FONAS

Forschungsverbund Naturwissenschaft, Abrüstung und internationale Sicherheit

Research Association Science, Disarmament and International Security

Nuclear Weapons - Armament of Space - Weapons of Mass Destruction - Chemical and Biological Weapons - Concepts for a Nuclear Weapon free world - Nanotechnology and new Weapon Systems - Detection of clandestine Fissile Material production - Technology assessment of an international fusion research and technologies - Verification of conventional Disarmament in Europe - Weapons of Mass Destruction and Terrorism - Modeling of Conflict and Cooperation-Climate change and Security - "Non-lethal" weapons - Non-Proliferation - Missile Defense - Laser Weapon - Modeling of Conflict and Cooperation - Weapons of Mass Destruction - Climate change and Security - "Non-lethal" Weapons – Non-Proliferation - Nuclear Weapons - Missile Defense-Laser Weapon - Nuclear Weapons - Armament of Space - Weapons of Mass Destruction - Chemical and Biological Weapons - Concepts for a Nuclear Weapon free world - Nanotechnology and new Weapon Systems - Detection of clandestine Fissile Material production - Technology assessment of an international fusion research and technologies - Verification of conventional Disarmament in Europe - Weapons of Mass Destruction and Terrorism - Modeling of Conflict and Cooperation-Climate change and Security - "Non-lethal" weapons – Non-Proliferation - Nuclear Weapons - Armament of Space - Weapons of Mass Destruction - Chemical and Biological Weapons - Concepts for a Nuclear Weapon free world - Nanotechnology and new Weapon Systems - Detection of clandestine Fissile Material production - Technology assessment of an international fusion research and technologies - Verification of conventional Disarmament in Europe - Weapons of Mass Destruction and Terrorism - Modeling of Conflict and Cooperation-Climate change and Security - "Non-lethal" weapons - Non-Proliferation - Missile Defense - Laser

NEWSLETTER No. 11

February 2012

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Editorial

FONAS ("Forschungsverbund Naturwissenschaft, Abrüstung und internationale Sicherheit", Research Association Science, Disarmament and International Security) is the most important network of scientists working on disarmament and peace research in Germany. The present report is the eleventh edition of the FONAS Newsletter, in which the reader will find scientific papers as well as summaries of conferences and other information regarding scientific peace research in Germany.

The Newsletter begins with two extensive contributions regarding the production of fissile material and nuclear nonproliferation. Moritz Kütt's report focuses on plutonium production in fast reactors and the associated proliferation risks using the example of the German reactor project "SNR-300". A comprehensive analysis of global plutonium production capabilities with research reactors is done by Jochen Ahlswede.

In the following section, the reader will find proceedings of ten conferences, both national and international, which were organized or attended by FONAS members (partly in German). Highlights of the last year definitely have been the 59th Pugwash Conference in Berlin, the 23rd Summer Symposium on Science and World Affairs in London and the XXIV ISODARCO Winter School in Andalo (Italy). But also other workshops and meetings on a variety of topics, like geo-engineering, disarmament verification, arms race in cyberspace, contributed to an active scientific exchange within the national and international community.

Martin Kalinowski, chairman of FONAS, reflects in his contribution the problematic situation at one of the largest institutions for scientific peace research in Germany, the Carl-Friedrich von Weizsäcker Centre for Science and Peace Research (ZNF) in Hamburg.

At the end, the annual report (in German) of the FONAS association as well as a list of selected publications of FONAS members are provided.

Jochen Ahlswede, February 2012

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Proliferation risks of Fast Reactors

by Moritz Kütt

Introduction

The following article presents a summary of my master thesis "Neutronic Calculations: Proliferation risks of Fast Reactors" which has been written at the Interdisciplinary Research Group on Science, Technology and Society (IANUS), Technische Universität Darmstadt. The master thesis studied the proliferation aspects of plutonium fuelled fast reactors able to breed more plutonium. It has been the main goal of the work to develop a software system to carry out burnup calculations in order to answer two key questions for different fast reactor models:

1. *How much plutonium can a fast reactor produce per year?*

   The amount of plutonium is relevant for the reactor's capability to support a weapon program in a state or the possibilities for non-state actors to divert material. In contrast, a negative rate could help to reduce plutonium stockpiles. For both cases the amount of plutonium that is required and handled during operation is also proliferation relevant.

2. *What is the isotopic composition of the produced plutonium?*

   Among the different plutonium isotopes, ^{239}Pu is the main fissile isotope. If a plutonium mixture contains fractions of other isotopes like ^{240}Pu or ^{238}Pu it becomes less attractive for the use in nuclear weapons. Compositions are often classified as reactor-grade or weapons-grade plutonium depending on the content of ^{240}Pu. However, nearly all variations of plutonium can be used in nuclear weapons.

The software system is based on MCMATH, a computer code developed by IANUS since 1998. Besides developing and validating the software, calculations for the German fast reactor project SNR-300 ("Schneller-Natrium-Gekühlter Reaktor", 300 MWe) are carried out, acting as a case study for future assessments.

Looking at the timeliness of the research question, two aspects are visible. First, many fast reactor programs (France, Germany, Italy, UK, USA) have been stopped or halted in the past. Second, in scenarios of a possible "nuclear renaissance", fast reactors are said to play a crucial role. Russia, Japan, China and India operate fast reactors or are in the process of building new sites. Two international initiatives ("Generation IV International Forum" and "International Project on Innovative Nuclear Reactors and Fuel Cycles") propose new generations of nuclear reactors, including fast reactors.

These facts indicate that there is again increasing interest in fast reactor technology. But in general the interest in and published knowledge of the proliferation aspects of the technology seem to be rather low. The master thesis will hopefully help create relevant knowledge in this field.

Breeding Fissile Materials

Actinides can be fissioned either with thermal or fast neutrons. But only a few of them can be fissioned with a high fission cross section over the whole energy spectrum and without competing absorption processes. These nuclides are usually referred to as fissile materials. ^{235}U and ^{239}Pu are the most prominent ones; others include ^{233}U, ^{241}Pu and ^{237}Np. Only ^{235}U can be found naturally on earth in large quantities.

A fertile material is a nuclide that can be converted into a fissile material by neutron capture(s). Typically, its absorption cross section is bigger than its fission cross section. The most important fertile material is ^{238}U, which can be converted into ^{239}Pu by

$$^{238}U \xrightarrow{(n,\gamma)} {}^{239}U \xrightarrow[T_{1/2}=23.45m]{\beta^-} {}^{239}Np \xrightarrow[T_{1/2}=2.54d]{\beta^-} {}^{239}Pu$$

A reactor that produces more fissile material than it consumes is called a breeder reactor. Besides using uranium as fuel and fertile material, it can also be constructed with other combinations of the fissile and fertile materials listed above. The fissile material produced during reactor burnup is embedded in fuel or breeding blanket elements. These elements also contain remaining fertile material, fission products and other actinides. The elements cannot be reused directly; the fissile material has to be separated from the mixture in reprocessing facilities. Afterwards new fuel elements can be produced.

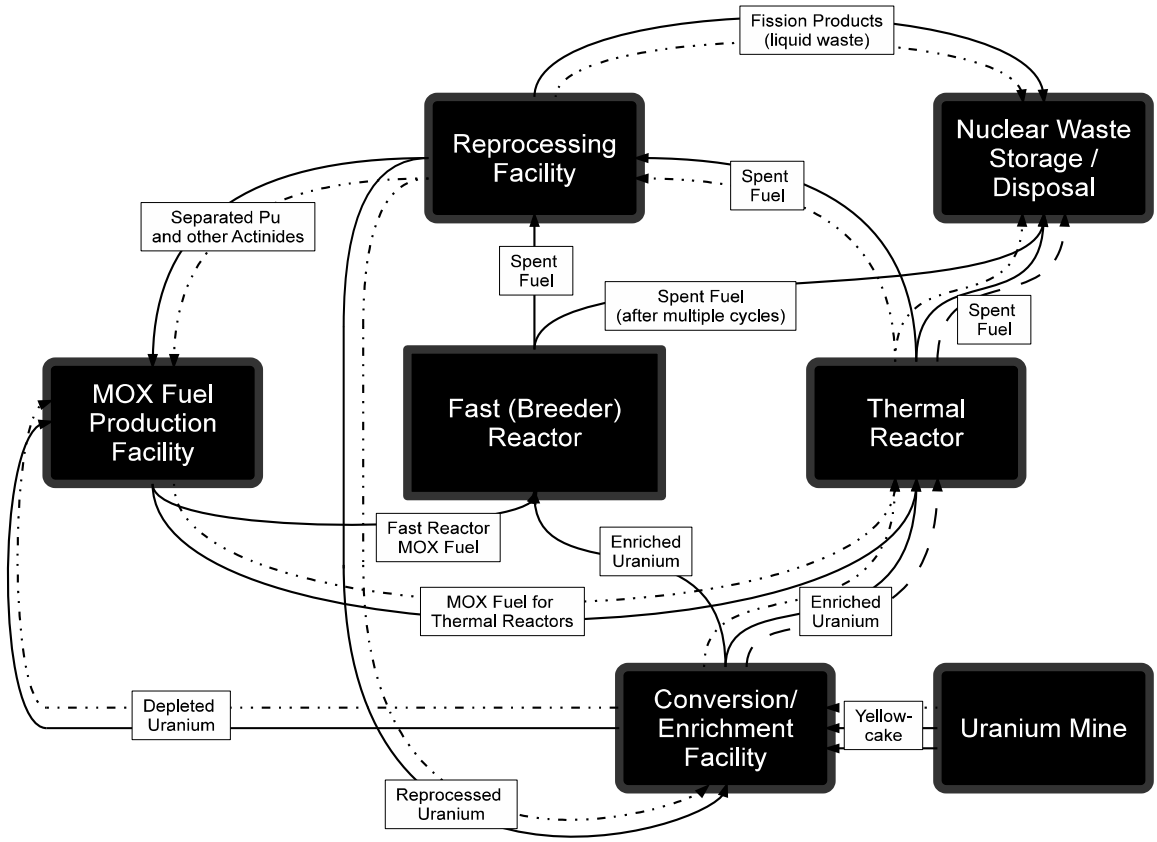

Figure 1: Breeder fuel cycle.

Reprocessing methods can be separated mainly into two groups, aqueous solvent extraction (hydrometallurgic) methods and pyrochemical processes. The most common process for reprocessing is the PUREX process (aqueous). It is the only process used on a commercial scale.

In Table 1, all plants that have the status "operational" in (IPFM 2010) are listed. Japan and the UK have facilities "temporarily shut down" and China has a facility "starting up". Belgium, Germany and the United States had reprocessing facilities in the past. Until today, most of the reprocessed fuel was produced in thermal reactors. Only in three countries, fuel from fast breeder reactors was reprocessed: Russia (450 t), France (100 t) and UK (10 t) (IAEA 2008).

Table 1: Currently operation reprocessing plants (IPFM, 2010).

Country	Site	Capacity (tHM/year)
France	La Hague UP2	1000
	La Hague UP3	1000
Israel	Dimona	40-100
India	Trombay	50
	Tarapur	100
	Kalpakkam	100
Russia	Chelyabinsk	200-400
Pakistan	Nilore	20-40

Proliferation Scenarios in Fast Reactor Fuel Cycles

If a country is using a plutonium-fuelled breeder for energy or fissile material production, a large amount of separated plutonium already exists in this country. However, the use of breeder reactors can still increase the proliferation risk. Figure 1 shows a simplified schematic drawing of elements of such a fast reactor fuel cycle. Important elements have been included, not all elements and connections necessarily need to be relevant for a specific case. Besides the fuel cycle for breeder reactors (solid arrows), two other fuel cycle options are shown. The simplest case is the once-through cycle (dashed arrows), where uranium is mined, converted/enriched, used once in a thermal reactor and the

spent fuel is stored in a final disposal. This is the currently predominant cycle (or fuel chain). The second option includes reprocessing spent fuel and reusing the reprocessed plutonium again in thermal reactors (dotted arrows). Currently, France, UK, Germany and Japan partly use this option.

The breeder fuel cycle has many more elements than the once-through cycle. After uranium fuel is used in thermal reactors, the spent fuel is reprocessed to extract plutonium for breeder reactors. The spent fuel from breeder reactors will also be reprocessed to fuel new breeder reactors or thermal reactors. Spent fuel cannot be recycled indefinitely, after one or a small number of cycles it must be disposed of as nuclear waste. Related to the breeder fuel cycle are two possible scenarios for proliferation.

In a **first scenario**, a proliferator would try to acquire enough fissile material for at least one nuclear weapon by diverting it covertly from an existing source in a state. The proliferator in this case could be either the state itself or a non-state actor. Such a diversion could take place at different points in the fuel cycle, especially at bulk handling facilities or during transportation.

In bulk handling facilities (e.g. reprocessing facilities, fuel production facilities) the materials are processed in form of powders, gases or liquids and stored in large containers or transported via systems of pipes. It is very difficult to account for all materials with a high precision because uncertainties in measurements, residual holdup of material and accumulation of scrap are quite likely. Such differences are called *material unaccounted for*. The amount of unaccounted material can be higher than a significant quantity, especially in large facilities with an annual throughput of several tons of plutonium. A possible proliferator could exploit this fact.

As far as it is publicly known, there are no examples of past proliferation cases as described by this scenario. But there have been several cases in which discrepancies in the accounting of materials occurred in bulk handling facilities (cf. French 2003, BNFL 2005, Lyman 2008).

Besides diversion in a facility, there is a risk of diversion during transport. Because often reprocessing and fuel production is done at distant places, transport of directly weapon usable material will be required. An intensive use of breeder reactors would not only lead to a large number of facilities, but also to a large number of material shipments, all increasing the proliferation risk.

A **second scenario** might be the possibility that a country will openly construct a breeder fuel cycle for the purpose of material generation for nuclear weapons, at least partially. It could also convert an existing fuel cycle for this goal. In these cases, large amounts of weapon usable material could be obtained by this state. Especially the conversion of an established civilian breeder fuel could be done very quickly.

In the past, there have been examples of this scenario. The French Comissariat à l'énergie atomique (CEA) has been a state authority equally responsible for research in the field of nuclear energy and the provision of fissile materials for France's weapon program. Its military department had a keen interest in breeders, and today it seems to be clear that the Phénix reactor was partly used for the generation of plutonium for military purposes (Schneider 2009). The French General Jean Thiry stated in the newspaper Le Monde January 19th, 1978: “France is able to make nuclear weapons of all kinds and all yields. It will be able to fabricate them in large numbers as soon as the fast breeder reactors provide it with abundant quantities of the necessary plutonium” (cited as in (Schneider 2009)).

The Indian breeder program could share a similar fate. Already the research and deployment of thermal reactors was carried out in the same institution that produced plutonium for weapons, the Bhabha Atomic Research Centre in Mumbai. Currently, India is constructing a Prototype Fast Breeder Reactor, for which it quite likely will not accept safeguards (Glaser/Ramana 2007).

MCMATH

During the irradiation in a nuclear reactor, a nuclide undergoes changes in its concentration caused by different reactions (burnup). The knowledge of these changes is necessary to analyse the proliferation risk of a specific nuclear technology and to answer the two key questions phrased in the introduction.

The burnup calculations for the master thesis have been done using a modified version of the computer code MCMATH, which couples Mathematica (version 8.0.1) with the Monte Carlo transport code

Monte Carlo N-Particle eXtended (MCNPX, version 2.7a). MCMATH has been developed since 1998 at the IANUS group for calculations with LWR (cf. Table 2). In 1998, a similar code was not easily available; today there are more software systems available (Xu 2003, Haeck/Cochet 2010, Leppänen 2010). But there are still advantages in improving MCMATH because having full access to the code enhances transparency and simplifies adaptations as well as output possibilities during calculations.

The change in concentration can be described with a differential equation that includes a positive term for the production of a nuclide and a negative term for its destruction. A nuclide is produced when other nuclides undergo neutron capture reactions, fission reactions or radioactive decays that form this nuclide. The nuclide is eliminated when it undergoes such reactions itself. The processes can be described by:

$$\begin{aligned}\frac{d}{dt}N^i(\vec{r},t) = & -\left[\int_0^\infty dE\left(\sigma_f^i(E,\vec{r},t)+\sum_{R\in AR}\sigma_R^i(E,\vec{r},t)\right)\phi(E,\vec{r},t)\right]N^i(\vec{r},t)\\ & +\sum_{j\neq i}\left[\int_0^\infty dE\, f^{ij}(E)\sigma_f^j(E,\vec{r},t)\phi(E,\vec{r},t)\right]N^j(\vec{r},t)\\ & +\sum_{R\in AR}\left[\int_0^\infty dE\,\sigma_R^{\xrightarrow{R}i}(E,\vec{r},t)\phi(E,\vec{r},t)\right]N^{\xrightarrow{R}i}(\vec{r},t)\\ & -\lambda^i N^i(\vec{r},t)+\sum_{j\neq i} l^{ij}\lambda^j N^j(\vec{r},t)\end{aligned}$$

Where

$N^i(t)$	Concentration of nuclide i
$\varphi(E,\vec{r},t)$	Neutron flux with Energy E at a point in space and time
$\sigma_{f/R}^i(E,\vec{r},t)$	Microscopic cross section for fission (f) or absorption reaction R of i
f^{ij}	Fission yield probability that nuclide j fissions into nuclide i
$\sigma_R^{\xrightarrow{R}i}$	Microscopic cross section of the nuclide that becomes i by reaction R
$N^{\xrightarrow{R}i}(\vec{r},t)$	Concentration of the nuclide that becomes i by reaction R
l^{ij}	Branching ratio for decay of j into i
λ^i / λ^j	Decay constant for nuclide i / j
AR	Possible absorption reactions (e.g. (n,γ), $(n,2n)$)

The equation is also called the *Bateman balance equation* (Turinsky 2010, p. 1244). For the many nuclides present in a nuclear reactor, this equation forms a system of coupled differential equations with most terms depending on energy, space and time. The neutron flux $\phi(E,\vec{r},t)$ also depends on nuclide concentrations, making the problem nonlinear. To resolve this non-linearity, the equation is typically solved for several time steps assuming that $\phi(E,\vec{r},t)$ is constant for each time step. It is also generally discretized in space, assuming homogeneous concentrations and physical properties for a specific zone. Such a zone is called a *burnup cell*.

By using Monte Carlo techniques, it is possible to calculate a pseudo-continuous energy spectrum for the neutron flux $\phi(E,\vec{r},t)$. This possibility can be used to introduce *effective cross sections* for the reaction *x* of nuclide *i*.

$$\sigma_{\mathrm{eff},x}^i(\vec{r},t)=\frac{\int_0^\infty dE\,\sigma_x^i(E,\vec{r},t)\phi(E,\vec{r},t)}{\int_0^\infty dE\;\phi(E,\vec{r},t)}=\frac{\int_0^\infty dE\,\sigma_x^i(E,\vec{r},t)\phi(E,\vec{r},t)}{\phi_{tot}(\vec{r},t)}$$

$\phi_{tot}(\vec{r},t)$ is the total neutron flux. The effective cross sections are calculated with criticality calculations MCNPX using nuclear data from version 3.1 of the Joint Evaluated Fusion and Fission (JEFF) library released by the Nuclear Energy Agency of the OECD.

The system of differential equations formed by the Bateman Balance Equation (for one time step and burnup cell) can be written in matrix form, the solution can be derived by calculating a matrix exponential. The matrix has the structure of a sparse matrix; its size depends on the number of nuclides that are included in a specific problem, typically at least several hundreds. A simple numerical solution by using the Taylor-expansion of the exponential is difficult to obtain because the matrix entries also cover a wide range of orders of magnitude. If such a matrix is now raised to powers, the difference between orders of magnitude increases further. As the solution of the burnup equation is a fundamental problem for reactor physics and engineering, many other algorithms or methods were developed (cf. Moler/van Loan 2003, Yamamoto/Tatsumi/Sugimura 2007, Pusa/Leppänen 2010, Knott/Yamamoto 2010, Cetnar 2006). In MCMATH, actinides and fission products are treated separately. Solutions for the actinides are calculated first; in addition for each fissionable actinide one fission channel is introduced. The fission channel is treated as a pseudo nuclide accounting for all fissions of one fissionable actinide. For the solution of the fission products, the fissions of the actinides and the yield probabilities have to be taken into account. A constant production rate due to fissions is assumed per time interval. To solve the burnup equation for the fission products, the method of linear chains is used, taking β^-- or β^+-decays and (n, γ)-reactions into account. The resulting differential equations can be solved analytically.

Table 2: Development history of MCMATH.

Version	Time	Author	Changes/Features
1.0	1998	A. Glaser, C. Pistner	Initial development (Pistner 1998, Glaser 1998)
1.1	1998-2000	C. Pistner	Center calculations for effective cross sections
2.0	2000-2005	C. Pistner	Isomeric states, burnable neutron poisons (Pistner 2006)
2.1	2007	M. Kütt	Automatization/parallelization of process flow (Kütt 2007)
3.0	2009	M. Englert	Fusion reactor blankets, multiple cells, external neutron sources (Englert 2009)
4.0	2010/11	M. Kütt	Fast reactors, normalization for entire reactors, maintenance steps, refueling

Mathematica is responsible for the flow control of a MCMATH calculation. It starts the calculations of effective cross sections with MCNPX. When a MCNPX calculation is finished, the output is processed and Mathematica solves the differential equations. Subsequently, Mathematica starts new calculations for the next time step, using the new material compositions.

During an operational reactor cycle, often some elements are changed or replaced. To accommodate for these changes, material of burnup cells can now be replaced by a different material at the beginning of a specific time step.

MCMATH is able to calculate multiple burnup cells. This offers a great flexibility, but computational effort increases approximately linearly to the number of burnup cells. When calculating a complex reactor, it is therefore useful and often necessary to combine different physical elements (e.g. fuel rods) to large burnup cells (one or more fuel elements). This can be done by grouping cells by similar neutron flux or due to symmetries in the geometry. The modified MCMATH can now calculate such groups as burnup cells of differing volume or weight in case of symmetries.

The total neutron flux for a time step in burnup calculations has to be estimated depending on a given power density or total reactor power. For a complex reactor system with many different burnup cells every cell contributes differently to the total power. MCMATH was modified to be capable to estimate a total flux level for reactors consisting of many different cells.

In fast reactors, fission product yields and the importance of fission products are different from thermal reactors. Hence, the data used for fission product yields was changed to include distributions for fissions by fast and thermal neutrons and fission products important for fast reactors were included in MCMATH. Fission products are important if they have a high yield probability and concentration in the reactor or (and) a high cross section for the absorption of fast neutrons.

Validation of MCMATH

Computer codes for burnup calculations like MCMATH combine numerical methods to solve complex systems of equations with a large number of nuclear data sets (decay constants, nuclear cross sections). It is reasonable to validate the outcomes of a code and to check its reliability.

Parallel to its development, MCMATH was validated constantly against a variety of different code systems using a number of different model problems using MOX and inert matrix fuels (IMF) in thermal reactors. Generally, good accordance with other calculations was achieved, especially for plutonium concentrations. (Pistner 1998, Pistner 2006)

In (OECD/NEA 1995), two sodium-cooled fast reactor models are described in detail as benchmarks for calculation methods and systems. Several participants from different countries calculated different properties of these models, among them the change in isotopic composition, based on burnup calculations. Both models describe fast burner reactors, nevertheless they can be considered as good candidates for validation because main properties like core fuel composition, neutron flux energy distribution and possible actinide transmutation pro-

cesses in fast burner reactors are very similar to breeder reactor models. These benchmark calculations have been used to validate the modified MCMATH.

In Table 3 the results of the modified MCMATH are shown. MCMATH values are in general close to the mean value of benchmark participants. If this is not achieved, the calculated value lies in the range of the benchmark results. For Model 1, only for ^{241}Pu, the value is slightly higher. For Model 2, three isotopes (^{238}Pu, ^{240}Pu, ^{241}Pu) show values that are not in the range of the five benchmark participants. The other isotopes are in good accordance to the field of participants. Given the spread of the other results, the differences should not be a reason of great concern. In general, one can say that MCMATH can be used to calculate the burnup.

Comparisons with experimental results were not considered for validation of the fast reactor capabilities. Worldwide fast reactor experience totals approx. 400 reactor years (WNA 2011) and it is very difficult to obtain adequate information for a specific set of experimental data (isotopic measurements after burnup).

SNR-300

The reactor "Schneller Natriumgekühlter Reaktor" or SNR-300 was selected to figure as a case study to show MCMATH's capabilities for neutronic calculations of fast reactors. The modified MCMATH has been used to analyse proliferation capabilities of this reactor type on an exemplary basis.

The reactor has been the prototype breeder reactor project in Germany. It was built in Kalkar in North Rhine-Westphalia. The project has been pursued for more than thirty years, from 1957 until 1991. Constantly, it was accompanied by debates of proponents and opponents, in the technical field as well as in the field of decision-making and politics.

Initially at the Kernforschungszentrum Karlsruhe a project group on fast reactors was founded in 1960 to develop fast reactor programs. Besides a sodium-cooled reactor, water steam was considered as coolant but soon abandoned. An industry consortium was formed to be the vendor and manufacturer of the plant, the "Internationale Natrium-Brutreaktor-Baugesellschaft mbH" (INB). Parts of this joint venture were German companies as well as Dutch and Belgian ones. The reactor itself was ordered by the to-be owner and operator, the "Schnellbrüter-Kernkraftwerksgesellschaft mbH" (SBK), a joint venture of electricity utilities of the three countries. Funds for the order were mainly given by the governments to SBK, the price tag of the reactor being 1.5 billion Mark at that time, already 5 times higher than first estimates in 1965 (310 million Mark, (Marth 1991, p. 60)).

Building of the reactor started in April of 1973. Parallel to the start of the construction work, local and nationwide opposition of the public began to grow. For nearly all phases of construction, the project lagged behind proposed schedules. Because of safety issues, the licensing authorities often made requests to change the design. In 1978, the German federal parliament decided that it would have a parliamentary reservation on the start of reactor operation and studied safety issues in two parliamentary commissions ("Enquête-Kommissionen"). In 1983, the parliament lifted the parliamentary reservation. Construction was finished in 1985.

Table 3: Comparison of mass balances (in kg) for the two reactor models calculated by MCMATH and mean values of benchmark participants as in (OECD/NEA 1995).

		235U	238U	238Pu	239Pu	240Pu	241Pu	242Pu	TotPu
Model 1	MCMATH	-5.75	-398	-48.6	- 171	-27.6	- 143	-31.2	-420
	Mean	-5.7	-399	- 47.1	- 159	- 27.6	- 133	-29.4	-396
	Std. Deviation	0.141	13.7	2.64	16.9	9.22	5.88	7.34	32.5
Model 2	MCMATH	-3.58	-251	15.1	-148	-3.84	-110	7.5	-239
	Mean	-3.52	-253	13.38	-148	-8.4	-104	7.26	-240
	Std. Deviation	0.117	7.39	1.37	2.64	2.18	1.96	2.46	2.65

Table 4: Properties of Fuel and Breeding elements of the SNR-300.

		Mark I Fuel	Mark II Fuel	Breeding Element
Element Can Thickness	**mm**	2.8	2.8	2.8
Number of Rods		166	127	61
Structure Rods		3	0	0
Rod diameter	**mm**	6	7.6	11.6
Pellet diameter	**mm**	5.09	6.4	10.498
Cladding	**mm**	0.38	0.5	0.55
Pitch to Diameter		1.32	1.16	1.15
^{235}U Enrichment	**at %**	0.719	0.719	0.25
Pu Enrichment Inner Core	**at %**	24.502 (MAGNOX) 25.65 (LWR)	20 (LWR)	
Pu Enrichment Outer Core	**at %**	36.163 (LWR)	29.2 (LWR)	

The state regulatory body never granted the two final licensing approvals for insertion of fuel and start-up due to safety concerns. In 1991 the federal ministry of research and technology and the project partners (vendor and operator) abandoned the project. Up to that time, a total amount of approx. 7.5 billion Mark were spent. (Spiegel 1995).

Reactor Design

To do burnup calculations of the SNR-300 it was necessary to compose simplified models from the design specifications. The following paragraphs give a short overview on the used specifications, not all necessary information will be listed here. The detailed description can be seen in chapter 6 of the master thesis itself. The SNR-300 reactor is a loop type reactor, with a design power of 762 MWth. Its core is based on a hexagonal lattice geometry. It contains a total number of 499 different elements. The diameter of one hexagonal element is 115 mm.

In the beginning, a diameter of 6 mm was envisaged for fuel rods (Mark I Core). To reduce fuel production costs, the diameter was increased to 7.6 mm for a new model (Mark II Core) from the second fuel loading on. The Mark II Core had an additional ring of fuel elements to achieve similar reactor power as the Mark I Core. For the first loading, an intermediate design change was introduced with the Mark Ia Core. It featured the thin fuel rods, but already a core configuration with the additional fuel element ring to avoid changes in the reactor core support plate between the first and second fuel loading. This article presents calculations for the Mark Ia Core and the Mark II core.

Both cores have nine primary control elements for reactivity control during operation and three secondary control elements for the shut-down of the reactor and as a safety margin. 12 additional elements for static reactivity control are included. For Mark Ia, six of them are B4C blind elements, containing boron carbide because of the high initial reactivity of this core. After the first and the second reactor cycle respectively, three of them are replaced by fresh fuel elements. The other elements for static reactivity control are sodium blind elements.

Some properties of fuel and breeding elements are listed in Table 4. The fuel elements of Mark Ia either contain reprocessed plutonium from MAGNOX reactors (~75 wt % ^{239}Pu) or from LWR (~65 wt % ^{239}Pu), Mark II contains only LWR fuel elements (~65 wt % ^{239}Pu).

The irradiation time (as in the original design) of Mark Ia is 441 FPD, Mark II 520 FPD. These irradiation times were used for the following calculations under the assumption that all breeding elements would remain for three full reactor periods in the reactor (1323 FPD, 1560 FPD). For both cores, two shutdown phases of 60 days are modeled during one reactor period. For burnup calculations in MCMATH the division of the burnup time into time steps is necessary. Because the time steps are too long if the time between shutdown phases would be used directly, burnup time steps were intro-

duced at one half of the time for Mark Ia, and at one third and two thirds for Mark II.

Results

The first important results are the changes of plutonium masses in different reactor regions (plutonium means the sum of the isotopes ^{238}Pu - ^{242}Pu). To calculate average annual production and consumption rates, mass balances are calculated as if no refueling would have taken place. In Figure 2, this is shown for the calculated reactor models. Looking at possible proliferation scenarios, it seems reasonable to exclude refueling needs from mass balances. If the state that built a breeder wants to use it to acquire nuclear weapons, it can be assumed some additional amounts of plutonium unwanted for the purpose of proliferation are available for refueling because already a very large amount was necessary for the initial fuel content. Additionally, for the assessment of a scenario in which the state or a non-state actor would divert some of the material produced in a breeder over time it is reasonable to ignore the plutonium needed for refueling as it would not be taken from the diverted plutonium anyway.

Table 5: Average annual plutonium production values for different reactor core models.

	Mark Ia	Mark II
Radial Breeding (kg)	59.2	70.4
Axial Breeding (kg)	42.8	59.3
Total Breeding (kg)	102	130
Possible Number of Nuclear Weapons	> 12	> 16
1 GWe Total Breeding (kg)	340	433

The average annual production rates in the blankets of the calculated reactor models are shown in Table 5. The Mark Ia core can produce enough plutonium for at least 12 nuclear weapons[1]. Mark II can produce enough plutonium for more than 16 nuclear weapons. A rough estimate of production rates for reactors similar to the SNR-300 but with an electric output of 1 GWe shows that such a reactor would be sufficient to produce enough plutonium for a small arsenal of nuclear weapons within a year.

Looking at shorter time periods, the calculations showed that both models would be able to produce approx. 7 kg plutonium in the blankets after 20 days, and approx. 35 kg after 100 days. These amounts are dispersed among all breeding blankets. In the inner row of radial breeding elements each individual element would contain about 50 g, after 100 days 260 g. The average annual production of such an element is 680 g for Mark Ia or 830 g for Mark II. For a possible proliferator, who has access to a small separation capacity for plutonium, a small number of these breeding elements would contain sufficient material for one nuclear weapon. Such a diversion would be a very complicated task because each breeding element has a total weight of several hundred kg. But in fuel cycle scenarios with a massive use of breeder reactors, many shipments of these elements are necessary and open up access possibilities for proliferators.

The second key question for the assessment of the proliferation risk of a nuclear technology is the resulting isotopic vector of plutonium. For the fuel region of the reactor, the isotopic vector does not change very much during reactor operation. In the breeding regions, where no plutonium is present at start-up, the plutonium vector starts with only ^{239}Pu in the beginning and shifts towards heavier isotopes while the blanket is irradiated.

Figure 3 shows the change of the plutonium isotopic vector averaged over different radial blanket elements. All reactor models show a similar behavior. Up to the end of the first reactor period, both models contain super grade plutonium (^{240}Pu content < 3 %). After three reactor periods (roughly six years), the plutonium vector of both models still contains at least 93 % ^{239}Pu and is weapon grade plutonium. This is true not only for the average values of the radial blanket but also for the elements in the inner row next to the fuel region, where the flux is higher than further away from the fuel region.

[1] The number of nuclear weapons can change depending on weapon design. A critical mass of 8 kg (significant quantity as defined by the IAEA) was used to make this estimated, but it is also quite likely that a state with the technology level to build fast reactors might be able to produce a weapon with a smaller amount of plutonium.

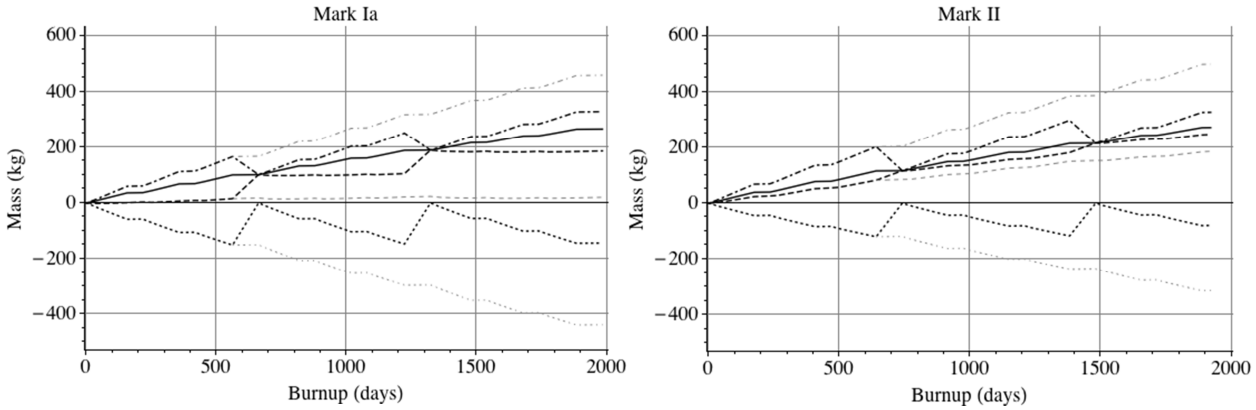

Figure 2: Mass balances in different reactor zones over 3 reactor periods. Lighter lines show mass balances excluding refueling (Reactor – Dashed, Fuel Total – Dotted, Breeding Total – Dashed/Dotted, Radial Breeding – Solid Line).

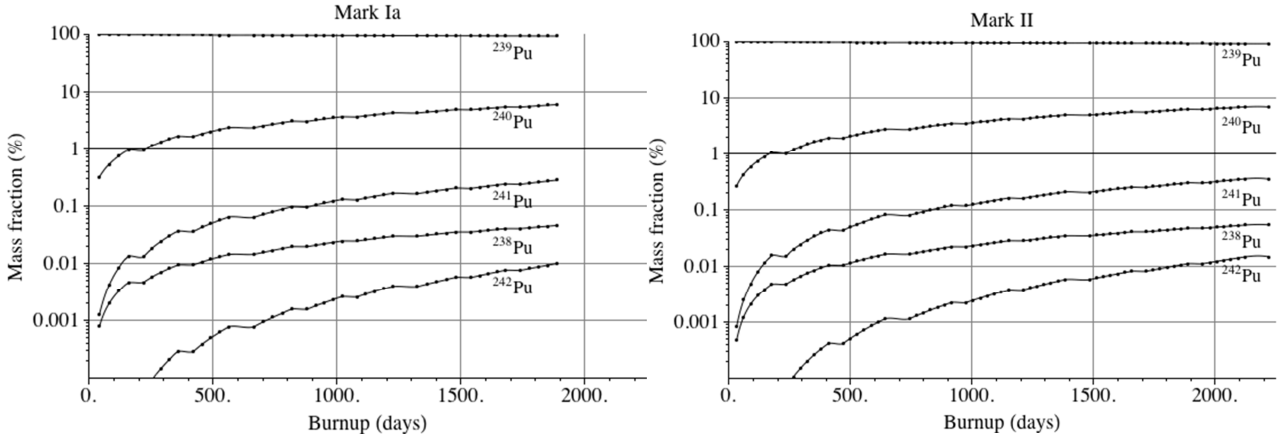

Figure 3: Isotopic composition of plutonium in Radial Breeding Element (in wt %).

For a state with the aim to openly or covertly build nuclear weapons, such reactors could be used as "plutonium converter". If the state has already a large amount of plutonium that is only reactor grade plutonium, it could fuel a fast reactor to produce super or weapon grade plutonium in the blankets for weapon purposes. Such a conversion could be done also in parallel to commercial operation, either using the blanket elements after the long irradiation time or removing some breeding elements as early as in the first shut down phase. Although the latter elements would not contain a large amount of plutonium, it would be almost pure ^{239}Pu.

Depending on the actual plutonium concentration and the amount of fission products in breeding elements, reprocessing can be more or less complicated. Fission products influence the reprocessing of spent fuel mainly by the amount of relatively short-lived isotopes emitting energetic gamma rays during their decay. Reprocessing of fuel from LWR relies mainly on remote control handling methods to protect workers from radiation. Similar requirements will be necessary for the reprocessing of spent fast reactor fuel.

From the burnup calculations carried out by MCMATH it has been possible to determine plutonium and fission product contents in breeding elements. Some of the resulting values are listed in Table 6. The resulting fraction of fission products for the fuel region is in the range of 10.7 % to 11.3 %. Although the radial breeding blankets have been in the reactor for three subsequent periods, the fraction of fission products in the radial blankets is less than 2 %, a fifth of the fraction in fuel elements, for all reactor models. After only one reactor period, the fraction is in the range of 0.362 %/0.422 %. One can therefore expect that the reprocessing of fast reactor blanket material might be easier than reprocessing of spent reactor fuel because with the reduced fraction of fission products the resulting gamma radiation will be reduced.

Table 6: Atomic fraction of fission products (FP) and plutonium (Pu) in the mixture of fission products and heavy metals. For radial blankets values for three and one reactor period are listed, for the axial blanket and the fuel region averages of three periods.

Reactor Model	Mark Ia		Mark II	
	FP at %	**Pu at %**	**FP at %**	**Pu at %**
Radial Breeding, 3 periods	1.82	3.31	2.17	3.74
Radial Breeding, Inner Row, 3 periods	2.31	3.63	2.91	4.2
Radial Breeding, 1st period	0.365	1.25	0.422	1.44
Radial Breeding, Inner Row, 1st Period	0.48	1.4	0.584	1.66
Axial Breeding	1.05	1.36	1.12	1.48
Fuel Region	11.7	25.4	10.9	21

Similar to the fission product fraction, the plutonium fraction in different reactor regions was calculated. In the fuel region, the fraction is reduced compared to reactor start-up, but still above 20 % for all reactor models. In axial and radial breeding blankets, where no plutonium was present at reactor start-up, the plutonium fraction after one reactor period is more than 1.2 % for both models. After three reactor periods, the models show values around 3.5 %. In spent fuel of LWR typical plutonium fractions are only 1 % (WNA 2009). Hence it seems clear that radial breeding blankets can be very attractive for any proliferator.

Conclusion

The computer system MCMATH, a computer system able to carry out burnup calculations, has been extensively modified and improved during the work for this master thesis. The use of the software for finding answers to the two key questions formulated in the introduction was made possible. The modifications and improvements include the usage of new nuclear reaction data for fast neutron spectra, the possibility of flux normalization for entire reactors, introduction of possible maintenance-induced reactor shutdown phases during burnup and a function to change material compositions of burnup cells during calculations (e.g. to simulate refuelling).

The fast reactor project SNR-300 was selected to act as a case study for MCMATH calculations. In the special axial and radial breeding blanket zones, annual productions were calculated to be about 40 kg to 60 kg (axial) and 60 kg to 70 kg (radial). The total annual production in these blankets would be enough for a small arsenal of nuclear weapons produced every year. The plutonium isotopic compositions are all very attractive for the use in nuclear weapons. Even after an irradiation periods of several years, radial breeding blankets still contain weapon grade plutonium.

The sample calculations showed that a fast reactor like the SNR-300 has a significant proliferation potential already with the irradiation times and core configurations that were designed for the use in electricity production. Special core configurations (e.g. a breeding blanket in the centre of the core) were not covered by the master thesis. They could be subject to further research, as well as other fast reactor models could be analysed using the computer code MCMATH. Besides, it could be interesting to shift the focus from the analysis of plutonium production towards possible plutonium reductions or nuclear waste transmutation with fast reactors.

The global underlying context of the work has been the abstract goal of a future world free of nuclear weapons. To reach this goal, it is necessary to avoid any nuclear proliferation. A country that aims to develop and use fast reactors must therefore carefully consider the proliferation risks of this technology. Independent of such an assessment, it is my personal opinion that to abstain from the use of fast reactors would be an easier undertaking as well as a small concrete step towards a nuclear weapons free world.

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Global Plutonium Production Capabilities in Civilian Research Reactors

by Jochen Ahlswede

Introduction

Plutonium production in nuclear reactors is one of the main proliferation risks associated with the civilian application of nuclear energy. In the commercial energy sector, the storage and transportation of fissile material, especially of separated plutonium, are of major concern. The global stocks of separated plutonium today are in the range of hundreds of tons. On the other hand, historical experience shows that states with a clandestine military nuclear program have used small research reactors for the production of fissile material rather than diverting plutonium from a civilian nuclear power reactor program: Israel used a heavy water reactor Dimona, India the two heavy water reactors CIRUS and DHRUVA, Pakistan three heavy water reactors at Khushab and North Korea used a graphite moderated reactor at Yongbyon.[1] States which reportedly pursued an unsuccessful nuclear weapon program in the past like Libya, Brazil, South Africa and Iraq had also no operational nuclear power plants at the time of their programs (they chose HEU rather than plutonium as fissile material). This observation can be explained by several reasons. First, states interested in a nuclear weapon program may simply not have power reactors, but only research reactors available for fissile material production. If they have any, the plutonium vector from spent fuel with high burn-up (as it is the case for power reactors) is not favorable for nuclear weapons because of the relatively low content of fissile isotopes (^{239}Pu and ^{241}Pu). Finally, the fuel or targets in research reactors are easier accessible - and harder to safeguard by IAEA - than in power reactors. As such, a research reactor is the first choice if a state wants to conduct and pursue a military production program. In conclusion, the worldwide plutonium production capabilities in research reactors are significant when addressing proliferation issues.

In this article, a review of the worldwide research reactor fleet and conceivable plutonium production scenarios is provided. For the most important types, burn-up calculations are performed. The outcomes are effective production rates which can be applied to derive quantitative conclusions on most of the research reactors in Non-Nuclear Weapon States (NNWS). The results allow conclusions both on the actually (inevitably) occurring plutonium production in the fuel as well as on the theoretical maximum capability to produce weapon-grade material. In doing so, the question of plutonium production capabilities of states which are not part of Annex II of the Comprehensive Nuclear Test Ban-Treaty (CTBT) will also be addressed in the latter part of this work. These so-called “Annex II” states are required to ratify the treaty before it can be entered into force. Considerable production capabilities of them would undermine the essence of the current conditions for the entry into force of the treaty and will consequently have a high impact on the current non-proliferation regime politically.

Research Reactors and their Plutonium Production Capability

Research reactors are used for a variety of purposes all over the world. They provide gamma radiation and neutrons for applied or basic research in natural sciences and for studying radiation effects. Furthermore, special isotopes for medical or industrial purposes are produced in some of these reactors. Finally, they are often used for training and teaching purposes. Research reactors are used by a great variety of states; many of them do not have a commercial nuclear power sector. The Research Reactor Database (RRDB) of the IAEA provides a comprehensive overview of the world’s research reactor fleet as well as critical and subcritical assemblies, including information on their basic technical specifications.[2] Altogether, 254 units are operational or in temporary shutdown, while 5 reactors are under construction or under planning (as of 6/1/2011). The thermal capacity of these units reaches from zero for subcritical/critical assemblies to 250 MW for the Advanced Test Reactor in the USA, but more than half of the units have a thermal capacity below 1 MW. The distribution of operational reactor units or assemblies according to the histogram of their thermal capacity is shown in figure 1.

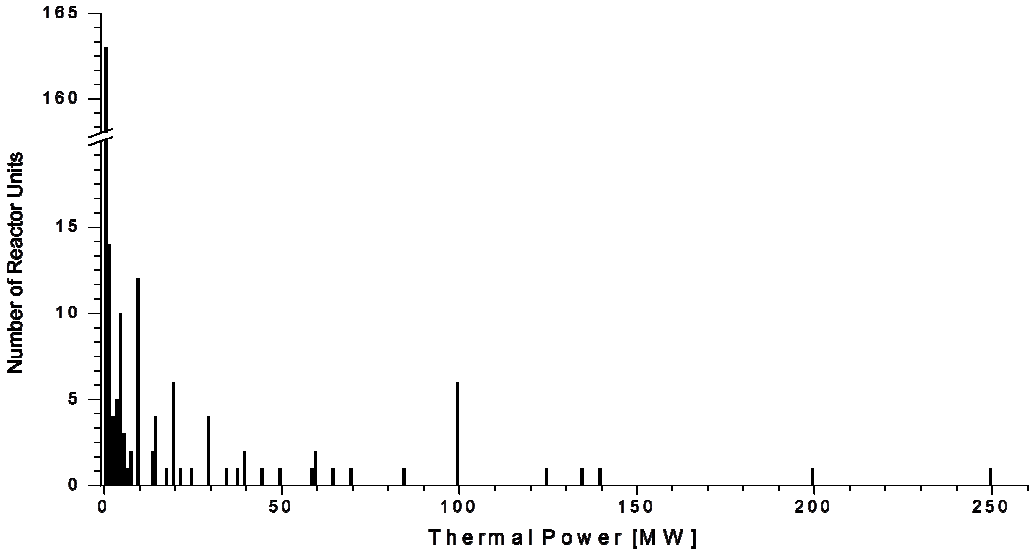


Figure 1: Number of operational research reactors in the world clustered by thermal capacity. The size of one class is 1 MW. Data is taken from IAEA's Research Reactor Database as of 6/1/2011.

The plutonium production capability of a reactor is highly dependent on its thermal design capacity. In conclusion, the number of reactors to be analyzed can be reduced significantly by introducing a lower bound for thermal capacity under which plutonium production is negligible. With regard to plutonium production, safeguards of IAEA concentrate on research reactors with a thermal capacity above 25 MW.[3] Although smaller reactors are also monitored by IAEA, additional safeguards (more frequent inspections etc.) are applied for these large reactors to increase detection probability in case of clandestine plutonium or ^{233}U production.[4] It is argued that this threshold is defined by the fact that below 25 MW, it is impossible to produce one significant quantity (SQ) per year by irradiation of fertile targets. However, for the subsequent analysis presented in this work, a lower threshold should be defined in order to achieve coverage of a broader variety of reactors in the first instance. Thus, the scenario in which a proliferator uses more than one reactor to produce plutonium or indulges in production for more than one year is included. The threshold for the following analysis is set to a thermal capacity (P_{th}) of 1 MW, which excludes 164 reactors below this threshold. From the five NWSs, there are 41 research reactors above the defined threshold, two of which are under construction and two under temporary shutdown. These reactors are also not considered further because they are not relevant with regard to horizontal proliferation. The residual number of reactors (a total of 54 reactors in NNWSs and de-facto NWSs) is more manageable for the scope of this work. On the other hand, the defined threshold is certainly not too high to disregard significant plutonium production capabilities. Following the argumentation of Binford,[5] the time to produce one SQ of plutonium (8 kg) with a 1 MW reactor is about 23.2 years (with a load factor of 100 %) using the theoretical upper production rate limit of 0.94 g Pu/MWd.

IAEA generally distinguishes between three scenarios for the clandestine production and diversion of fissile material for military purposes.[6] These include the diversion of fresh fuel or slightly irradiated fuel, the diversion of spent fuel and the clandestine production of plutonium or ^{233}U. The first scenario is not considered in this work because it normally does not mainly deal with plutonium but rather only with negligible amounts of it (apart from exceptions like experiments including Mixed-Oxide (MOX)-fuel). Furthermore, the fresh fuel especially interesting for theft or diversion is HEU (direct-use material) but this is relatively unsuitable for plutonium production because of low concentrations of fertile nuclides. As such, spent fuel diversion and clandestine plutonium production can be addressed - in principle - by the distinction of three operational modes:

Normal operation ("Scenario A"): The reactor is used for research purposes or the production of medical isotopes. In this case, the end of the cycle length is reached when criticality, ρ drops below

$\rho = 1$ to exploit the fuel as long as possible and therefore keeping the fuel costs low. Plutonium is inevitably produced in the reactor core, but the plutonium vector of the discharged fuel is not of interest and probably unfavorable for a weapon because of high burn-ups. After the fuel is discharged it will be stored but, in principle, still available for a proliferator. After a certain cooling period (several months at minimum), the fuel could be reprocessed. As spent fuel is subject to IAEA safeguards, it is routinely sealed and periodically controlled. Thus, it would be difficult to hide any diversion of plutonium. Furthermore, the diversion and reprocessing of spent fuel with high burn-up is technically more demanding than the plutonium extraction from targets because of the higher level of radioactivity and heat generated by the fuel.

Optimization for irradiation of targets ("Scenario B"): Certain positions in the reactor core or in its close vicinity could be used for placing fertile targets with high concentrations of ^{238}U. For example, irradiation channels which are normally present for research purposes can be used for undeclared irradiation.[7] The volume available for targets is, of course, limited by the reactor core design. Natural or depleted uranium ("NU", "DU"), in form of oxide or metal, would probably be used as target material. The purposes of research reactors require a core design that is in fact relatively easy to access. Insertion and retrieval of irradiation targets for research purposes or civilian isotope production are frequent activities in many facilities. This makes safeguards more difficult and costly. The actual accessibility of a core depends on the reactor type. For example, it is easier to remove fuel elements or targets from an open pool arrangement than from tank type research reactors. Generally, this scenario provides the highest probability of successful undetected diversion of plutonium out of the three considered here.

Full core for weapon material production ("Scenario C"): The whole reactor core could be used for weapons material production. This scenario is relevant if there is no distinction between driver fuel and target material, e.g. in case of heavy water reactors that are completely fuelled with NU. The discharge burn-up is not predetermined by criticality, but by the isotopic composition of the plutonium produced in the fuel assemblies. The maximum burn-up is then marked by the limit of 7 % ^{240}Pu to ensure the material is "weapon-grade".[8] Although it is a somewhat artificial limit because "fuel grade" or "reactor grade" plutonium can also be used for an explosive device,[9] this threshold assumes that the proliferator is interested in material which is most effective for military purposes.

All scenarios represent ideal cases. A real proliferator would perhaps choose modified fuel cycle patterns to avoid safeguards detection or accept plutonium with a more unfavorable isotopic composition. But in the course of this study, the scenarios seem to be reasonable because they cover the most important diversion pathways and particularly allow the estimation of upper production limits. However, if IAEA is able to apply all necessary safeguards to a research reactor and its fuel, a clandestine diversion or production of fissile material in any of these scenarios will be quite difficult (with the highest chances of success for scenario B). In conclusion, the following analysis is more relevant for a so-called "break-out" scenario in which a state pursues a military program without any intention of hiding it from the international community. Another conceivable possibility to decrease chances of detection while staying inside the non-proliferation regime could be the secret utilization of a reactor which is declared as "shutdown".

Research Reactors in Non-Nuclear Weapon States

As previously mentioned, there is a total number of 54 reactors in Non-Nuclear and de-facto Nuclear Weapon States[10] having a thermal capacity of above 1 MW which translates to 20 % of the overall number of research reactors in the world. Out of them, five reactors are temporarily shut down and two are under construction. The dedicated military production reactors of Pakistan (three operational reactors at Khushab and one under construction) and Israel (one reactor at Dimona) are not included in IAEA's RRDB and not considered in the following analysis. Both Indian heavy-water moderated reactors CIRUS and DHRUVA are dual-purpose plants, contained in the RRDB and therefore included in the analysis (CIRUS is reported to have been shut down at the end of 2010,[11] but still included in the list as it is useful in the assessment of the country's production capability which is the aim of this study).

Neutronic calculations for every single reactor would exceed the scope of this analysis by far. An

assessment of plutonium production capabilities can only be made from classes of reactors with similar properties. Table 1 provides this classification on the basis of fuel geometry or, if no standard geometry can be identified, on the basis of used moderator. For every class, the installed capacity and fuel enrichments are stated. This list shows that Heavy Water Reactors (HWR) and Material Test Reactors (MTR) are the dominant types, both in terms of thermal capacity and installed number. Other light water moderated designs are "IRT", "VVR" and "TRIGA". Fast Breeders constitute another major group on the basis of thermal capacity, but there are only two units present. Furthermore, there are one "High Temperature Reactor" and one "Graphite Moderated Reactor". The fuel enrichments for LWRs vary from 19.75 % to 93 %. These enrichments, which are much higher than in power reactors, are used in research reactors because they are necessary to provide high specific reactivity allowing a compact core design with high power densities and thus high neutron fluxes. HWRs are partly fuelled with high enrichments, but can also be fuelled with NU. In comparison, NWSs used almost exclusively natural uranium fuelled reactors, either moderated with graphite (coolant: H_2O or gas) or heavy water (coolant: H_2O or D_2O), to produce their weapon-grade plutonium. Few exceptions are only breeding targets in HEU-fuelled reactors. All four de-facto Nuclear Weapon States also used natural uranium fuelled reactors, mostly with heavy water as moderator.[12]

Methodology for the Assessment of Plutonium Production Capabilities

For the estimation of plutonium production in a nuclear reactor, burn-up calculations have to be performed, which take coupling of energy dependent neutron flux and the system of depletion equations for a specific geometry and materials into account. The result of the calculations is the plutonium content in fuel as a function of burn-up (in MWd/kg). The gradient of this curve is the amount of plutonium produced per MWd, or the production rate *C*. Since the gradient changes with burn-up (or with irradiation time, respectively) it has to be averaged over a certain burn-up interval. For calculating the plutonium produced in the reactor with a fixed discharge burn-up B_d, the averaged plutonium production rate *M*in [kg/a] is then given by

$$M = C_B \cdot L \cdot P_{th} \cdot 365\mathrm{d}$$

where C_B is the production rate averaged over B=[0, B_d], L is the load factor and P_{th} the nominal thermal

Table 1: Research Reactor types according to IAEA's Research Reactor Database in Non-Nuclear Weapon States and de-facto Nuclear Weapon States with P > 1 MW clustered according to their type (see appendix for references). The thermal capacity refers to the sum of all reactors of the specified type. This list includes 5 reactors temporarily shut down, two reactors under construction and one planned.

Reactor Type	P_{th} [MW]	No. of Units	No. of States	Moderator	Occurring Enrichments	Coolant
Heavy Water	402	9	7	D_2O	NU (3), LEU (1), 3.5 % (1), 19.75 % (1), 6 % (1), 20 % (1), 93 % (1)	D_2O or H_2O
MTR	362.5	23	18	H_2O	LEU (3), 19.75 % (12), 20 % (5), 93 % (2)	H_2O
Fast Breeder	180	2	2	none	MOX	liquid Na
IRT (IRT-4M/2M)	32	4	4	H_2O	19.75 % (3), 36 % (1)	H_2O
HTR	30	1	1	Graphite	LEU	He
VVR (VVR-M2, VVR-K, EK-10)	28	4	4	H_2O	LEU (1), 19.75 % (2), 36 % (1)	H_2O
TRIGA	25	6	6	H_2O, ZrH	19.75 % (3), 20 % (3),	H_2O
Graphite	4	1	1	Graphite	NU	Air
Other LWR	103	4	4	H_2O	19.75 % (2), 90 % (1), unknown (1)	H_2O

capacity. If one is interested in the annual production capacity at other burn-up intervals, *C* has to be evaluated over these intervals, whose length must correspond to one year of reactor operation.

For performing the burn-up calculations, SCALE-6 (Software Computer Analyses for Licensing Evaluation) is used.[13] It is a computer code developed by Oak Ridge National Laboratory for the US Nuclear Regulatory Commission and consists of several modules that work together according to the control sequence called by the user. These modules allow neutronic transport calculations, criticality calculations, depletion calculations and others. For burn-up calculations performed in this work, the control sequence TRITON-5 (Transport Rigor Implemented with Time-dependent Operation for Neutronic depletion) was used, which couples the three-dimensional Monte-Carlo transport code KENO V.a and the depletion code Origen-S.

An exact calculation of plutonium production would require the modeling of each reactor separately with neutronic transport codes taking all different fuel geometries, core dimensions etc. into account. Such a task would exceed the scope of this work by far. Therefore, an approach has to be chosen that requires less simulation complexity but still is able to provide results applicable to all reactor units or at least a large majority of them. For that purpose, two reactor designs which are representative for a maximum of the reactors listed in table 1 are identified and analyzed for this study.[14]

LWRs are the most common type of research reactors in the world. In 2010, they account for a total thermal capacity of about 550 MW (sum of types “MTR”, “IRT”, “VVR”, “TRIGA” and “other LWR”, cf. table 1; without considering reactors with P_{th}≤1MW). Their average thermal capacity per unit is 14.1 MW. As shown in the previous section, the most common research reactor type that uses light water as moderator is the MTR. Its plate-type fuel will be used as basis for calculating the plutonium production in light water research reactors.

Research reactors with heavy water as moderator (and coolant) constitute the second largest group of research reactors worldwide, cf. table 1. The sum of their thermal capacity equals 372 MW (including one reactor under construction). The average thermal capacity per unit is 46.5 MW, which is considerably larger than the average size of light water moderated units. Exemplary for this reactor type is that burn-up calculations for the Iranian heavy water reactor at Arak are performed for different production scenarios. Like all heavy water research reactors, except for FRM II, it uses rod-type fuel assemblies.

Plutonium Production Capability of Light Water Moderated Research Reactors

The design of MTR fuel was developed in the early 1950s by the USA and spread around the world in the following decades. It is a standard type which has been used by several countries that wanted to start nuclear their own research programs.[15] Today, there are 23 units with P_{th} > 1 MW in 18 of the analyzed countries (cf. table 1). The uranium (in form of oxide or as alloy, for example with aluminum) in MTR is arranged in plates which are enclosed by aluminum. Several of these plates, are combined to form a fuel assembly. Their exact number varies from type to type and depends whether it is a control assembly or a normal assembly (control assemblies have fewer plates in order to accommodate neutron absorbers). Typical values are 17 - 23 plates per assembly. The gap between the plates is filled with the moderator which functions simultaneously as coolant. Several of these assemblies are placed side by side in the rectangular reactor core that is surrounded by water or other reflectors like graphite or beryllium. Some fuel assembly positions may be available for the irradiation of targets. For the subsequent calculation of plutonium production rates, a representative reactor configuration has to be chosen. In the context of core conversion programs, IAEA proposed a generic 10 MW pool-type MTR for neutronic calculations,[16] which will be used here. As the capacity is in the same range as the average existing capacity per reactor unit (14.1 MW), the choice is reasonable. The reactor core of IAEA's generic model consists of a 5 x 6 lattice with 23 standard (23 plates) and 5 control (17 plates) fuel assemblies, as well as two irradiation positions (one central and one edge). The core is reflected by graphite at the two short sides (the core as a whole consists, therefore, of a 7 x 6 lattice) and by water at the two other sides. The exact dimensions of the fuel assembly geometry are given in table 2.[17]

Table 2: Design parameters for the IAEA MTR generic 10 MW reactor core (see footnote 17 for references).

Item	Attribute	Description
Fuel Plate	Meat dimension	0.38 mm x 63 mm x 600 mm
	Meat composition	UAl-Al
		93 % enrichment: 0.63 gU/cm^3, 21 weight-% U in UAl-Al
		36 % enrichment: 2.50 gU/cm^3, 40 weight-% U in UAl-Al
		19.75 % enrichment: 4.45 gU/cm^3, 72 weight-% U in UAl-Al
	Plate dimension	1.27 mm x 66.40 mm x 660 mm
	Cladding composition	aluminum, 2.7 g/cm^3
Assembly structure	Dimension	80.65 mm x 4.80 mm x 660 mm
	Composition	aluminum, 2.7 g/cm^3
Lattice Pitch	-	77 mm x 81 mm
Moderator/Coolant	-	H_2O

The calculations are performed both for production scenarios relevant for light water reactors (scenarios A and B) for three different enrichments (19.75 %, 36 %, 93 %), which are chosen in accordance to the values given in table 1. The simulations with the Scale-6/Triton5 sequence were run for standard fuel elements in an infinite lattice for scenario A and for the whole reactor core configuration for scenario B.

The cycle length is limited by reactivity of the reactor fuel, frequency of maintenance, economic factors and the experimental program. Binford (1984) provides a typical value for cycle length equal to two to four weeks.[18] This also corresponds well to the length proposed for the generic MTR which is 16.7 d.[19] The subsequent refueling can take a few hours up to several days. The number of batches for the whole core is 7 - 9. The average discharge burn-up given by literature is consistently about 50 %.[20]

In scenario A, the standard MTR-fuel configuration without irradiation targets is used to calculate the plutonium amount that can be produced at different enrichment levels. Results show that HEU as fuel leads to an almost negligible plutonium production (1.3 mg Pu/cm^3) at a burn-up of 50 % due to the very low ^{238}U content in the fuel. The medium enriched fuel (36 %) contains at this burn-up about 21.5 mg Pu/cm^3, whereas LEU fuel reaches a concentration of about 35.0 mg Pu/cm^3. The production rates derived here are in the same range as the values found in literature.[21]

In scenario B it is assumed that the proliferator introduces targets with high ^{238}U amount into the core. In this case, natural uranium (about 0.7 weight-% ^{235}U) is assumed. According to the MTR benchmark design, targets can be positioned at two points inside the core (one central position and one edge position) and at the 12 positions where normally the graphite reflector is located.[22] More tar-

Table 3: Design parameters for Arak reactor core model (for references, see footnote 26).

Item	Attribute	Description
Fuel pellet	Radius	0.575 cm
	Composition	UO_2 (NU, 3.5 %, 6 % 19.75 %)
Inner fuel bundle	Radius	1.605 cm
Outer fuel bundle	Radius	3.101 cm
Fuel pin	Outer radius	0.68 cm
	Inner radius	0.5975 cm
	Clad	Zr: 98.97 %, Nb: 1 %, Hf: 0.03 %
	Fill gas	He (0.1 MPa, $5.36 \cdot 10^{-5}$g/cm^3)
Central tube	Outer radius	0.625 cm
	Inner radius	0.75 cm
	Clad	Zr: 97.47 %, Nb: 2.5 %,
		Hf: 0.03 %
	Content	N_2
Assembly pressure tube	Outer radius	4.4 cm
	Inner radius	4.0 cm
	Clad	Zr: 97.45 %, Nb: 2.5%
Moderator/Coolant	-	D_2O

gets could be positioned outside of the reactor's 7 x 6 grid but this would only be possible with significant design changes to provide sufficient cooling which is not considered here. The target material is contained in MTR fuel plates which possess a larger fuel meat region than normal plates in order to accommodate high amounts of natural uranium. Following the proposal of Miller and Eberhard,[23] 10 plates per target assembly are assumed, each with a meat thickness of 0.5 cm. To get a reasonable upper boundary for plutonium production capability, it is assumed that the only leading constraint is the isotopic composition (weapon-grade plutonium). Simulations were run with all three driver fuel enrichment levels and differentiated between central, edge and reflector position.

Plutonium Production Capability of Heavy Water Moderated Research Reactors

In June 2004, Iran began to build a HWR ("IR-40") near Arak, which has a thermal design capacity of 40 MW and is supposed to be operational in 2013.[24] The Arak reactor will be deployed with RBMK fuel assemblies which could contain natural or low enriched uranium.[25] These fuel rod bundles are 3.5 m high and consist of 18 separate fuel pins, which are arranged in two concentric circles around a gas filled central tube. The bundle is encased by a pressure tube, giving the whole assembly an outer radius of 4.4 cm. Two bundles are put vertically together forming a fuel cell with a height of 7 m. The clad materials of the pins and tubes are zirconium-niobium-alloys. Heavy water will not only be used for moderation but also function as coolant. Detailed specifications from RBMK fuel assemblies, which are subsequently used for calculations, are provided in table 3.[26] The lattice pitch in RBMK reactors is 25 cm. Since RBMKs use pressure tubes like CANDUs, it is quite certain that a reactor like Arak has the possibility of being refueled online.

Each calculation is performed for an infinite array of single fuel assemblies with 25 burn-up steps ranging from 0 - 30,000 MWd/kgHM for scenario A and 0 - 2,800 MWd/kgHM for scenario C. Besides NU fuel, three different enrichments are chosen in accordance with the values given in table 1 for heavy water moderated reactors.

The maximum burn-up for scenario A can be calculated by using the method described in Driscoll et al, 1990.[27] Because of the small core size, a batch size of 10 is used for the subsequent calculations which corresponds to B_d = 13.7MWd/kgHM. This estimation resembles that of Binford's,[28] which mentions n = 7...9 as typical value for research reactors. The average production rate over the whole fuel burn-up with B_d = 13.7 MWd/kgHM is C_B = 0.36 g/MWd. The value calculated for steady-state operations assumes a higher discharge burn-up and is therefore lower. If the reactor is operated normally over a longer period of time with periodic change of fuel assemblies, the more realistic production rate is 3.94 kg/a, which is the value for moderate load factor and *C* averaged over the whole fuel cycle.

If LEU fuel is used instead of natural uranium, the production rates decrease according to the fuel enrichment. The highest production rate can be achieved with 3.5 % enriched fuel. At a typical discharge burn-up of 50 %, the production rate is 0.23 g/MWd, which is less than half of the rate possible by using natural uranium fuel.

Regarding scenario C, the maximum burn-up required to ensure weapon grade material is about 1,330 MWd/kg. This value seems reasonable: Albright, 1997 assumes a value of 1,000 MWd/kg for weapon grade plutonium production with heavy water reactors.[29] *C* is determined at low (0 - 250 MWd/kg, Pu_{fiss} > 98 %) and middle (0 - 500 MWd/kg, Pu_{fiss} > 97 %) burn-up intervals, as well as for the whole irradiation period. With a moderate load factor and *C* averaged over the maximum burn-up, 7.9 kg could be produced annually. With high load factor and very low burn-up (corresponding to a plutonium vector with ca. 1.5 % non-fissile isotopes), the reactor would be capable of producing 10.4 kg/a. These values are relatively consistent with the lower range of the estimation on the Arak's production capability found in literature (8 kg/a - 12 kg/a). Likewise, the production rate of 0.72 - 0.79 g/MWd agrees well to literature value given in IPFM, 2010 for a heavy water reactor (0.78 g/MWd).[30]

Summary

The results of the work presented in this paper provide a transparently derived database on the global plutonium production in civilian research reactors. It can serve as a source for technical background

information for the assessment of a country's nuclear capabilities.

Using the plutonium production rates calculated above, the worldwide plutonium production capabilities in civilian research reactors can be evaluated (with limitations of adaptability as discussed previously). Table 4 provides this overview for all light water and heavy water moderated research reactors in NNWSs and de-facto NWSs. A moderate load factor of 75 % (which translates to 274 full power days per reactor per year) is assumed for all calculations as well as the fuel enrichment, as specified in table 1. According to these calculations, 40 LWRs produce about 10.7 kg/a in their normal operation mode (scenario A). The two largest single unit (HFR, Netherlands and JMTR, Japan) are in fact capable of producing more than 1 kg/a, but the median of the distribution is only 136 g/a and the third quartile is found at 261 g/a. This rate is doubled in the case of weapons material production in natural uranium targets (22.1 kg/a, scenario B). In this case, reactors in Belgium, Indonesia, Kazakhstan and Poland exceed the 1 kg/a-threshold, but still 50 % of the reactors are only capable of producing less than 180 g/a. The reactor unit with the highest production rate in fuel is JMTR in Japan (1.3 kg/a). The unit with the highest production capability with targets is BR-2 in Belgium (5.2 kg/a). Heavy water moderated reactors are capable of producing much more plutonium. The total annual production in NNWSs in normal fuel (scenario A) is 33.6 kg, the median of the distribution is about 940 g/a. These reactors have the capability to significantly produce more weapon material if the operator wants to. For scenario C, the median moves to 6.9 kg/a, the third quartile to 10.8 kg/a. Iran, whose reactor was chosen as representative model, would be capable of producing nearly one SQ per year (7.9 kg/a). For these calculations, a load factor of 75 % is assumed and CIRUS in India (recently shut down) and Arak in Iran (under construction) are included. The reactor with the highest production rate for scenario A is located in India (DHRUVA, 19.7 kg/a). The one with the highest production capabilities in scenario C is in Canada (NRU, 26.6 kg/a). The practice of IAEA to concentrate its safeguards on research reactors above a thermal capacity of 25 MW seems cautious enough compared to the results calculated here: An MTR with the same capacity LEU driver-fuel (19.75 % enriched) and NU targets with a load factor of 75 % would need around 9 years to produce one SQ of weapon-grade material (scenario B). The situation changes dramatically for a HWR, which needs only around 1.6 years for one SQ, if the whole reactor is fuelled with NU (scenario C, load factor of 75 % and maximum burn-up for weapon-grade material assumed). In this case, IAEA's criterion that a reactor must be able to produce one SQ within one year of operation to justify additional safeguards is still not violated. In the context of nuclear non-proliferation, it is worthwhile to take a look at the country's status within the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This treaty forbids any nuclear testing, provides for a global verification system and is even now considered to be a major milestone in today's nuclear non-proliferation regime.[31] It has not entered into force until now since a provision has not been fulfilled which requires that 44 states listed in Annex II of the treaty have to ratify it first. These so called "Annex II" states are defined as members of the Conference on Disarmament in 1996 who have formally participated in the CTBT negotiations *and* have either power reactors or research reactors in 1996. The intention behind this provision was to guarantee a certain universality of the treaty among the group of states that theoretically possess fissile material production capabilities *before* the treaty actually becomes legally binding. Not all of the states which run research reactors today are covered by this list. The additional states are: Czech Republic, Greece, Jordan, Kazakhstan, Libyan Arab Jamahiriya, Morocco, Taiwan, Thailand and Uzbekistan. Morocco's reactor went critical in 2007 and the Jordan JRTR is not built yet, but the other seven states actually possessed research reactors in 1996. The only reason for not being listed in the CTBT Annex II is a purely political one: They were not members of the Conference on Disarmament in 1996, but rather only observers to the negotiations. Apparently, none of the states which are not part of the Annex II list of the CTBT has plutonium production capabilities that could be a source of concern (all under 0.5 kg/a).

The only exception is Kazakhstan with the possibility to produce a total of over 2 kg/a by two reactors. This is the only case in which the original intention of the Conference on Disarmament - to guarantee that all countries with significant nuclear material production capabilities must be part of the treaty before entry into force - is undermined. Nevertheless, it must be admitted that all of these states

except for Thailand have already ratified the treaty.[32]

Table 4: Plutonium production in civilian light water moderated research reactors in NNWSs and de-facto NWSs with a thermal energy below 1 MW. A load factor of 75% is assumed, the plutonium production rate is chosen corresponding to a burn-up of 50% ^{235}U. The third column shows the annual production in the reactor fuel in normal operation (scenario A), the fourth column provides the production capability with NU targets (scenario B). Germany's FRM II is not included because of its unconventional core design.

(*) temporary shutdown, (+) under construction

Country	Facility name	Plutonium Production in Fuel [g/a]	Plutonium Production in NU targets [g/a]
Algeria	ES-SALAM	944	2,960
Argentina	RA-3	261	359
Australia	OPAL	522	717
Bangladesh	TRIGA MARK II	78	108
Belgium	BR-2	141	5,250
Brazil	IEA-R1	130	179
Bulgaria	IRT-SOFIA*	53	72
Canada	MNR MCMASTER, NRU	126	26,708
Chile	RECH-1, RECH-2*	182	251
Czech Republic	LVR-15 REZ	165	368
Egypt	ETRR-1, ETRR-2	626	860
Germany	BER-II	261	359
Greece	GRR-1*	130	179
Hungary	BUDAPEST RR	261	359
India	CIRUS, DHRUVA	27,580	27,580
Indonesia	TRIGA BANDUNG, GA SIWABESSY	834	1,152
Iran, Islamic Republic of	TRR, IR-40^{+}	4,070	8,059
Israel	IRR-1	7	262
Japan	JRR-3M, KUR*, JRR-4, JMTR	2,043	2811
Jordan	JRTR^{+}	130	179
Kazakhstan	WWR-K ALMA ATA, EWG 1	148	2,061
Korea, Dem. P.R. of	IRT-DPRK	209	287
Korea, Republic of	HANARO	11	5,930
Libyan Arab Jamahiriya	IRT-1	261	359
Morocco	MA-R1	52	72
Netherlands	HOR HFR	1,222	1,682
Norway	HBWR, JEEP II	1,057	4,330
Pakistan	PARR-1	261	359
Peru	RP-10	261	359
Poland	MARIA	782	1,080
Romania	PITESTI	365	502
South Africa	SAFARI-1	522	717
Taiwan	THOR	52	72
Thailand	TRR-1/M1	52	72
Ukraine	WWR-M KIEV	261	359
Uzbekistan	TASHKENT	261	359

[1] International Panel on Fissile Materials, *Global Fissile Material Report 2010*, Princeton (2010).

[2] International Atomic Energy Agency, *Research Reactor Database*, http://nucleus.iaea.org/RRDB/ (last access: 12/01/2011).

[3] G. Zuccaro-Labellarte and R. Fagerholm, "Safeguards at Research Reactors: Current practices, future directions," *IAEA Bulletin*, 4 (1996): 20–24.

[4] ^{233}U is a fissile isotope which can be used for a nuclear weapon. It is produced by neutron capture of ^{232}Th.

[5] F.T. Binford, "Diversion Assumptions for High-Powered Research Reactors," Oak Ridge National Laboratory, ISP C-50 Phase I (1984).

This rate is derived by a simple neutron balance for the reactor core: Assume ν = 2.47 and an average energy released per fission of 200 MeV. The neutron production is then $7.71 \cdot 10^{16}$ $(MWs)^{-1}$. Subtracting the neutrons needed to sustain chain reaction and taking into account an utilization factor f = 75 % and η = 84 % (values for a typical research reactor with HEU-fuel), a neutron number of $2.76 \cdot 10^{16}$ $(MWs)^{-1}$ remains for capture in ^{238}U. This number is equal to a ^{239}Pu production of 0.94 g/MWd. In reality, this rate will be significantly lower due to leakage, other fissions than ^{235}U and so on. Therefore, the exclusion of reactors with a thermal energy below 1 MW in this analysis is rather conservative.

[6] G. Zuccaro-Labellarte and R. Fagerholm, "Safeguards at Research Reactors: Current practices, future directions," *IAEA Bulletin*, 4 (1996): 20–24.

[7] M.M. Miller and C.A. Eberhard, "The potential for upgrading safeguards procedures at research reactors fuelled with highly enriched uranium," Massachusetts Institute of Technology (1982).

[8] U.S. Department of Energy, "Plutonium: The First 50 Years. United States plutonium production, acquisition, and utilization from 1944 through 1994," DOE/DP-0137, (1996).

[9] J.C. Mark, "Explosive Properties of Reactor Grade Plutonium," *Science and Global Security*, 4 (1993): 111–128.

[10] In this work, Nuclear Weapon States are defined according to the Non-proliferation treaty (China, France, Russian Federation, UK, USA), de-facto Nuclear Weapon States as India, Israel, North Korea and Pakistan and Non-Nuclear Weapon States as all remaining states.

[11] International Panel on Fissile Materials, *Global Fissile Material Report 2010*, Princeton (2010).

[12] ibid.

[13] Oak Ridge National Laboratory, *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation.* ORNL/TM-2005/39.. (2009).

[14] The three other types are breeder reactors (2 units), high temperature gas cooled reactors (1 unit) and graphite moderated (1 unit). These reactors cannot be included in the following analysis.

[15] International Atomic Energy Agency, *Research Reactor Core Conversion from the use of Highly Enriched Uranium to the use of Low Enriched Uranium Fuels Guidebook*, TECDOC-233 (1980).

[16] ibid.

[17] ibid.

[18] F.T. Binford, "Diversion Assumptions for High-Powered Research Reactors," Oak Ridge National Laboratory, ISP C-50 Phase I (1984).

[19] M.M. Miller and C.A. Eberhard, "The potential for upgrading safeguards procedures at research reactors fuelled with highly enriched uranium," Massachusetts Institute of Technology (1982).

[20] M.M. Miller and C.A. Eberhard, "The potential for upgrading safeguards procedures at research reactors fuelled with highly enriched uranium," Massachusetts Institute of Technology (1982).

and

F.T. Binford, "Diversion Assumptions for High-Powered Research Reactors," Oak Ridge National Laboratory, ISP C-50 Phase I (1984).

[21] For example, the production rate at 60% burn-up for LEU fuel is 89 mg Pu/MWd compared to 100 mg Pu/MWd given by A. Glaser, "On the Proliferation Potential of Uranium Fuel for Research Reactors at Various Enrichment Levels," *Science and Global Security*, 14 (2006):1–24. However, a detailed comparison is not possible due to the fact that the calculations by Glaser assume a different uranium density in the fuel (0.948 gU/cm^3 for all enrichment levels) than used in this assessment.

[22] International Atomic Energy Agency, *Research Reactor Core Conversion from the use of Highly Enriched Uranium to the use of Low Enriched Uranium Fuels Guidebook*, TECDOC-233 (1980).

[23] M.M. Miller and C.A. Eberhard, "The potential for upgrading safeguards procedures at research reactors fuelled with highly enriched uranium," Massachusetts Institute of Technology (1982).

[24] International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," 23 November, 2010.

[25] D. Albright, P. Brannan, and R. Kelley, "Mysteries Deepen Over Status of Arak Reactor Project," Institute for Science and International Security, 2009, http://www.isisnuclearіran.org/assets/pdf/ArakFuelElement.pdf (last access: 12/01/2011).

and

D. Albright, P. Brannan, and R. Kelley, "Update on the Arak Reactor in Iran," Institute for Science and International Security, 2009, http://isis-online.org/uploads/isis-reports/documents/Arak_Update_25_August2009.pdf (last access: 12/01/2011).

[26] D. Albright, P. Brannan, and R. Kelley, "Update on the Arak Reactor in Iran," Institute for Science and International Security, 2009, http://isis-online.org/uploads/isis-reports/documents/Arak_Update_25_August2009.pdf (last access: 12/01/2011).

and

B.D. Murphy, "ORIGEN-ARP Cross-Section Libraries for the RBMK-1000 System," Oak Ridge National Laboratory ,ORNL/TM-2006/139, (2006).

and

U.S. Nuclear Regulatory Commission, "Report on the Accident at the Chernobyl Nuclear Power Station," NUREG-1250, (January 1987).

[27] If an operator wants to utilize fuel as economically as possible, he will certainly have to consider in-core fuel management strategies like a batch reloading scheme in order to keep the "reactivity swing" (positive excess reactivity of the core) as low as possible. Thus, a batch reloading strategy will be included in the calculation of discharge burn-up as described by Driscoll et al, 1990 for heavy water reactors.

[28] F.T. Binford, "Diversion Assumptions for High-Powered Research Reactors," Oak Ridge National Laboratory, ISP C-50 Phase I (1984).

[29] D. Albright, F. Berkhout, and W. Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*, (Oxford University Press Inc., 1997)

[30]International Panel on Fissile Materials, *Global Fissile Material Report 2010*, Princeton (2010).

[31] Comprehensive Nuclear-Test-Ban Treaty, 1996.

[32] Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, *Status of Signature and Ratification*, http://www.ctbto.org/the-treaty/status-of-signature-and-ratification/?Fsize=a

Conference Proceedings

Severe Atmospheric Aerosol Events Conference

Hamburg, 11 and 12 August 2011

Huge amounts of aerosols can be generated by volcano eruptions, forest fires and asteroid impacts. However, they would also occur as a result of nuclear weapons detonations and subsequent fire storms. Climate engineering might make use of the strong effects of large amounts of aerosols with the goal of reducing the solar radiation that warms the atmosphere. These events were topic of an international workshop at the KlimaCampus of the University of Hamburg on 11 and 12 August 2011. The workshop was organized by the Carl Friedrich von Weizsäcker Centre for Science and Peace Research (ZNF) in cooperation with the Max-Planck-Institute for Meteorology, the Research Group Climate Change and Security (CLISEC) of KlimaCampus Hamburg, and the King Abdullah University of Science and Technology, Saudi Arabia (KAUST). For the first time all kinds of aerosol sources were discussed in one meeting in all aspects from pathways and impacts to policies.

The first session dealt with the life-cycle of large aerosol injections from particle generation, injection into the atmosphere, vertical transport mechanisms and transfer into the stratosphere as well as various kinds of removal processes. The experts agree that the life-cycle depends sensitive on environmental conditions like temperature and humidity. If these conditions are not well understood, the simulation of the further development is unreliable.

The second session considered both the direct climate impacts (changes in temperature, precipitation, ozone depletion etc.) and secondary environmental impacts that are of relevance for the biosphere (conditions for agriculture, ultraviolet intensity etc.). The impact of historic volcano eruptions on the climate is still debated. In particular, it is still unclear to what extent the younger Toba tuff eruption contributed to the decrease in average surface temperatures. New simulations of a nuclear war show a much stronger "nuclear winter" than previous studies, even if one hundred nuclear weapons are involved instead of thousands. Other severe aerosol events like extended forest fires and asteroid impacts may also have tremendous impact on the environment.

The third session discussed the socio-economic consequences that climatic and environmental changes could have. The presentations dealt with medical implications, extinction of species, loss in agricultural productivity and spread of famine. Significant uncertainties are inherent to all these issues.

In the final session the experts reflected on actions for aerosol event mitigation and adaptation that may be required. Due to severe consequences on human security, significant challenges for regional and global governance will have to be tackled. The experts agreed that the risks of various hypothetical severe aerosol events are often ignored or underestimated and not adequately taken into account yet.

Source: Official Conference Summary

Workshop on nuclear weapons and their disarmament

Hamburg, 10 August 2011

On August 10, 2011, ZNF, IFSH, the Research Group Climate Change and Security (CLISEC, University of Hamburg), the Federation of German Scientists (VDW) and FONAS held a workshop on nuclear weapons and their disarmament in Hamburg. This one-day event was part of the 2011 Severe Atmospheric Aerosol Events Conference.

Due to this linkage, most of the workshop participants had a strong background in atmospheric science so that one of the foci of this workshop was the environmental effect of nuclear war, i.e. research into the so-called nuclear winter. Steven Starr reported on “Environmental consequences of tactical weapons and implications on disarmament“; Valery Yarynich discussed “Perceptions of environmental consequences of nuclear war in nuclear disarmament“.

A second focus of this workshop was tactical weapons in Europe. Oliver Meier discussed the diversity of opinions within Europe when it comes to nuclear sharing and possible steps in the future to support disarmament of tactical weapons. He presented

some ideas on possible next steps in negotiations between the US, Russia and NATO in his talk "European positions on tactical nuclear weapons disarmament". Susi Snyder presented her paper "Withdrawal Issues: What NATO countries say about the future of tactical nuclear weapons in Europe". This study found out – inter alia – that there is sufficient political will within NATO to end the deployment of US tactical nuclear weapons. This was her main result of talks with a wide range of government officials.

In a last session, Martin Kalinowski discussed "Scientific contributions to support progress in nuclear disarmament towards zero", where he introduced past and present projects such as the Trilateral Initiative and the UK-Norway Initiative and introduced various verification techniques relevant for disarmament verification.

Malte Göttsche

Meeting on disarmament verification

Hamburg, 30 September 2011

On September 30, 2011, after the FONAS meeting, another meeting was held discussing a possible engagement of the German science and peace research community in disarmament verification issues. Initial presentations were delivered by Martin Kalinowski and Malte Göttsche. While Martin Kalinowski focused on the road to Global Zero – introducing the idea of combining quantitative disarmament (in warhead numbers) with qualitative disarmament (e.g. changing the deployment status of warheads), Malte Göttsche presented the wide range of possible scientific contributions to disarmament verification. He discussed both verifying the dismantlement of declared warheads as well as verifying the completeness of declarations. Furthermore, he introduced existing networks and initiatives dealing with disarmament verification.

Possible German contributions were discussed and the participants of this meeting showed vital interest in exploring possibilities. Besides an existing research project on information barriers for warhead authentication at ZNF, there is interest within the German peace research community in growing expertise relevant to the topic in Germany. The next step will be a workshop in January 2012, where not only members of the peace research community, but more broadly all scientists with an interest in disarmament verification, are invited. The main goal is to better define the scope of a future network on disarmament verification.

Malte Göttsche

Forscher berieten sich am KlimaCampus über die Folgen von Geo-Engineering

Hamburg, 10. – 11. November 2011

Taugt Geo-Engineering als Notfallplan gegen die Folgen des Klimawandels? Welche möglichen Gefahren bergen diese neuen Technologien für Umwelt und Gesellschaft? Und wie sehen damit einher gehende Konfliktpotenziale oder sogar Sicherheitsrisiken aus? Betrachtet man das Thema Geo-Engineering aus Sicht der Friedensforschung, sind noch viele Fragen ungeklärt.

Um ihnen auf den Grund zu gehen, kamen am KlimaCampus Hamburg vom 10. bis 11. November mehr als 50 Klima- und Friedensforscher aus den USA, England und Deutschland zusammen. Auf der Tagung "Geoengineering the Climate: An Issue of Peace and Security Studies?" diskutierten sie die Perspektiven einer absichtlichen Klima-Intervention.

Derartige Eingriffe ins Klimasystem zeigen den wachsenden Einfluss des Menschen auf das Erdsystem, für den der an der Tagung teilnehmende Nobelpreisträger Paul Crutzen den Begriff "Anthropozän" geprägt hat.

Eröffnungsplenum mit (von links): Jürgen Scheffran (Moderator), Gernot Klepper, Peter Liss und Paul Crutzen; Foto: UHH/ KlimaCampus

Öffentliche Diskussion mit (von links): Jason Blackstock, Timo Goeschl, James Fleming, Konrad Ott und Michael Brzoska (Moderator); Foto: UHH/ KlimaCampus

Der Ökonom Gernot Klepper vom Kieler Institut für Weltwirtschaft verwies daraufhin in seinem Diskussionsbeitrag auf Ergebnisse einer von ihm geleiteten umfangreichen Studie im Auftrag des Bundesministeriums für Bildung und Forschung ("Gezielte Eingriffe in das Klima?"). Denn mit einer Klima-Intervention werden komplexe Fragen der Verteilung von Nutzen, Kosten und Risiken zwischen verschiedenen Weltregionen und Generationen aufgeworfen. In der anschließenden öffentlichen Podiumsdiskussion diskutierten James Fleming, Timo Goeschl, Jason Blackstock und Konrad Ott historische, ökonomische, politische sowie ethische Aspekte des Geo-Engineering. Nachdem dann am zweiten Tagungstag die Verfahren des Geo-Engineering im Einzelnen vorgestellt, die Konfliktpotenziale und Sicherheitsrisiken angesprochen sowie die Möglichkeiten von Risikodiskursen und internationalen Regulierungsmaßnahmen diskutiert wurden, ist am Ende ein deutliches Meinungsbild unter den Teilnehmern entstanden: Einigkeit herrschte darüber, dass angesichts der hohen Komplexitäten und Unsicherheiten der Einsatz von Geo-Engineering derzeit nicht zu rechtfertigen ist und viele Aspekte erst noch erforscht werden müssen. Wie mit Feldversuchen umgegangen werden soll, darüber gab es dagegen unterschiedliche Ansichten.

Für die Mitveranstalter Jürgen Scheffran und Michael Link (KlimaCampus), Michael Brzoska, Götz Neuneck (IFSH) und Achim Maas (adelphi) war die Tagung ein voller Erfolg: Zum ersten Mal konnte das Thema Geo-Engineering gemeinsam aus der Sicht der Klimaforschung sowie der Friedens- und Konfliktforschung bearbeitet werden.

Source: Conference Summary, www.klimacampus.de

XXIV ISODARCO Winter School: "Eliminating Nuclear Weapons and Safeguarding Nuclear Technologies"

Andalo (Italy), January 9 to 16 2011

The 24th ISODARCO Winter Course, which took place in Andalo (Italy) from 9 to 16 January 2011, had the title „Eliminating Nuclear Weapons and Safeguarding Nuclear Technologies". It was the third Winter Course in a row dedicated to the issue of nuclear disarmament, after a number of courses in the years 2003 to 2008 were dedicated to a critical appraisal on the war on terror.

The ISODARCO Courses have a long tradition in the realm of peace and conflict studies and have been taking place regularly since 1968 at an annual (and sometimes biennial) rate. Whereas in the first 20 years the "International School on Disarmament and Research on Conflicts" (this is the official label for ISODARCO) held its courses prevalently in summer, since 1988 there is an annual Winter Course taking place for a week in a ski resort in the Italian Alps.

The Director of the School, Physics Professor Carlo Schaerf from Rome University, noticed that during the Winter Course participants were generally more concentrated, more committed to the lectures and less distracted so that we can expect (and we hope) that this quite successful format will continue for many more years. The Winter Courses offer a good balance between the lectures and time for leisure in between the presentations and discussions. Besides the friendly atmosphere, the excellent food, the fresh air of the Italian Alps, the ski slopes and the hiking trails, ISODARCO is a unique opportunity for students and junior researchers to liaise with senior experts both from the academia and the governmental sector.

The 24th ISODARCO Winter Course was quite unique in this respect, as it brought together academic heavyweights on nuclear issues, both from the natural as well as from the social sciences, established policy analysts from a number of think-tanks, leading NGO-activists on nuclear disarmament as well as

career diplomats specialized in nonproliferation policies. The course was directed by Prof. Matthew Evangelista from Cornell University, together with FONAS-Member Giorgio Franceschini from Darmstadt University of Technology and the Peace Research Institute Frankfurt (PRIF).

The opening lecture was given by Rebecca Johnson from the Acronym Institute on nuclear weapons and international humanitarian law. Dr. Johnson highlighted that the road to nuclear zero could and should be pursued as humanitarian action, and not just within a narrow security framework. Hence, regardless of the value states might attach to nuclear weapons, these weapons should be eliminated by virtue of their incompatibility with basic humanitarian norms. Harald Müller from PRIF addressed "nuclear zero" from another perspective and asked what arrangements must be taken to enforce the rules in a nuclear weapon free world.

After these two initial lectures addressing two big issues of nuclear disarmament there were a number of more focused lectures on the New START Treaty (Alexei Arbatov from Carnegie Moscow), the new NATO Strategic Concept (Tom Sauer from the University of Antwerp together with Harald Müller), the Iranian nuclear crisis (Paolo Cotta-Ramusino, current Secretary General from Pugwash), the North Korean nuclear conundrum (Jae-Jung Suh from John Hopkins University) and the nuclear juxtaposition in South Asia (Peter Topychkhanov from Carnegie Moscow).

As the ISODARCO Winter Schools are part of the activities of the Italian Pugwash Group, and Pugwash has a strong tradition in the natural sciences (first and foremost in physics), the course also had a number of more technical lectures, which were given by two renowned physicists working in the field of nuclear arms control: whereas Prof. Rajaraman from Delhi University lectured on the (worrying) fissile material production trends in South Asia, Pavel Podvig, a major expert of the Russian nuclear complex, provided a critical appraisal on Moscow's campaign to downblend highly-enriched uranium (HEU), which – in Podvig's eyes – created more risks than benefits.

Rajaraman and Podvig were also present at a round-table questioning the narrative of a nuclear renaissance for the 21st century. Whereas Marco de Andreis, an Italian economist and former EU consultant, pointed out that nuclear energy was in general decline all over Europe and provided sound economic explanations for this trend, Rajaraman and Podvig highlighted that in their home countries (India and Russia, respectively) the trend was exactly the opposite: both countries are investigating a number of innovative nuclear technologies (first and foremost breeder reactors) and seem committed to bet on nuclear energy for their future electricity supply. Hence, the nuclear energy landscape will change and the nuclear energy hotspots of the 21st century might shift from (Western) Europe to Asia, Russia and (maybe) Latin America.

The 2011 ISODARCO Winter School concludes a series of consecutive Winter Schools dedicated to nuclear arms control. This was certainly due to the "Obama effect", which revived the stagnant arms control spirit within the U.S. Administration and brought to the conclusion the New START Treaty with Russia, and is still committed to convince the U.S. Senate to give their approval for the CTBT. The 2012 ISODARCO Winter School will be dedicated to a highly topical subject: the issue of cyberwar, cyberterrorism and cybercrime. The cyberattacks, which were directed again Iran's nuclear program in 2011 show that this topic is an

Participants of the XXIV ISODARCO Winter School in Andalo (Italy).

ideal continuation for a discussion on the security challenges of the 21st century.

The program and lecturers (and some presentations) from the ISODARCO Winter and Summer courses can be viewed at www.isodarco.it.

Giorgio Franceschini

Workshop „Wettrüsten im Cyberspace?“

Hamburg, 24. Juni 2011

Der Forschungsverbund Naturwissenschaft, Abrüstung und Internationale Sicherheit (FONAS) und die Interdisziplinäre Forschungsgruppe Abrüstung, Rüstungskontrolle und Risikotechnologien (IFAR^2) des Institutes für Friedensforschung und Sicherheitspolitik an der Universität Hamburg (IFSH) organisierten am 24. Juni einen Workshop zum Thema „Wettrüsten im Cyberspace?“. Ziel der Veranstaltung war die Analyse der aktuellen Situation bezüglich der möglichen Bedrohungen und der verschiedenen Reaktionsmöglichkeiten aus deutscher Sicht.

An der interdisziplinär ausgelegten Veranstaltung nahmen ca. 40 Teilnehmer aus den Bereichen Wissenschaft, Ministerien und der Praxis teil und gingen u.a. der Frage nach, was unter einem Cyberwar zu verstehen ist und welche Begrenzungsmaßnahmen möglich sind. Unter den Referenten, die Vorträge hielten, waren auch jeweils ein Vertreter des Auswärtigen Amtes und des Verteidigungsministeriums.

Die Experten identifizierten u.a. sowohl das Problem der Nicht-Attribution von Cyberangriffen als auch die teilweise fehlende Visibilität und Nachweisbarkeit von Schäden als zentral in der aktuellen Debatte. Da Schadsoftware wie Stuxnet auch kein vorübergehendes Phänomen darstellt - immer mehr Länder sind im Bereich Cybersecurity aktiv - werden Themen wie Prävention und Schadensbegrenzung immer wichtiger. Daher werden u.a. auch verstärkt Natur- und Computerwissenschaftler gefordert sein, durch ihre Expertise sowohl bei der Einschätzung der Bedrohungslagen als auch bei der Erarbeitung von Begrenzungsmaßnahmen mitzuwirken. Eine Stärkung der internationalen Zusammenarbeit und eine Steigerung der Staatenverantwortlichkeit, Angriffe von ihrem Territorium aus zu vermeiden, sind auch essenziell, um das Risiko zu verringern.

Kerstin Petermann

59th Pugwash Conference „European Contributions to Nuclear Disarmament & Conflict Resolution“

Berlin, 29 and 30 June 2011

Since 1957, Pugwash Conferences bring together scientists, diplomats, decision makers and other actors to discuss issues related to nuclear disarmament and other armed conflicts in the world. The 59th conference was hosted by Federation of German Scientists (VDW) and took place in the German Federal Foreign Office in Berlin. More than 300 participants made the conference one of the biggest Pugwash Conferences. Among the participants were many FONAS members.

Besides many other topics two events in spring 2011 had a large influence on the conference and the discussions: The Arab spring with the uprisings of civil societies in many Arab countries and the Japanese catastrophe that lead to the Fukushima nuclear accidents. Both issues were referred to by many speakers and discussants, linked to nearly all other topics.

Two days before the main conference (29.06. – 30.06), the International Student / Young Pugwash (ISYP) held a conference “Conflict and Cooperation - The Global Impact of Regional Security Efforts” giving 32 young people a chance to present their views on various issues, mainly split in two groups covering issues with regional or global focus respectively. All participants of this conference had the chance to meet and talk to the Pugwash Council members during an evening event and to participate on the 59th Pugwash conference, too.

On the first day of the Pugwash conference, the Simons Symposium on “European Security and Nuclear Disarmament” was co-organized by the European Leadership Network (ELN). It started with an opening keynote address by the German foreign minister Guido Westerwelle. Two plenary sessions followed on nuclear weapons in Europe and relations between Europe, the US and NATO. The symposium closed by a joint discussion between Ellen Tauscher (Under Secretary of State, USA) and Sergei Ryabkov (Deputy Foreign Minister, Russia).

The next three days held in turns plenary sessions and parallel meetings of six different working groups. The working groups were:

1. Nuclear Disarmament, Non-proliferation (after the 2010 NPT Review Conference)

2. Prospects for Peace and Security in the Middle East
3. Regional Stability in Central and South Asia: the situation in Afghanistan, and Indo-Pakistani relations
4. European Security and Disarmament (nuclear and conventional arms control and disarmament)
5. Social Responsibility of Scientists
6. Climate Change, Resources, and Conflict Prevention

Working Group sessions were held under the Chatham House Rules, most of the plenary sessions were open to the public and media. Reports of the working groups written from the view point of the individual rapporteurs are available to the public on the website mentioned earlier.

The plenary sessions of the second day dealt with the Middle East region, namely Iran's nuclear policy, the elimination of WMD in the Middle East and possible future developments for Palestine. One session was also hold on the progress on the CTBT.

During the third day, a plenary session on the Indo-Pakistan conflict took place after a session on the prospects for conflict resolution in Afghanistan. In the afternoon of this day more working group sessions took place. On the last day, Tatsujiro Suzuki presented the talk "The Fukushima nuclear accident: lessons learned (so far) and possible implications" during the Dorothy Hodgkin Lecture. It was followed by an address of the Pugwash president Jayantha Dhanapala. The conference ended with a last plenary session on "Problems and Opportunities in the Changing Middle East".

Moritz Kütt

Many reports, presentations and other information are available from:
http://www.pugwash.org/reports/pic/59/general_information.htm

DPG AG Physik und Abrüstung

Dresden, 16. bis 18. März 2011

Die Fachsitzung der Arbeitsgruppe Physik und Abrüstung behandelte in insgesamt 20 Haupt- und Fachvorträgen ein breites Spektrum naturwissenschaftlicher Arbeiten im Bereich internationaler Sicherheit. Den Auftakt bildete die Problematik des Umgangs mit spaltbarem Material. Bis heute gibt es weltweit einige hundert Tonnen separierten Plutoniums und über 1000 Tonnen hochangereicherten Urans. Mit diesen kernwaffentauglichen Materialien könnten zehntausende Kernwaffen gebaut werden. Ein Großteil lagert in den Kernwaffenländern, aber nicht unbedeutende Mengen sind auch im zivilen Bereich vorhanden. Pavel Podvig (Genf) stellte die komplexen Stoffströme spaltbarer Materialien in Russland und die damit verbundenen Reduktionsmaßnahmen dar. Über die Auslegung eines angestrebten Vertrages zum Stopp der Produktion waffenfähigen Materials (Fissile Material Cut-off Treaty) berichtet Annette Schaper (HSFK, Frankfurt).

Ein großes Problem stellt das militärische Potential von Dual-Use-Technologien dar. Urananreicherung mittels Gaszentrifugen wird u.a. vom Iran und Nordkorea betrieben. Matthias Englert (CISAC, Stanford) berichtete über die Nutzung dieser Technologie in den beiden Ländern. Ein wichtiges Element zur Verhinderung der Weitergabe von Dual-Use-Technologien sind Exportkontrollen. Dieter Müller (Leybold Vakuum/Oerlikon) zeigte auf, welche Maßnahmen Industrieunternehmen eingeführt haben, um eine effektive, interne Exportkontrolle zu ermöglichen. Raketentechnologie ist ebenfalls eine Dual-Use-Technologie. Iran und Nord-Korea betreiben selbst ambitionierte Raketenprogramme. Robert Schmucker (Schmucker Technologies, München) berichtete umfassend über die Raketenentwicklung dieser Staaten und bezweifelte deren Eigenständigkeit und Zuverlässigkeit. Eine Antwort auf die Raketenproliferation sind die neuen US-Raketenabwehrpläne zur Verteidigung Europas. Götz Neuneck (IFSH Hamburg) berichtete über die geplanten Ausbaustufen und über mögliche destabilisierende Auswirkungen in Bezug auf Russland. Die Stationierung von Raketenabwehr kann einen Rüstungswettlauf auslösen und weitere nukleare Abrüstung verhindern.

Im Zusammenhang mit der Abrüstung von Kernwaffen und des damit verbundenen Materials ist deren Überwachung und Verifikation von großer Bedeutung. Die IAEO übernimmt heute schon einen Teil der Überwachungsaufgaben. Vor allem die Entwicklung neuer Safeguards-Technologien ist hier gefragt. Irmgard Niemeyer (FZ Jülich) berichtete über die zahlreichen deutschen Aktivitäten im Rahmen des deutschen IAEO-Unterstützungsprogramms. Martin Kalinowski (ZNF Hamburg) zeigte die steigende Rolle der Zivilgesellschaft bei der Überprüfung nuklearer Rüstungskontrolle auf z.B. im Bereich verbesserten Messverfahren oder bei der Detektion von Sig-

naturen für Kernwaffenaktivitäten. Dabei ist auch die Simulation der atmosphärischen Ausbreitung von Radioaktivität von großer Bedeutung. Jürgen Altmann (TU-Dortmund) stellte seismische Methoden vor, um in einem Salzbergwerk sicherzustellen, dass aus dem endgelagerten radioaktivem Müll kein Plutonium unbemerkt entnommen werden kann. Markus Kohler (ZNF Hamburg) stellte den Aufbau und die Nutzung von Atomfallen vor, um die illegitime Wiederaufarbeitung anhand von Kr85-Emission extrem genau nachzuweisen. Wolfgang Rosenstock (INT Euskirchen) stellte Messverfahren vor, die bei der Abrüstung von Kernsprengköpfen eingesetzt werden können und die die Balance zwischen Nachweis der Zerstörung und Nichtoffenlegung des Kernwaffendesigns erhalten. Steinar Hoibraten (Norwegian Defence Research Establishment, Oslo) berichtete von der Planung und Durchführung einer Zerstörungs- und Verifikationsmission, die von Großbritannien und Norwegen durchgeführt wurden.

Aufgrund des Ausfalls eines Hauptvortrags organisierte der Arbeitskreis eine Sondersitzung zu Fukushima, bei der einige Mitglieder des AKA (M. Englert, G. Neuneck, W. Liebert, O. Ross) Kurzvorträge zu Risiko, Unfallverlauf, Ausbreitung der Radioaktivität etc. hielten, was auf eine gute Resonanz des Publikums stieß.

Die Vorträge waren wie stets mit 50-150 Besuchern pro Vortrag sehr gut besucht. Dieses rege Interesse sowie die angeregten Diskussionen zeigen, dass die Bearbeitung physikalischer Fragestellungen im Bereich internationaler Sicherheitspolitik weiterhin von hoher Relevanz ist.

Mathias Englert und Götz Neuneck

23rd Summer Symposium on Science and World Affairs

London, 3 - 10 August 2011

From 3rd - 10th August 2011, the 23rd Summer Symposium on Science and World Affairs took place at the premises of the King's College in London. This annual international meeting is held in changing countries to encourage and support the development of young scientists working on policy-oriented research on international security and arms control issues.

Besides the important substantive work the symposia should serve as a platform for improved networking, sharing of ideas, help with projects, publications, in applying for funding and motivation for young scientists. The format of the conference consists of presentations of all participants (25 minutes presentation with 20 minutes discussion) and several joint discussions on selected topics. Scheduled are also times when the participants do sight-seeing in the city together.

Teri Grimwood (as well as the London on-site team) did a great job by organising this event: starting with shuttle transports to and from the airport to on-the-fly food upgrades for those who did not like the British kitchen. A balanced mixture of experienced and first-time participants covered mainly the topics: space security, the nuclear fuel cycle and proliferation/verification issues. From a given occasion one afternoon was used for information sharing and discussions on the Fukushima accident and its possible impact on the power supply of different countries. Especially the old hands Ed Lyman and George Lewis were able to help with their enormous knowledge if discussions got stuck or if detailed knowledge was useful to answer comprehensive questions. As last year the country the most participants came from was China (their foci were in the range of space security and nuclear weapons); this year for the first time there were also participants from Mongolia and Iraq. The present FONAS members held talks on their research topics: Jochen Ahlswede (Assessment of Global Inventories and Production Capabilities of Plutonium from Civilian Nuclear Reactor Operation), Felix Gorschlüter (Removing Periodic Noise from Impulsive Nuclear Explosion Aftershocks), Frederik Postelt (Detectability of Nuclear Underground Explosions). Malte Göttsche was also able to join the meeting for a few days as he was in London during that time.

Felix Gorschlüter

FONAS-Jahrestagung 2011

Osnabrück, 28. bis 29. September 2011

Wie in den Jahren zuvor fand die FONAS Jahrestagung wieder in den Räumen der Deutschen Stiftung Friedensforschung in Osnabrück statt. Die 15 Teilnehmer tauschten sich über aktuelle und kürzlich abgeschlossene Forschungsprojekte – hauptsächlich im Bereich der nuklearen Rüstungskontrolle und Nichtweiterverbreitung – aus. Auch die FONAS Mitgliederversammlung fand im Rahmen der Jahrestagung statt. Das Programm ist im Folgenden dargestellt.

Teilnehmer der FONAS Jahrestagung 2011.

Mittwoch, 28. Sept. 2010, 14.00 – 18.30

14:00	Begrüßung	
14:15	Felix Gorschlüter	Unterdrückung periodischer Störgeräusche zur CTBT Verifikation (10 min)
	Frederik Postelt	Detectability of nuclear underground explosions by radioxenon (10 min)
	Moritz Kütt	Brutpotentiale in schnellen Brütern (15 min)
	Malte Göttsche	Informationsbarrieren zur Authentifizierung von Kernwaffen (10 min)
16:00	Kaffeepause	
16:30	Giorgio Franceschini	Safeguards-Konzepte für Fusionsreaktoren (20 min)
	Martin Kalinowski	Science Diplomacy – Wissenschaftskooperation zur Stärkung des Arabischen Frühlings (10 min)
	Matthias Englert	Was ist eigentlich schwierig? (15 min)
18:30	Gemeinsames Abendessen	

Donnerstag, 29. Sept. 2011, 09.00 – 19.00

9:00	Jochen Ahlswede	Zukünftige Entwicklung ziviler Plutoniuminventare aus Leistungs- und Forschungsreaktoren (15 min)
	Wolfgang Liebert	Verfügbarkeit von Uran (20 min)
	Jürgen Altmann	Akustisch seismische Messungen für Endlager-Sicherungsmaßnahmen – erste Ergebnisse (20 min)
11:00	Kaffepause	
11:30	Götz Neuneck	Cyber security: Aktuelle Debatte und Perspektiven (10 min)
	Götz Neuneck	Update on BMD: Cooperation with Russia (10 min)
	Martin Kalinowski	Zertifizierung von Rohstoffen. Ein möglicher naturwissenschaftlicher Beitrag zur Friedensforschung? (15 min)
13:00	Mittagspause	gemeinsames Mittagessen in der Osnabrücker Mensa Schlossgarten
14:00	Ole Roß	Atmosphärische Transportmodellierung am Deutschen NDC und die Ausbreitung von Radionukliden aus dem AKW Fukushima (20 min)
	Christoph Pistner	Fukushima (20 min oder mehr)
16:00	Kaffeepause	
16:30	FONAS Mitgliedsversammlung	Auch: Planung gemeinsamer Aktivitäten: Insbesondere Aufbau Kontakte FONAS nach Europa
19:00	Gemeinsames Abendessen	

Das Zentrum für Naturwissenschaft und Friedensforschung (ZNF) nach der Beurlaubung des Carl Friedrich von Weizsäcker-Professors

von Martin B. Kalinowski

Sechs Jahre nach Gründung des Zentrums für Naturwissenschaft und Friedensforschung an der Universität Hamburg steht ein einschneidender Umbruch bevor. Der Leiter des Zentrums wird ab April 2012 beurlaubt und aller Voraussicht nach für drei Jahre bei der Organisation des Vertrags über das umfassende Verbot von Nuklearversuche (CTBTO) in Wien arbeiten. Der Hauptgrund für diesen Schritt liegt in der übermäßigen Arbeitsbelastung des Stiftungsprofessors: Obwohl selbst der Evaluationsbericht eine „exorbitante Belastung" bescheinigte, sah sich die Universität nicht in der Lage, eine nachhaltige Arbeitsgrundlage für die umfangreichen Aufgaben des Stiftungsprofessors zu schaffen. Nachdem alle anderen Möglichkeiten bis hin zu Bleibeverhandlungen ohne ausreichendes Ergebnis ausgeschöpft waren und eine längerfristige personelle Verstärkung oder wenigstens marginale Entlastung unerreichbar war, zieht der Leiter des ZNFs damit die nötigen Konsequenzen – nicht zuletzt zum Erhalt seiner Gesundheit.

In den ersten fünf Jahren seines Bestehens (März 2006 bis Februar 2011) wurde das ZNF mit einer Grundfinanzierung für die Carl Friedrich von Weizsäcker-Stiftungsprofessur von der Deutschen Stiftung Friedensforschung (DSF) sowie der Einwerbung von zusätzlichen Drittmitteln betrieben. In diesen fünf Jahren war das ZNF vollständig drittmittelfinanziert. Das Ziel wurde erreicht, gemeinsam mit dem Institut für Friedensforschung und Sicherheitspolitik (IFSH) ein Kompetenzzentrum der Friedens- und Konfliktforschung mit überregionaler Ausstrahlungskraft zu schaffen. Für die Universität Hamburg hat das ZNF ein umfangreiches Lehrangebot etabliert bestehend aus Modulen zu Naturwissenschaft und Friedensforschung für alle Studiengänge im freien Wahlbereich, für Ergänzungsfächer in Studiengängen der MIN-Fakultät und für den Master for Peace and Security Studies (MPS). Im März 2011 erfolgte die Auslösung der Drittmittel der DSF durch Landesmittel. Die Universität hat damit ihre Verpflichtung eingelöst, die naturwissenschaftliche Friedensforschung nach Ablauf der fünfjährigen „Anschubfinanzierung" selbstständig zu tragen. Dabei ist die finanzielle Bestandssicherung des ZNF ist trotz allgemeiner Sparzwänge ohne Abstriche garantiert. Auch in Gesprächen mit dem Präsidium und den Dekanaten der Universität Hamburg ist immer wieder dieselbe positive Haltung bestätigt worden und dessen Bemühen ausgedrückt worden, sich für das ZNF einzusetzen. Dies ist trotz aller Sachzwänge auf allen Ebenen der Verwaltung spürbar.

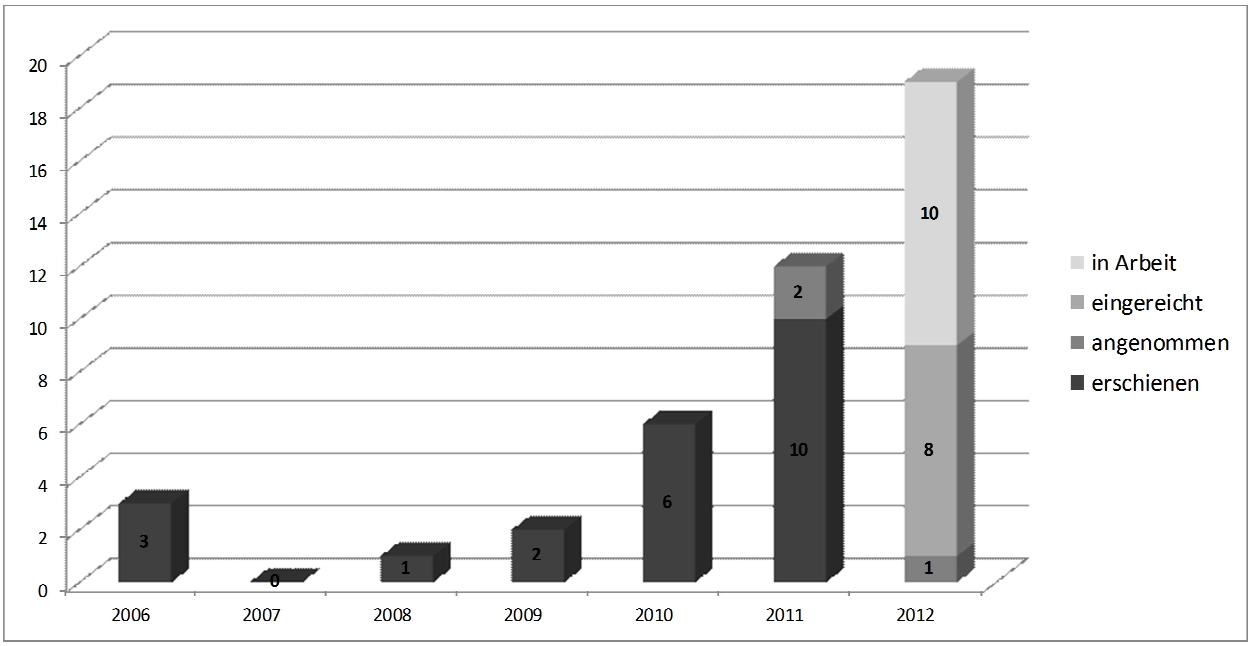
Der Einschnitt am ZNF durch die Beurlaubung des Direktors passiert zu einer Zeit, in der die Forschungsergebnisse des ZNF nach fünf Jahren zur vollen Blüte gelangen. Das wichtigste Teilprojekt ist das Labor für Ultraspurenanalyse von Krypton-81 und Krypton-85 mittels einer Atomfalle (Atom Trap Trace Analysis – ATTA), das in der erwarteten Effizienz die Pioniere vom Argonne National Laboratory überholt hat und sich an die weltweite Spitze dieser Zukunftstechnologie setzt. Die Internationale Atomenergieorganisation in Wien zeigt Interesse, diese Methode für den Nachweis geheim gehaltener illegaler Waffenplutoniumproduktion anhand des Spurenstoffs Krypton-85 in der Atmosphäre einzusetzen. Die bahnbrechenden meteorologischen Studien zum Nachweis des Ferntransportes von Kryptongasemissionswolken hat das ZNF erarbeitet. Dieses Projekt wird auch nach der Beurlaubung des Stiftungsprofessors durch einen Post-Doc, zwei Doktoranden sowie Diplomanden weitergeführt werden. Weitere Kooperationen bestehen insbesondere mit der CTBTO in Wien, die auch in Zukunft fortgeführt und z.T. sogar intensiviert werden sollen (Auftragsarbeiten zur Weiterentwicklung des Verifikationssystems, Beteiligung von Lehrenden an Trainingsveranstaltungen, Teilnahme von Studierenden an Trainingskursen). Die hohe Forschungsleistung wird auch nicht zuletzt an der positiven Entwicklung der Zahl begutachteter Publikationen deutlich.

Die Zukunft anderer Arbeitsfelder des ZNFs ist jedoch sehr ungewiss. Die drittmittelfinanzierte Forschungsstelle Biologische Waffen und Rüstungskontrolle wird ab Januar 2012 nur noch aus einem Mit-

arbeiter bestehen (statt in 2011 drei). Die Finanzierung der Forschungsstelle über April 2012 hinaus ist bisher nicht gesichert. Viele Projekte, die eng mit der Person des Stiftungsprofessors verbunden sind, scheinen zumindest gefährdet. Im laufenden Semester geht es nun darum, die Arbeitsfähigkeit des ZNFs so weit wie möglich nachhaltig abzusichern. Der C.F.v. Weizsäcker-Professor nutzt das laufende WS 2011/2012 dafür, die von ihm geleiteten Projekte entweder noch abzuschließen oder an andere Personen abzugeben (z.B. die Betreuung von Qualifizierungsarbeiten). Das Ziel ist es, den Fortbestand der Arbeit von einer Vertretungsprofessur unabhängig zu machen, einerseits um den Projekten eine sichere Grundlage zu verschaffen und andererseits damit die Vertretung weniger Belastungen unterliegt und frei ist, eigene Projekte zu realisieren. Wegen des Fehlens einer zweiten Professur im ZNF kann der Fortbestand zahlreicher Projekte des C.F.v. Weizsäcker-Professors nur durch eine Auslagerung der wissenschaftlichen Leitung aus dem ZNF in Fachbereiche und das IFSH erfolgen. Dies hat jedoch zum Vorteil, dass die Friedensforschung noch mehr als bisher schon in den Fachbereichen der MIN Fakultät sowie in anderen Fakultäten ankommt und dort verankert wird.

Schnellst möglich muss die Vertretungsprofessur geeignet besetzt werden. Das Aufgabenspektrum, das diese Vertretung wird ausfüllen müssen, ist herausfordernd: Es muss die Geschäftsführung des ZNF sowie ein Großteil der Lehre zu Naturwissenschaft und Friedensforschung übernommen, interdisziplinäre Kooperationen gesucht und laufende Projekte begleitet werden. Daneben wird es aber auch zahlreiche Gelegenheiten geben, ein eigenes Forschungsprofil umsetzen und damit neue Impulse für die Friedensforschung in Hamburg zu setzen.

Insofern steht dem ZNF nach seinem guten Start nun eine Zeit bevor, die zahlreiche Unsicherheiten birgt, aber auch Chancen zur Weiterentwicklung bereithält. Bedauerlicherweise muss aber unterm Strich festgestellt werden, dass für grundlegende Probleme in Struktur und vor allem Finanzierung keine Besserung in Sicht ist. Eine Erhöhung des Budgets ist strikt ausgeschlossen, gleichzeitig wird aber eine Entlastung der extrem vielfältigen Anforderungen unmöglich, weil alle sechs Fakultäten aufgrund ihrer Beteiligung an der Finanzierung des ZNF legitime Erwartungen an die Produktion von Ergebnissen haben, die ihnen zugutekommen. Es bleibt zu hoffen, dass die/der Vertreter/in sich von diesen Hürden nicht abschrecken lässt, sondern die Chancen ergreift, naturwissenschaftlichen Friedensforschung in Hamburg - und weit darüber hinaus – voranzutreiben.



Anzahl der begutachteten Publikationen pro Jahr, die aus Forschungsarbeiten des ZNFs hervorgegangen sind.

Tätigkeitsbericht des FONAS-Vorstandes für den Zeitraum Oktober 2010 bis September 2011

Dieser Bericht umfasst die Tätigkeitsfelder und Aktivitäten des vergangenen Jahres bis zur Mitgliederversammlung am 29. September 2011. Am 6. Oktober ist der Vorstand in der folgenden Zusammensetzung gewählt worden: Jürgen Altmann (Essen/Dortmund), Matthias Englert (Darmstadt), Martin Kalinowski (Hamburg, Vorsitz), Ulrike Kronfeld-Goharani (Kiel), Wolfgang Liebert (Darmstadt, stellv. Vors.), Christoph Pistner (Darmstadt), Ole Roß (Hannover), Christian Alwardt (Hamburg), Jochen Ahlswede (Hamburg) und Frederik Postelt (Hamburg). Dieser Bericht umfasst die erste Hälfte der Amtszeit des gegenwärtigen Vorstands.

1. Stand des Vereins

Im Berichtszeitraum gab es weder Ein- oder Austritte von Mitgliedern. Die Mitgliederzahl bleibt stabil bei derzeit 69. Der Verein besteht nun über fünfzehn Jahre und versteht sich weiterhin als der deutsche Fachverband für naturwissenschaftlich orientierte Friedensforschung.

Die Gemeinnützigkeit des Vereins wird turnusmäßig alle drei Jahre überprüft. Derzeit wird die Prüfung der Kassenberichte für die Kalenderjahre 2008, 2009 und 2010 zur Bestätigung der Gemeinnützigkeit durch das Finanzamt Hamburg vorbereitet. Den Finanzstand weist ein gesonderter Bericht des Kassenwarts (Christoph Pistner) aus.

2. Interne Zusammenarbeit

Auch im vergangenen Jahr wurden größere halbjährliche FONAS-Treffen (bei der DPG-Jahrestagung und die Herbsttagung) vorbereitet und die Gelegenheit zum intensiven inhaltlichen und persönlichen Austausch genutzt. Darüber hinaus wurden weitere Interessenten im Umfeld angesprochen.

Der von Christoph Pistner betreute FONAS-Listserver wurde für Mitteilungen aus dem Kreis der Mitglieder weiterhin genutzt. Der zehnte FONAS-Newsletter (Erstellung durch Ulrike Kronfeld-Goharani) erschien zum zweiten Mal in englischer Sprache im Oktober 2010. Der zehnte Newsletter befindet sich zurzeit in Arbeit und wird aller Voraussicht nach im Herbst 2010 erscheinen.

3. Vorstandstätigkeiten

Der Vorstand hat sich am 16. März persönlich in Dresden zur Vorstandssitzung getroffen. Per Telefonkonferenz wurde vier Mal getagt (22. November, 16. Dezember, 20. Juni und 4. August 2010). Sofern es relevante Ergebnisse gab, wurden nach den Vorstandssitzungen kurze Informationsschreiben per Email an die Mitglieder geschickt.

Eine Buchpublikation, die Beiträge zur Jubiläumsveranstaltung zu zehn Jahren FONAS und zu den letzten Fachgesprächen enthalten wird, ist in Vorbereitung. Die Videoaufnahmen zur 10-Jahresveranstaltung wurden Anfang 2010 von Christian Alwardt auf die FONAS Homepage gestellt. Auch die Liste von Qualifizierungsarbeiten (Diplom, Master, Promotion), die von FONAS-Mitgliedern betreut bzw. erstellt wurden, ist nun online lesbar. Im Juni 2010 wurde die Aktualisierung des Faltblatt zur Selbstdarstellung von FONAS fertig gestellt und auf der Homepage zur Verfügung gestellt.

Der Newsletters in englischer Sprache wurde erneut an internationale Adressaten versandt, um die Bemühungen um eine Vernetzung von FONAS im europäischen Rahmen voranzubringen.

Der Aufsatz „Naturwissenschaft, Krieg und Frieden“ (Autoren: Jürgen Altmann, Martin Kalinowski, Ulrike Kronfeld-Goharani, Wolfgang Liebert, Götz Neuneck) ist 2010 im Sammelband „Friedens- und Konfliktforschung – ein Studienbuch“ im Nomos Verlag erschienen (Seiten 410-445), das von Peter Schlotter und Simone Wisotzki herausgegeben wurde. In diesem Übersichtsbeitrag werden die Motivation, Geschichte und aktuelle Ausführung naturwissenschaftlich orientierter Friedensforschung dargestellt.

Während der DPG-Tagung in Dresden wurden erste Schritte zur Bildung eines Netzwerkes, vereinbart, dass die an der Verifikation nuklearer Abrüstung Interessierten zusammen führt. Dazu wurde zunächst von Malte Göttsche (Diplomand beim ZNF) ein Fragebogen erstellt, um festzustellen, wer aus unserem Kreis woran arbeitet.

Die Organisation von Tagungen, das Editieren des Newsletters (Ulrike Kronfeld-Goharani) und die Führung der Finanzen (Christoph Pistner) sind wesentliche und unverzichtbare Vorstandstätigkeiten, die einen erheblichen Arbeitsaufwand mit sich bringen.

FONAS-Tagungen im Berichtszeitraum

2010		
16. – 17. Sept.	8. FONAS-Herbsttagung	Osnabrück
2011		
16.-18. März	DPG-Fachsitzung „Physik und Abrüstung“ (mit DPG-AGA)	Dresden
24. Juni	Workshop “Wettrüsten im Cyberspace?” gemeinsam mit IFAR[2]	Hamburg
10. August	Workshop “Nuclear weapons and their disarmament” gemeinsam mit clisec, IFAR[2], VDW und dem ZNF	Hamburg
28.-30. Sept.	9. FONAS-Herbsttagung	Osnabrück
30. Sept.	Treffen zu Verifikation nuklearer Abrüstung	Osnabrück

4. Tagungen und Veranstaltungen

Im vergangenen Jahr wurden die üblichen Frühjahrs- und Herbsttagungen durchgeführt. Erstere wird mit der Arbeitsgruppe Physik und Abrüstung der Deutschen Physikalischen Gesellschaft (DPG-AGA) veranstaltet, letztere fand erneut bei der Deutschen Stiftung Friedensforschung (DSF) in Osnabrück statt. Zwei Workshops wurden in Hamburg durchgeführt.

Vom 16. – 17. September 2010 bzw. 28. – 30. September 2011 fanden in Osnabrück die achte und neunte FONAS-Herbsttagungen statt, die von Ulrike Kronfeld-Goharani, Jochen Ahlswede und Frederik Postelt vorbereitet wurden. An der Tagung in 2010 nahmen etwa 20 Personen teil.

Zum 16. mal veranstaltete die Arbeitsgruppe Physik und Abrüstung (AGA) im Rahmen der Jahrestagung der Deutschen Physikalischen Gesellschaft vom 16. – 18. März 2011 in Dresden die Fachsitzung „Physik und Abrüstung“. Verantwortlich für die Vorbereitung zeichnen Götz Neuneck, Jürgen Altmann und Matthias Englert. Am Abend des 17. März hielt Prof. Dr. Siegfried Hunklinger vom Kirchhoff-Institut für Physik, Universität Heidelberg, in einem voll besetzten Hörsaal die Max-von-Laue Vorlesung zum Thema „Redlichkeit in der Wissenschaft“. Die Sitzungen waren insgesamt alle gut besucht.

Am 24. Juni veranstaltete FONAS, in Zusammenarbeit mit IFAR[2], den Workshop “Wettrüsten im Cyperspace” in Hamburg. Für FONAS waren an der Vorbereitung Götz Neuneck und Christian Alwardt maßgeblich beteiligt.

Am 10. August veranstaltete FONAS, in Zusammenarbeit mit clisec, IFAR[2], VDW und dem ZNF die internationale Tagung “Nuclear Weapons and their disarmament” in Hamburg. Für FONAS war an der Vorbereitung Martin Kalinowski maßgeblich beteiligt.

Im Anschluss an die FONAS Herbsttagung in Osnabrück findet am Freitag, 30. September 2011 ein Treffen zu Verifikation nuklearer Abrüstung statt.

Martin Kalinowski, September 2011

(im Namen des gesamten FONAS-Vorstands)

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Announcements

26 – 30 March 2012: 76th Annual Conference of the Deutsche Physikalische Gesellschaft (DPG), and the meeting of the Working Group "Disarmament and Verification" in Berlin (28 – 30 March 2012).

6 - 13 July 2012: 24th Annual Summer Symposium on Science and World Affairs, Princeton University, USA.

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IFAR²: Interdisciplinary Research Group on Disarmament, Arms Control and Risk Technologies

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P&D: Physics and Disarmament

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Published by: Forschungsverbund Naturwissenschaft, Abrüstung und internationale Sicherheit (FONAS), c/o IANUS TU Darmstadt, Hochschulstr. 4a, 64289 Darmstadt, Tel.: 06151-164368, Fax: 06151-166039, Homepage: www.fonas.org

Bank Account: FONAS e.V., Hamburger Sparkasse, BLZ: 200 505 50, Kto.: 1238 123 077

Editorial Board: Jochen Ahlswede, Dr. Jürgen Altmann, Prof. Dr. Martin Kalinowski, Frederik Postelt, E-Mail: jochen.ahlswede@physnet.uni-hamburg.de

Print: PriMa, Universität Hamburg

Layout: Jochen Ahlswede