce the nuclear threat to the U.S. Such an agreement would allow almost 4000 Russian missile warheads to be removed from their launchers by the end of 2007.

This comparison between defense and negotiated reductions illustrates the difficult truth that each U.S. Administration has had to relearn. The most effective protection against nuclear weapons is to strengthen the nuclear nonproliferation and disarmament regime in cooperation with other like-minded nations. As both Russia and our West European allies have emphasized, these cooperative efforts would most likely be derailed by a U.S. decision to go it alone in pursuit of illusory defenses.

Bill Bradley has thus far been the only presidential candidate to warn against a precipitous decision on national missile defense. He has also broken ranks by advocating that the U.S. respond to Russia's concerns about the unequal impact of START II by agreeing to begin negotiations on deeper START III cuts.

Other national politicians should follow Bradley's example and think again about the momentous choice between missile defense and missile reductions. If they do not, the undoing of post-Cold War reductions of the nuclear danger is all too predictable.

**'Radiation Risk and Ethics: Health Hazards, Prevention Costs, and Radiophobia,** letter to the editor, *Physics Today* 53, April 2000, p. 11.

Zbigniew Jaworowski's article, "Radiation Risk and Ethics" (*Physics Today*, September 1999, p. 24) revisits an issue which has been fought over for decades: Is there a threshold dose below which ionizing radiation is not harmful – or may even be beneficial?

This debate took place most publicly in the late 1950s and early 1960s, during the worldwide furor over the global radioactive fallout caused by the testing of multi-megaton nuclear weapons in the atmosphere. On the one hand, Edward Teller argued that the low-dose effects of the radioactive fallout were not proven and might even be "helpful."<sup>39</sup> On the other, Linus Pauling and Andrei Sakharov pointed out that, if the harmful effects of ionizing radiation were linearly proportional to dose, extrapolation from the observed effects of high doses would predict millions of cancers and other serious genetic diseases from the admittedly small individual doses but to billions of people.<sup>40</sup>

Since nuclear testing was driven underground, the main battleground for this debate has been in the regulation of nuclear power. Some believe that, if regulators were willing to act as if there were a threshold dose-rate level for cancer induction several times higher than natural background, nuclear reactors could compete more successfully with other sources of electrical power. Jaworowski claims that regulations based on the linear hypothesis cost "hundreds of billions of dollars" a year, a claim that is hard to fathom given that the *gross* annual worldwide revenues from nuclear electric power production is less than \$100 billion. (In 1997, nuclear power plants worldwide generated  $2.3 \times 10^{12}$  kWh.<sup>41</sup> In the U.S., the price for power at the power plant is 2-3 cents/kWh.<sup>42</sup> At that price, gross revenues in 1997 would have been between \$40 billion and \$70 billion.)

Jaworowski states that the political tide in the radiation-health community is now turning against the linear hypothesis. He even claims that the 1994 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) "recognized and endorsed the very existence of radiation hormesis," which he defines as "the stimulating and protective effect of small doses of radiation." In actuality, the UNSCEAR review concludes that, although such effects have been found in single-cell systems under special conditions, "extensive data from animal experiments and limited human data provide no evidence to support the view that the adaptive response of cells decreases the incidence of late effects such as cancer induction in humans after low doses."<sup>43</sup>

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<sup>39</sup> A. Serafini, *Linus Pauling*, Simon and Schuster (1989), p. 187.

<sup>40</sup> See, for example, Andrei D. Sakharov, *Sov. J. At. En.* 4, 576 1958; reprinted along with an analysis and update of the assumptions by F. N. von Hippel, *Science & Global Security* 1, 175-187 (1990).

<sup>41</sup> *Nukem Market Report*, September 1998, Table 1.

<sup>42</sup> *Nukem Market Report*, June 1998.

<sup>43</sup> United Nations Scientific Committee on the Effects of Atomic Radiation (hereafter UNSCEAR), *Sources and Effects of Ionizing Radiation*, New York (1994), p. 5.

The debate over the effects of low doses of ionizing radiation has raged for so long because it is impossible to detect statistically the small increases in cancer deaths predicted by the linear hypothesis. For example, the predicted increase in the fractional probability of dying from cancer due to the average cumulative dose of about  $10^{-3}$  Sieverts (0.1 rem) from global radioactive fallout would be less than  $10^{-4}$  according to UN and National Academy of Science reviews.<sup>44</sup> This is less than 0.0005 times the overall cancer death rate (about 0.2 per lifetime) which varies with lifestyle, genetic endowment, and environment. (It is worth noting that  $10^{-4}$  of the world's 1960 population of three billion predicts only about 300,000 extra deaths. Pauling and Sakharov's larger estimates also included the genetic consequences of the 5600-year half-life carbon-14 produced by [n,p] reactions on atmospheric nitrogen-14.)

An alternative avenue to the resolution of this debate may become available as molecular biologists sort out the genetic causes of cancer. At this point, it appears that several genes must be damaged before a cell can become cancerous.<sup>45</sup> Some critics of the linear hypothesis argue that, if radiation must damage  $n$  independent genes to cause a cancer, the cancer risk at low doses should go as (dose) <sup>$n$</sup> . Given that low doses of radiation add to other much larger sources of genetic damage, however, there will be a linear term when radiation damages only one gene and the other  $n-1$  are damaged by other causes -- or were inherited damaged.

***Using Commercial Observation Satellites to Verify that Uranium Enrichment Gaseous Diffusion Plants are Not Operating***, PU/CEES Report # 325, May 2000 (with Hui Zhang)

***Helping Russia Downsize its Nuclear Complex: Focus on Closed Nuclear Cities***

A Report of an International Conference held at Princeton University, March 14-15, 2000 (with Oleg Bukharin, Harold Feiveson, Sharon Weiner; Matthew Bunn; William Hoehn and Kenneth Luongo, June 2000 (see Bukharin for Executive Summary)

***A Longer Nuclear Fuse***, *Washington Post*, June 6, 2000 ; A27 (with Bruce Blair)

START II, the latest U.S.-Russian strategic arms reduction treaty, did not take effect when the Russian parliament finally voted approval in April. Conditions were attached. One is that the U.S. Senate first ratify amendments to the Anti-Ballistic Missile (ABM) Treaty negotiated by the Clinton administration in 1997 to allow theater missile defenses. The Senate's Republican leadership seeks instead to jettison the ABM Treaty, in order to clear the way for an ambitious U.S. national missile defense. Therefore, seven years after Presidents Bush and Yeltsin agreed to reduce deployed ballistic-missile warheads by about 60 percent, implementation of START II may still be many years away.

This means that the United States and Russia are each likely to keep an extra 1,000 missile warheads on alert, ready to launch within minutes if space- or ground-based sensors report an incoming missile attack.

The U.S. nuclear bureaucracy continues to be heedless of the dangers of this hair-trigger configuration. This was recently revealed in leaked U.S. government "talking points" from the January session of the negotiations aimed at persuading Russia to accept a "thin" U.S. national missile defense. Incredibly, the United States argued that, if Russia launched its missiles on warning of an incoming U.S. missile attack, enough would survive even a surprise attack to overwhelm U.S. defenses. This would only reinforce Russia's reliance on hair-trigger readiness and increase the risk of accidental firing of hundreds to thousands of nuclear warheads at the United States.

Presidents Clinton and Putin could dramatically reduce the risk of accidental launch by repeating the bold actions of Presidents Bush and Gorbachev when faced with a similar conundrum over START I implementation in 1991. To reduce the danger quickly, the presidents ordered immediate removal from launch readiness of a large fraction of the missiles slated for elimination.

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<sup>44</sup> UNSCAER, *Ionizing Radiation: Sources and Biological Effects* (New York, U.N., 1982), Table E-32; and *Health Effects of Exposures to Low Levels of Ionizing Radiation* (Washington, D.C., National Academy Press, 1990), Table 4-2.

<sup>45</sup> See e.g. Robert A. Weinberg, "How Cancer Arises," *Scientific American*, September 1996.

Presidents Clinton and Putin should similarly accelerate the downloading and storage of the approximately 3,000 warheads to be taken off missiles on each side by START II. This could be verified during the short-notice, on-site inspections allowed by START I. Final irreversible measures, such as destroying missile launchers, would be taken only after the START II treaty officially comes into force.

President Clinton, as the head of the country with much more invulnerable forces, should initiate this action, just as President Bush did in 1991. Wearing his hat as commander in chief, Bush announced that redundant U.S. missiles and bombers would unilaterally be taken off alert, and called on President Gorbachev to reciprocate. Russia's nuclear forces have become much more vulnerable since then, and President Putin probably cannot take the first step. If the United States led, however, world opinion would press Putin to follow suit.

In a recent speech, presidential candidate George W. Bush urged the rapid, even unilateral, de-alerting of nuclear missiles. He should join forces with a bipartisan effort to overturn Republican legislative strictures that attempt to limit the president's authority to change missile alert levels and warhead loadings. Former president Bush enjoyed wide latitude in this area. So should the sitting and future presidents.

Last weekend, at the Moscow summit, Presidents Clinton and Putin announced plans for a center in Moscow where early-warning data will be shared to address the growing danger of false warnings from Russia's crumbling missile-attack early-warning system. This is a constructive move. But the United States has only offered data that have been filtered through U.S. computers. The Russian military would surely disregard such data if it suspected a deliberate U.S. attack. In any case, this plan leaves the nuclear hair-trigger in place.

The immediate removal of the warheads in excess of the START II deployment limits would substantially reduce the risk of accidental nuclear attack. The United States would still have an enormous deterrent, including more than 1,000 survivable nuclear warheads in submarines at sea. Whoever occupies the White House after the election should take additional actions to lengthen the nuclear fuse.

**“The Hazard Posed by Depleted Uranium Munitions,”** *Science & Global Security* 8 (2000), pp. 125-161 (with Steve Fetter).

**ABSTRACT.** This paper assesses the radiological and chemical hazards resulting from the use of depleted uranium (DU) munitions. Due to the low radioactivity of DU, radiological hazards to individuals would become significant in comparison to natural background radiation doses only in cases of prolonged contact—for example, when shards of a DU penetrator remain embedded in a soldier's body.

Although the radiation doses to virtually all civilians would be very low, the cumulative “population dose” resulting from the dispersal of hundreds of tons of DU, as occurred during the Gulf War, could result in up to ten cancer deaths. It is highly unlikely that exposures of persons downwind from the use of DU munitions or consuming food or water contaminated by DU dust would reach the estimated threshold for chemical heavy metal effects. The exposures of soldiers in vehicles struck by DU munitions could be much higher, however, and persons who subsequently enter such vehicles without adequate respiratory protection could potentially be at risk. Soldiers should be trained to avoid unnecessary exposure to DU, and vehicles struck by DU munitions should be made inaccessible to curious civilians.

**“Building confidence in a fissile materials production moratorium using commercial satellite imagery,”** *UNIDIR Disarmament Forum* 3, 2000, pp. 71-77 (with Hui Zhang).

**Using Commercial Imaging Satellites to Detect the Operation of Plutonium-Production Reactors and Gaseous-Diffusion Plants,** (to be published by *Science & Global Security*, 2000, abstract under Hui Zhang).

**Using commercial satellites to build confidence in a moratorium on the production of fissile materials for weapons,** (to be published in *Disarmament Diplomacy*, with Hui Zhang), 2000.

**“U<sup>232</sup> and the Proliferation-resistance of U<sup>233</sup> in Spent Fuel,”** submitted to *Science & Global Security*, 2000 (see abstract under Jungmin Kang).

**“Getting Back to Basics: Controlling Fissile Materials,”** chapter for a book to be published by the Nonproliferation Policy Education Center (in press), 2000.

ABSTRACT. No nuclear weapon can be made without kilogram quantities of fissile material such as highly-enriched uranium (HEU -- uranium containing more than 20 percent U<sup>235</sup>) or plutonium.<sup>46</sup> Hopefully this situation will not change. Thus far it has been impossible to develop pure fusion weapons which would make it possible to bypass the choke point on nuclear-weapons manufacture provided by controls on fissile materials.<sup>47</sup>

Therefore, both arms-control and nonproliferation policy must deal with the problems of safeguarding fissile materials, controlling additional production, and secure disposition of materials made excess by nuclear disarmament or changes in nuclear-energy policy.

## SHARON WEINER

***Nuclear Cities Newsletter***, Electronic Newsletter, Volume I (December 1999), Volume II (forthcoming)

ABSTRACT. Nuclear Cities Newsletter is an electronic newsletter that provides information about events in Russia's ten closed "nuclear cities" that is relevant to U.S. efforts to create civilian jobs in these cities as well as discourage proliferation of the nuclear-material and weapons-making knowledge found there. Volume I chronicles developments in these cities over the last few years, with an emphasis on events since June 1999. It is divided into three parts. Section I discusses government and non-governmental initiatives in the nuclear cities; Section II provides a status report on U.S. government funding to date for activities in these cities; and Section III offers a closer look at recent developments in one of the nuclear cities. Volume II provides a web-based searchable database of assistance projects in the nuclear cities as well as updates on agreements, funding, and potential collaborations.

**Nuclear Disarmament and Nonproliferation: Choices for the World**, proceedings from the 31<sup>st</sup> United Nations Issues Conference, convened by the Stanley Foundation, February 25-27, 2000.

ABSTRACT. The Stanley Foundation's 31<sup>st</sup> United Nations Issues conference examined the current state of the nuclear arms control regime, the role of the United Nations in furthering disarmament, and prospects for the NPT Review Conference. Participants made several policy recommendations including reforms to the U.N. Security Council, increased resources for the U.N.'s Department of Disarmament, and renewed commitments by the nuclear weapons states to disarmament as outlined by the NPT.

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<sup>46</sup> According to the IAEA, it would require about 8 kg of Pu or 25 kg of weapon-grade uranium (90% U-235), including processing losses, to make a first-generation (Nagasaki-type) nuclear weapon. Advanced designs would require somewhat less. Among possible alternative fissile materials are U-233, which is produced by neutron capture in natural thorium-232 and Np-237 which is produced by two successive neutron captures starting with U-235.

<sup>47</sup> It should be international policy not to pursue the development pure-fusion explosives. In the near term only the U.S. has the technical and economic wherewithal to do so. See also Suzanne Jones, Ray Kidder and Frank von Hippel, "The Question of Pure Fusion Explosions Under the CTBT", *Physics Today*, September 1998, pp. 57-59.

***Helping Russia Downsize its Nuclear Complex: Focus on the Closed Nuclear Cities***, A Report of an International Conference held at Princeton University, March 14-15, 2000 (with Oleg Bukharin, Harold Feiveson and Frank von Hippel, Matthew Bunn, William Hoehn and Kenneth Luongo, June 2000 (see Bukharin for Executive Summary)

## **HUI ZHANG**

***The Application of Commercial Observation Satellite Imagery for the Verification of Declared and Undeclared Plutonium Production Reactors***, PU/CEES Report No. 319, August 1999, <http://www.princeton.edu/~cees/pdf/reactor.pdf> (with Frank von Hippel).

***Using Commercial Observation Satellites to Verify that Uranium Enrichment Gaseous Diffusion Plants are Not Operating***, PU/CEES Report # 325, May 2000 (with Frank von Hippel).

**Ending the N-race** (with Zia Mian and M. V. Ramana) *The Hindu*, 25 May 2000 (see Zia Mian).

**“Uses of Commercial Satellite Imagery in FMCT Verification,”** *The Nonproliferation Review*, Vol.7, No.2, 2000.

**“Potential Application of Commercial Observation Satellite Imagery for the Verification of Declared and Undeclared Nuclear Production Facilities,”** *The Proceedings of the INMM 41<sup>st</sup> Annual Meeting*, July16-20, 2000, New Orleans, Louisiana, to be published, 2000.

**“Detecting Undeclared Reprocessing Activities through Sampling Analysis,”** *The Proceedings of The INMM 41<sup>st</sup> Annual Meeting*, July16-20, 2000, New Orleans, Louisiana, to be published, 2000.

**“Potential Uses of Commercial Imaging Satellites to Strengthen Nuclear Non-Proliferation Regime,”** *The Proceedings of the 220<sup>th</sup> National Meeting of the ACS*, August 20-25, D.C. Washington, to be published, 2000.

**“Building confidence in a fissile materials production moratorium using commercial satellite imagery,”** *UNIDIR Disarmament Forum 3*, 2000, pp. 71-77 (with Frank von Hippel).

**“Using commercial satellites to build confidence in a moratorium on the production of fissile materials for weapons,”** (to be published in *Disarmament Diplomacy*, with Frank von Hippel), 2000.

**“Analysis of High Level Waste from a Reprocessing Plant—Issues of On-site Inspection of a Fissile Material Cutoff Treaty,”** *Science and Global Security*, to be published, 2000.

**Using Commercial Imaging Satellites to Detect the Operation of Plutonium-Production Reactors and Gaseous-Diffusion Plants**, to be published by *Science & Global Security* (with Frank von Hippel), 2000.

ABSTRACT. The operation of dedicated plutonium-production reactors and large gaseous-diffusion uranium-enrichment plants (GDPs), can be detected remotely using commercial observation-satellite imagery. Declassified Corona imagery is used to demonstrate that the new generation of commercial observation satellites with 1-meter spatial resolution will be able to detect vapor plumes inside and downwind from large operating natural-draft cooling towers. Low-resolution Landsat-5 thermal infrared images have been shown by other authors to be able to detect warm water discharges from reactors into lakes, rivers, etc. Here, the same systems are shown to be able detect the elevated temperature of the roofs of large operating GDPs. Commercial-satellite observations could therefore play an important role in increasing confidence in declarations that plutonium-production reactors and GDPs have been shut down as a result of a fissile-material-production moratorium or Fissile Material Cutoff Treaty.

## APPENDIX C. LECTURES, TALKS, WORKSHOPS

### OLEG BUKHARIN

Date	Title	Organization/Occasion
May 2, 2000	U.S.-Russian Warhead and Nuclear Material Security Cooperative Programs	Global Security Forum: Visit of Members of the State Duma of the Russian Federation, , Washington, DC
March 15, 2000	Down-Sizing of Russia's Nuclear-Weapons Production Infrastructure	Princeton University Conference "Helping Russia Down-Size Its Nuclear Weapons Complex," Princeton, NJ
November 4, 1999	The Status and Future of the Russian Nuclear Weapons Production Complex	RANSAC Briefing, The Stimson Center, Washington, DC

### HAROLD FEIVESON

Date	Title	Organization/Occasion
August 30, 1999	"Proliferation-Resistant Nuclear Power in a Greenhouse Constrained World"	Global 99: International Conference on Future Nuclear Energy Systems, American Nuclear Society, Jackson Hole, Wyoming
Sept. 14 - 17, 1999	Participant, "Nuclear Waste Dialogue"	Aspen Institute, Wye Plantation, Maryland
Feb. 18, 2000	"Compliance with Arms Control Regimes"	Project on International Law and Organization, Center of International Studies, Princeton University, Princeton
March 14-15, 2000	Participant, "International Conference"	International Conference on "Helping Russia Down-Size its Nuclear-weapons Complex," Princeton University
April 16, 2000	"An Israeli-Palestinian Water Accord,"	Middle East Association, Princeton
May 3, 2000	Participant, "Iran's Nuclear Policy and the Nuclear Non-Proliferation Treaty"	Institute for Science and International Security and the Persian Gulf/2000 Project, Columbia University, New York
June 24, 2000	"Diversion-Resistant Nuclear Power"	Workshop, Does Nuclear Energy Have a Role in Climate Change Mitigation?, Stanford University, Stanford
June 28-29, 2000	Participant, "Security Dialogue with Chinese"	Union of Concerned Scientists and Fudan University, Fudan University, Shanghai
June 30, 2000	"De-alerting"	Institute of Science and Public Affairs, Beijing

### JOSHUA HANDLER

Date	Title	Organization/Occasion
26 April 2000	U.S.-Russian Efforts to Improve Russian WPC&A: Shutting the Barn Door Before the Horse has Left?",	INMM/Carnegie Endowment Special Seminar "Russian Nuclear Security Programs and Prospects" Hyatt Capitol Hill, Washington, DC
5 October 1999	Russian Nuclear Weapons Storages and De-Alerting Measures	PIR Research Council, Moscow
23-26 September 1999	Russia's Nuclear and Strategic Forces in 2008-2013	VIII International Castiglione Conference, New Challenges in the Spread of Weapons of Mass Destruction, Castiglione, Italy

## JUNGMIN KANG

Date	Title	Organization/Occasion
July 28 – August 6, 1999	“U-232 Contamination and the Weapons-Usability of U-233”	The 11 <sup>th</sup> International Summer Symposium on Science and World Affairs, Shanghai, China
June 4-8, 2000	“Proliferation Resistance of Spent Thorium-Uranium Dioxide Fuel”	American Nuclear Society 2000 Annual Meeting, San Diego, CA

## ZIA MIAN

Date	Title	Organization/Occasion
August 8, 1999	Nuclear Weapons in South Asia	Peace Action 12th Annual National Congress, Albuquerque, N.M.
February 17, 2000	Pakistan, State-Building, and the Bomb	Workshop on Nuclear Understandings: Science, Society, and the Bomb in South Asia, Dhaka, Bangladesh
February 18, 2000	Nuclear Weapons: The Reality in South Asia	Opening Speech, International Conference on Nuclear Disarmament in South and Southeast Asia, Dhaka, Bangladesh
February 23, 2000	War, Peace, and Diplomacy: The Many Uses of Nuclear Weapons	Invited Lecture, Princeton Old Guard, Princeton University, Princeton
March 10, 2000	A Nuclear South Asia: What Next?”,	Invited Lunchtime Lecture to ‘The Chiefs’ (a group of Presidents and Directors of U.S. international affairs educational societies)
April 13, 2000	Mass Production, Mass Consumption and Mass Destruction - South Asia’s Coming of Age	Annual Mahatma Gandhi Lecture, Center for International and Area Studies, Yale University, New Haven,
April 14, 2000	Arms Control and South Asia	Briefings to editors and journalists: <i>Time</i> , <i>New York Times</i> , <i>Newsweek</i> , <i>Washington Post</i> , and <i>Associated Press</i> on issues to be debated in the year-2000 Nonproliferation Treaty review, New York City
April 24 2000	Our Nuclear Future	NGO Panel and Press Conference coinciding with the start of Nuclear Non-Proliferation Treaty Review 2000 Conference , UN Plaza Hotel, New York
May 2, 2000	South Asian Nuclearisation	Panel discussion organized by Movement in India for Nuclear Disarmament and Lawyers’ Committee on Nuclear policy to coincide with Nuclear Non-Proliferation Treaty Review 2000 Conference , United Nations, New York
May 17, 2000	What’s Next?: Strategies for Nuclear Disarmament After the Review Conference	Panel discussion organized by Lawyers’ Committee on Nuclear policy to coincide with Nuclear Non-Proliferation Treaty Review 2000 Conference, United Nations, New York,

## M.V. RAMANA

Date	Title	Organization/Occasion
July 28 - August 5, 1999	"Health Effects of Reactor Accidents"	11 <sup>th</sup> International Summer Symposium on Science and World Affairs, Shanghai, China
August 6, 1999	"Effects of a Nuclear Blast over Bombay"	Hiroshima Day Meeting, Chennai, India
August 19-23, 1999	Overview presentation for plenary on "Nuclear Policy and Understandings in India"	13 <sup>th</sup> Annual SSRC-MacArthur Foundation Fellows' Conference, New Delhi, India
August 25, 1999	"Bombing Bombay? Effects of a Nuclear Explosion and a Case Study"	Talk organized by the Movement in India for Nuclear Disarmament, India International Centre, New Delhi, India
February 17, 2000	Overview presentation	Workshop on "Nuclear Understandings: Science, Society and the Bomb in South Asia," Dhaka, Bangladesh
March 25, 2000	"The Future of Post-Nuclear South Asia"	Conference on "Rethinking the Past, Shaping the Future: Partition, History and Identity," South Asian Students Association of Smith College, Northampton, MA
April 8, 2000	"The Movement Against Nuclear Weapons"	South Asian Solidarity Seminar for Youth, Northeastern University, Boston, MA
April 18, 2000	"NPT Forecast: Cloudy or Sunny"	NGO Presentation in preparation for the Nuclear Non-Proliferation Treaty Review Conference, United Nations, New York

## FRANK VON HIPPEL

Date	Title	Organization/Occasion
July 26, 1999	"A U.S. Perspective On The Commercial Separation And Recycle Of Plutonium In Spent Power-Reactor Fuel"	Briefing for Minister of Technology and Industry, John Battle, London, U.K.
July 28, 1999	"Next Steps in Nuclear Disarmament"	Oxford Research Group Workshop, Oxford, UK
Sept. 3, 1999	"To Reprocess or Not: Security Issues"	Radioactive Waste Management Workshop, Beijing, China
Sept. 13, 1999	"Getting Back to Basics: Controlling Fissile Materials"	Nonproliferation Policy Education Center, Army-Navy Club, Washington, D.C.
Nov. 19, 1999	"Taking Nuclear Weapons Off Hair-Trigger Alert,"	Jones Seminar on Science and Society, Dartmouth College, Hanover, NH
Dec. 2, 1999	"The Need for a Report that Clarifies and Puts into Perspective the Technical Arguments Against the Comprehensive Test Ban Treaty"	Arms Control and Nonproliferation Advisory Board, State Dept., Washington, D.C.
Dec. 2, 1999	"Whither Production-Reactor Conversion?"	Vice President's National Security Advisor and interagency group, Old Executive Office Building, Washington, D.C.
Dec. 8, 1999	"The Train Wreck in Nuclear Disarmament"	Paideia student discussion group, Princeton University
Feb 3, 2000	"The End of Arms Control?"	Science, Technology, Environment and Policy Seminar, Princeton University
March 14, 2000	"Conference Overview,"	Opening talk at International Conference on "Helping Russia Down-Size its Nuclear-weapons Complex," Princeton University

## FRANK VON HIPPEL (CONTINUED)

Date	Title	Organization/Occasion
April 13, 2000	“Report on the Conference, ‘Helping Russia Downsize its Nuclear Complex’”	Annual meeting of the Center for International Studies Advisory Council, Princeton University
April 14, 2000	“De-alerting and National Missile Defense”	Briefings to editors and journalists: <i>Time</i> , <i>New York Times</i> , <i>Newsweek</i> , <i>Washington Post</i> , and <i>Associated Press</i> on issues to be debated in the year-2000 Nonproliferation Treaty review, New York City
May 4, 2000	“Taking Nuclear Weapons Off Hair-Trigger Alert”	Peace Studies Seminar, Cornell University
May 24, 2000	“The NMD Decoy-discrimination Flap: An Achilles Heel?”	Arms control lunch, Princeton University
June 3, 2000	“The Clinton-Putin Summit”	Coalition for Peace Action rally; Palmer Square, Princeton
June 7, 2000,	“Preserving the Safety and Reliability of U.S. Nuclear Warheads Under a CTBT”	DC Science Writers’ Association, Washington
June 27, 2000	“Reviving the Nuclear Cities Initiative”	NCI Workshop, Institute for Physics and Power Engineering, Obninsk, Russia

## SHARON WEINER

Date	Title	Organization/Occasion
March 14, 2000	“Background on U.S. Cooperative Activities in Russia’s Nuclear Cities”	International Conference on “Helping Russia Down-Size its Nuclear-weapons Complex,” Princeton University

## HUI ZHANG

Date	Title	Organization/Occasion
Feb. 29, 2000	Use of Satellite Images to the Verification of Nuclear Facilities and Transparency of China’s Nuclear Facilities	Kennedy School of Government, Harvard University.
August 1999	Civilian Imaging Satellites and the Verification of Plutonium Production Reactors and Gaseous Diffusion Plants	Center for Energy and Environmental Studies, Princeton University.
August 2000	Potential Uses of Commercial Imaging Satellites to Strengthen Nuclear Non-Proliferation Regime	The 220 <sup>th</sup> National Meeting of the ACS, August 20-25, D.C. Washington.
July 2000	Detecting Undeclared Reprocessing Activities through Sampling Analysis	The INMM 41 <sup>st</sup> Annual Meeting, July16-20, 2000, New Orleans, Louisiana.
July 2000	Potential Application of Commercial Observation Satellite Imagery for the Verification of Declared and Undeclared Nuclear Production Facilities,	The INMM 41 <sup>st</sup> Annual Meeting, July16-20, 2000, New Orleans, Louisiana.

## **APPENDIX D. SOURCES OF FUNDING FOR RESEARCH**

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## APPENDIX E. ARTICLES ENCLOSED

Oleg Bukharin et al, *Helping Russia Downsize its Nuclear Complex* (Princeton University, June 2000)

Joshua Handler, “Lifting the Lid on Russia’s Nuclear Weapons Storage,” *Jane’s Intelligence Review*, August 1999

Zia Mian, M. V. Ramana and Hui Zhang, “Ending the N-race,” *The Hindu*, 25 May 2000

M. V. Ramana, “A Recipe for Disaster,” *The Hindu*, September 9, 1999

Zia Mian, “Nuclear Dangers of Another Kind”, *The News on Sunday*, Islamabad, 8 August, 1999; “Almost too Late,” *The News*, Islamabad, 17 December 1999

Zia Mian, and A.H. Nayyar, “Potential Risks and Consequences of an Accident at the Chashma Nuclear Power Plant”, *The News on Sunday*, 23 January, 2000

Zia Mian, “Chernobyl’s Children”, *The News*, 30 April 2000

Zia Mian, “Risking It All”, *The News on Sunday*, 16 April 2000

Steve Fetter and Frank von Hippel, “When the dust settles: Depleted uranium is not the radioactive nightmare some say but it is still a dangerously toxic heavy metal,” *Bulletin of the Atomic Scientists* 55, Nov.-Dec. 1999

Harold Feiveson and Bruce Blair, “How to Lengthen the Nuclear Fuse,” *IEEE Spectrum*, March 2000

Frank von Hippel and Bruce Blair, “A Longer Nuclear Fuse,” *Washington Post* op-ed , June 6, 2000.

Philipp Bleek and Frank von Hippel , “Missile defense -- A dangerous move,” *Washington Post*, Dec. 12, 1999

Ray Kidder, Lynn Sykes and Frank von Hippel, “False Fears About a Test Ban,” *Washington Post*, Oct. 10, 1999

Joshua Handler, “Under Suspicion,” *IEEE Spectrum*, March 2000

Joshua Handler, “The Nikitin Affair: An Acquittal at Last?” *Bulletin of the Atomic Scientists*, March/April 2000

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