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A Nuclear Weapon Free World - Can it be verified?

PRIF Report No. 53

Preface

This report was written as part of the PRIF non-proliferation project which is under the direction of Mr Harald Müller.

We would like to thank him and the members of the research group for numerous interesting and helpful discussions from which our work profited greatly.

Many thanks to Matthias Dembinski, Alexander Kelle, Bernd Kubbig, Bernhard Moltmann, Harald Müller, Hans-Joachim Schmidt, Christof Stephan, Simone Wisotzki und Rudolf Witzel, who read draft versions and provided us with helpful criticism and comments.

However, all errors and opinion in this report are exclusively our own responsibility.

We thank Ms Susanne Schmidt who completed the editing work in short time. Our thanks is also due to Una Becker for the excellent translation.

This study is part of the PRIF project "A Realistic Path Towards Nuclear Disarmament" which is supported by a grant of the Volkswagen Foundation. PRIF's non-proliferation project is in addition supported by the W. Alton Jones Foundation and the Merck Foundation.

Also, the support of the Deutsche Forschungsgesellschaft (DFG) has significantly contributed to the completion of this study. Parts of the research work were carried out in the course of the project "The Security Dilemma in Europe 1992-1996. Theoretical-empirical Review of the Central Categories of Neo-Realism". In addition, we made use of the special literature collection "Foreign Policy of the USA" which is funded by the DFG.

PRIF gratefully acknowledges the support of all funders.

Summary

This report was created as part of a project dealing with the preconditions, strategies and problems of comprehensive nuclear disarmament, and addresses an important aspect of the disarmament problem – verification.

A one-hundred percent successful verification will never be achieved, but it would be wrong to conclude that a nuclear weapon free world is only acceptable in the casee of perfect verification. The demands on verification depend to a large extent on mutual trust between states and on previous experience of nuclear disarmament and its verification to date. The requirements will, however, rise in the course of the disarmament process. Particularly in the final phases, when the number of arsenals falls below a hundred, verification will have to satisfy extremely high demands both in terms of quantity and quality.

The nuclear disarmament of nuclear weapon states can be carried out in many individual steps, the first of which are already taking place now or will be doing so in the near future. These steps include, among other things, deactivation measures, further reductions, dismantling of warheads, disposition of nuclear material from disarmed warheads and, finally, the destruction or conversion of nuclear weapon-related facilities. Only very few of these steps are already being verified today. Apart from declarations and transparency measures, the internationally binding commitment not to rescind measures once they are taken is an important factor. Verification would have to consist of a synergy of different methods. These include: the identification of warheads with the aid of nuclear-physical measurements, seals, all the IAEA safeguards used in the non-nuclear weapon states, extensive rights of access for challenge inspections, the use of satellite surveillance, National Technical Means, the disclosure of historical documents, the creation of maximum transparency in former nuclear weapon states, and the possibility of enforcing clarification of suspicions if necessary. The protection of proliferation relevant information must be considered. Once a nuclear weapons complex is destroyed, any further possession of nuclear weapons is extremely unlikely.

Even after comprehensive disarmament, the world will have to live with permanent verification in order to detect any future attempts at secret rearmament in time. To this end, a universal verification system will have to be established which is capable of early detection of the different elements of a nuclear-weapon program. These include the acquisition of either high enriched uranium or plutonium, the development of ignition technology, the development of theoretical principles, the development of an infrastructure, acquisition activities, and not least secrecy measures. Here, too, a synergy of different verification measures will have to be implemented which should be based on the further development of IAEA safeguards, including all reforms. Other important elements of this synergy are the inclusion of all data, including those gathered by National Technical Means and espionage, the extremely extensive rights of access for the verification agency, the use of state-of-the-art equipment, including satellites, maximum transparency of all relevant activities, the reconstruction of production histories with the aid of historical documents, the impossibility of rejecting challenge inspections, the readiness of as many states as possible to co-operate, and the protection of informants. The probability that the

construction of several warheads will remain undetected despite a verification system of this kind is very low.

There will always be a few states under suspicion which do not co-operate with the verification authorities, but it is precisely their activities that must be detected by verification. Historical cases of proliferation are South Africa, Iraq and North Korea. In all three cases, the verification system fell short of the standard which would be necessary for a nuclear weapon free world. The cases demonstrate that although it was possible to establish a number of suspicious indications using the then insufficient verification, important information was never revealed to the international community, for example, that South Africa had built six warheads, or that Iraq had intensively developed electromagnetic uranium enrichment. With the measures in place today, suspicions would have been aroused much earlier. South Africa’s activities would not have remained undetected with full-scope safeguards. In the case of North Korea, the measures of the IAEA were already more intrusive and lead to the emergence of concrete suspicion. But precise clarification of the North Korean activities is so far not possible, since there are no means of enforcing the inspections against the will of the state. The surveillance of the international transfer of technology plays an important role for the early detection of suspicious acquisition activities. How far subsequent verification of whether a state has totally disarmed is possible can be examined by studying the case of South Africa. There are, however, limitations for the comparison between South Africa and the established nuclear weapon states.

An important element of a future system must be the possibility of using any kind of information and National Technical Means. A maximum level of transparency of all nuclear activities in all states, which must far exceed present levels of transparency, continues to be a prerequisite. This relates in particular to the nuclear activities of disarming nuclear weapon states. Furthermore, it must be possible to implement the measures flexibly. In the event of suspicion and a lack of co-operation, verification activities must be reinforced, whereas in cases where trust has become firmly established over a long period of time, it must be possible to reduce the level of activities.

The successful implementation of verification measures depends not least also on the organisational structure of the verification system and must therefore be carefully considered. Rapid decision-making structures and the ability of assertion are of great importance. The decision-making body must be representative for the community of states. The Security Council could only be considered for this after a comprehensive reform. All technologies used should be internationalised as far as possible, e.g. the use of satellites, which are currently employed almost exclusively as National Technical Means. In the long term, individual verification organisations could be consolidated. The IAEA should provide the starting point for the development of the final organisational form for verification. The role of social verification must be reinforced. Even if the process of total nuclear disarmament is initiated by a relatively small number of states, in the end, all states must have committed themselves to relinquishing nuclear weapons.

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1 Introduction

In the debate on the feasibility of armament reductions, the goal of a nuclear weapon free world has long been totally neglected. The last official proposals for total nuclear disarmament, which were developed before the end of the Cold War, originated from the 1960s.[1] The permanent failures in the attempt to find a method for the elimination of nuclear weapons, the cementing of the bipolar structure of the Cold War and the accompanying nuclear arms race caused the chances of success for efforts towards nuclear disarmament to sink to zero. Given this situation, the concept of partial arms control seemed vastly more promising. The goal of comprehensive nuclear disarmament was abandoned, and instead, efforts were made to reach partial agreements which were to increase international security. In this instance, arms control treaties were not necessarily aimed at reducing or eliminating nuclear potentials, but could also involve armament restrictions (in the sense of upper limits) or even controlled rearmament. The most important aim was to guarantee the stability of the two superpowers' fragile nuclear deterrent system. On one hand, that meant reinforcing national controls of nuclear weapons in order to exclude the possibility of an “unintended“ nuclear war. On the other hand, the nuclear weapon arsenals had to be structured in such a way as to ensure that the deterrent remained effective also in times of crisis, and that, consequently, a first strike would be pointless.[2] Arms control was little more than an amendment to the nuclear deterrent doctrine. Nuclear disarmament was forced to take a back seat in the debate as a whole.

Today, a few years after the end of the East-West Conflict, the idea of a nuclear weapon free world is gathering momentum. Moving forces behind the idea are primarily non-governmental organisations. As part of a whole range of projects, they are currently concerned with the terms and conditions for additional disarmament steps, the ultimate goal being a nuclear weapon free world.[3] At government level, especially in nuclear weapon states and among their allies, the possibility of complete denuclearisation is still met with scepticism, and also in part with rejection. However, the circle of advocates of nuclear disarmament is increasingly widening. In 1995, the Australian government established the Canberra Commission. This forum with international membership comprehensively and systematically discussed the possibilities and problems of

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1 Franz W. Seidler, Die Abrüstung. Eine Dokumentation der Abrüstungsbemühungen seit 1945, München/Wien (Günter Olzog Verlag), 1974.

2 Harald Müller, Von der Feindschaft zur Sicherheitspartnerschaft - Eine neue Konzeption der Rüstungskontrolle, in: Berthold Meyer (ed.), Eine Welt im Chaos?, Frankfurt/M. (Edition Suhrkamp, Friedensanalysen 25), 1996, pp. 399-426 und Uwe Nerlich (ed.): Strategie der Abrüstung, Gütersloh (Bertelsmann), 1962; Erhard Forndran, Rüstungskontrolle. Friedenssicherung zwischen Abschreckung und Abrüstung, Düsseldorf (Bertelsmann), 1970, esp. pp. 85-124.

3 In addition to the Hessischen Stiftung Friedens- und Konfliktforschung, the Henry L. Stimson Center, the Center for Strategic & International Studies, the Union of Concerned Scientists, the International Network of Engineers and Scientists Against Proliferation (Inesap) and the Verification and Technology Centre (Vertic) work on issues of total nuclear disarmament. One of the first international studies with a technical focus is: Federation of American Scientists in collaboration with the Committee of Soviet Scientists for Global Security and the Center for Program Studies of the USSR Academy of Sciences, Ending the production of fissile materials for weapons, verifying the dismantlement of nuclear warheads – The technical basis for action, Washington D.C., June 1991.

comprehensive nuclear disarmament.[4] In December 1996, sixty-one former high-ranking members of the military, from countries including Russia, France and the USA, advocated an immediate, drastic reduction and eventual abolition of all nuclear weapons. In February 1998, this was followed by a declaration by over a hundred political leaders, heads of state and former heads of state from all over the world, who supported the abolition of nuclear weapons.[5]

This report was written as part of a project which is concerned with the prerequisites, strategies and problems of comprehensive nuclear disarmament, and is devoted to one important aspect of the disarmament problem – verification.

Verification, i.e., the controlling of compliance with obligations accepted by the parties to an arms control agreement, is often an important prerequisite for the achievement of a treaty. It becomes especially relevant in cases where the treaties affect weapon stockpiles which are perceived as particularly threatening or which play an important role in the deployment strategy of the military. Various proposals for total nuclear disarmament forwarded by the USA and former USSR broke down on the verification issue, and even today, no reduction in the nuclear potential of nuclear weapon states is even thinkable without sufficiently reliable verification. Yet how well a verification system must work for states to accept restrictions in their armament potential remains controversial. Depending upon how high they set their requirements, a whole range of measures are available to them which can be applied individually or collectively.

Verification in the arms control area is usually based on the verification of declarations concerning kind, number, and location of certain weapon systems. These inspections can be carried out in a number of ways. When applying so-called National Technical Means (NTM), verification is usually carried out without the active co-operation of the state under inspection. Classic NTM are satellites, seismic sensors and radar systems, but they also include the intelligence service activities and the collecting and processing of information via government departments. [6] On-site inspections are more extensive than NTM since they intervene more fundamentally in the sovereignty rights of states and presuppose a readiness to co-operate. Routine inspections allow inspectors to carry out controls at predefined times and at previously agreed locations on a state territory. Challenge inspections are used to look into specific indications for non-compliance. They are more intrusive than routine controls since the state under inspection would have problems adapting to them, if it really did want to hide something. However, their execution is always connected with certain conditions in order to prevent the uncontrolled collection of data (i.e. espionage). The results of the data collection emanating from NTM and on-site inspections must, in some cases, be analysed by laboratories before conclusions can be drawn about compliance with treaty obligations. This, too, is a part of the verification.

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4 See Report of the Canberra Commission on the Elimination of Nuclear Weapons, August 1996.

5 Disarmament Diplomacy, no. 11 (December), 1996,p. 38 and no. 23 (February), 1998, p. 24.

6 Data is, of course, also collected by intelligence services. Here, we mean authorities which, due to the nature of their activities, possess information which could be useful for the verification of a treaty, e.g. an authority which licenses exports.

After all, “whistle-blowing“ supplements the range of verification elements. A whistle-blower is someone who passes on information regarding banned activities to the appropriate recipient (a verification organisation, the media, and/or intelligence services etc.). Whistle-blowers are often people who are employed on secret projects.

Thus, despite enormous variations in detail, verification systems consist of constantly recurring elements:

- Declarations
- National Technical Means (NTM)
- Routine inspections
- Challenge inspections
- Technical data analysis / data processing
- “Whistle-blowing“

These elements are mostly employed in combination. However, there are also verification agreements which are based solely on, for example, NTM.

In many cases, the verification of arms control and/or disarmament agreements encounters the principle problem of non-military and military ambivalence. Many of the components from which weapons are made are also used in non-military industries, and therefore cannot simply be banned. In the case of these so called dual-use goods, verification is very difficult since it is not their existence, but the way in which they are used that is crucial. The verification of nuclear disarmament and a nuclear weapon free world is confronted by precisely this problem. Nuclear fissile material and numerous other nuclear weapon components have a variety of non-military applications, not least in the nuclear energy industry.

In this report, we address the matter of whether a nuclear weapon free world is verifiable. For this purpose we first of all work out which requirements must be set for the control of the disarmament process and subsequently for the verification of an already denuclearised world, and outline the methods which could be used to implement this verification. Both these sections also have the task of providing the background knowledge necessary for understanding the discussions which follow. Then we take three case examples – South Africa, Iraq, and North Korea – to illustrate potential problems and limitations of the verification methods which can arise in practice, and with which a future verification system for nuclear disarmament must cope.

After this extensive outline of the problems, we take stock of the possibilities and limitations of the applicable methods and the organisational variations for a nuclear verification system. Finally, we can set the political requirements on and the practical problems of nuclear disarmament into perspective with the technical and organisational possibilities.

2 Trust and Control

2.1 Technical Limits and their Political Toleration

A good part of the verification of arms control treaties is only made feasible by the deployment of state-of-the-art technology. The developments over the last decades in terms of satellite surveillance, sensor technology, communication and data processing, today provide a whole range of potential controls, which earlier seemed unattainable. The existence of these state-of-the-art technologies improves the chances of reaching agreements that were previously unacceptable due to the lack of technical verification possibilities. However, we must be aware of the fact that technology has its limitations. Even with the use of the finest means, there is still no one hundred percent certainty about the compliance with arms control agreements, neither today nor in the foreseeable future. There will always be a certain degree of uncertainty. However, this fact never was and never will be a reason for a total abandonment of arms controls. Otherwise, agreements such as the Treaty on Conventional Forces in Europe, the Chemical Weapons Convention, the Comprehensive Test Ban Treaty (CTBT), or the START treaties would never have been achieved.[7] The verification system should not be measured in terms of perfection; the crucial factor is rather the guarantee of security for participating states. Not the perfecting of verification methods was responsible for the achieving of these treaties, but an interaction of improved technological means and of the alteration of political conditions which mark the end of the East-West Conflict.

One example worth mentioning is the CTBT, the negotiations for which were concluded in 1996. A whole range of varyingly lavish technological systems was available for its verification. The negotiating forum did not choose the technically most sophisticated (and most expensive) system, but opted for one which represented an acceptable compromise in terms of various crucial criteria such as price, trust, effectiveness and control.[8] They did not touch upon its furthest technical limits. Instead, a certain amount of remaining uncertainty regarding the fact that one of the contractual parties could cheat, was tolerated by the negotiating delegations.

A further example is the verification of the NPT, which is implemented by the International Atomic Energy Agency (IAEA). One task is "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown".[9] The terms "timely detection" and "significant quantity" are quantitatively defined by the IAEA and form an adaptable measure for the compromise between trust and

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7 Explanation of abbreviations in appendix.

8 A. Schaper, Der umfassende Teststoppvertrag: kurz vor dem Ziel - oder gescheitert?, Frankfurt/M. (HSFK-Standpunkte no. 7), August 1996.

9 IAEA, INFCIRF/153 (corrected), para.28.

control.[10] Additional criteria, such as costs, for example, play a role here, too. During the last IAEA safeguards reform, the discussion focused just on this relationship between trust and control. The verification in states which might wish to cheat, for example Iraq, was said to be insufficient, whereas the expenditure in trustworthy nations with non-military nuclear industries, for example the number of inspections in Japan, Germany or Canada was said to be too high. The reform attempts to take this criticism into account and to apply the measures in a more flexible way. At the same time, the technological possibilities were extended, and the selective and quantitative reduction of expenditure was made possible.[11] In this respect there is to be a transition from the previous system exclusively defined by calculations to a more qualitative one.[12]

The question as to how good a verification system has to be is a recurrent theme in the arms control and verification debate. Opponents of total nuclear disarmament argue that the abolition or even only drastic reduction of nuclear weapons, if at all, must only take place, if attempts at early detection of the secret acquisition of nuclear weapons can be one hundred percent effective. Since this is not feasible in the foreseeable future, total nuclear disarmament cannot be implemented. It would even pose a danger for those states that do disarm and their allies.[13] Advocates of a nuclear weapon free world instead pose the question as to how high the level of uncertainty regarding contractual compliance may be in order to still make allowance for the security needs of states.

Various attempts have been made to develop a generalisable formula for the definition of requirements on verification. In the debate on total nuclear disarmament an approach from the 1960's is still recurring. The then scientific advisor to President Kennedy, Jerome Wiesner, developed a model which required an inversely proportional ratio between the number of weapon systems allowed and the frequency of inspections. In other words, with the decreasing number of available weapons, the number of inspections ought to increase. Wiesner's model is based on the assumption that national security is to be measured in terms of military defence capability. The intensity of inspections would depend on the dangers posed by undiscovered violations.[14] If the weapon stockpiles of a state were only moderately reduced, i.e. if a relatively high amount of residual stocks remains in service, then minor treaty violations would not result in any relevant military advantage for the potential opponent. However, the further-reaching the reductions, the greater is the

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10 IAEA Safeguards Glossary, 1987 (Edition), Vienna, 1987. Some terms are explained in the appendix (Glossary of Some Specialist Terms Used in the Verification System of the IAEA).

11 On the problem of transition from rigid, quantitative regulations, to flexible, more subjective regulations, which take account of suspicion, see A. Schaper, Implementing Safeguards in Countries of Concern, in Erwin Häckel (ed.), in preparation.

12 The reform is, at present, in the early stages of implementation. For this reason, there is, as yet, no practical experience which could be used for a critical evaluation.

13 C. Paul Robinson/Kathleen C. Bailey, To Zero or Not to Zero: A US Perspective on Nuclear Disarmament, in: Security Dialogue, vol. 28, no. 2, 1997, pp. 149-158; Kathleen C. Bailey, Problems Facing Total Nuclear Disarmament, in: Director's Series on Proliferation, no. 5, 1994, pp. 71-86.

14 See Jerome B. Wiesner, Umfassende Systeme der Rüstungsbeschränkung, in: Uwe Nerlich (ed.), Strategie der Abrüstung, Gütersloh (Bertelsmann), 1962, pp. 219-257, esp. p. 234.

potential danger posed by small, undiscovered illegal stocks, and the higher are the requirements on the verification system.

Wiesner's approach is, in principle, still accepted today - we have merely deviated from his purely quantitative orientation. On one hand, verification is no longer understood as merely an expression of the frequency of inspections, but rather as a comprehensive control system which can above all be measured in terms of qualitative standards. On the other hand, it is no longer only the number of weapon systems which is considered, but also their type and capability. The Wiesner model can thus be amended and/or modified as follows:

The greater the potential threat posed by the weapons systems subject to control measures, the more important is the early detection of illegal stockpiles, and the higher are the requirements on the capability of the verification system.

The more difficult it is to counter a military threat caused by illegal weapon systems, the greater is the danger to national security, and the higher are the requirements on the verification system.

The influence of Wiener's model on the academic and political debate on arms control and disarmament issues is unmistakable. The 1982 Palme Commission came to the conclusion that "[the] more a treaty intervenes in existing arsenals [...], the more comprehensive the means must be, which are defined in the agreement for its verification."[15] During the negotiations of the INF treaty, the chairman of the American Senate Intelligence Committee doubted the verifiability of the agreement since " the value of any Soviet cheating would be far greater after substantial cuts in superpowers' arsenals".[16] Many of the more recent efforts towards nuclear disarmament are based on this premise, too.[17]

2.2 The Relationship between Verification and National Security in the Case of Total Nuclear Disarmament

If the two foregoing criteria are applied to the verification of total nuclear disarmament or a nuclear weapon free world, we come at first glance to a sobering conclusion:

15 See Der Palme-Bericht. Bericht der Unabhängigen Kommission für Abrüstung und Sicherheit, Berlin (Severin und Siedler), 1982, p. 152.

16 Quoted in James A. Shear, Verification, Compliance and Arms Control: The Dynamics of Domestic Debate, in: Lynn Eden/Steven E. Miller (eds.), Nuclear Arguments Ithaca/London (Cornell Univ. Press), 1989, p. 284.

17 The American project on the elimination of weapons of mass destruction of the American Stimson Center and the work of the British Verification Technology Information Centre (VERTIC) can be given as examples. An Evolving US Nuclear Posture, Second Report of the Steering Committee. Project on Eliminating Weapons of Mass Destruction, The Henry L. Stimson Center, Report no. 19, December, 1995, p. 3; Patricia Lewis, Laying the Foundations. Verifying the Transition to Low Levels of Nuclear Weapons (VERTIC), July, 1998.

In the early phases of the disarmament process[18], i.e. as long as the number of nuclear weapons is still in the hundreds, a relatively large number of warheads would have to be produced secretly in order to achieve a substantial military advantage over other disarming states. The requirements on a verification system would be lower at this point, since small stockpiles of illegal weapons would not impair the security of other treaty member states, and the acquisition of large quantities would be difficult to keep secret. At a more advanced stage in the reduction of the nuclear arsenals, the efficiency of the verification system would have to be constantly improved since the danger posed by each single nuclear weapon presumably increases as the total number decreases.

The potential threat posed by nuclear weapons is generally estimated to be very high. Warheads have an enormous destruction potential. Teamed with modern carrier systems, they are also capable of reaching far-distant targets in a very short time. The long-term damage caused by radioactive contamination raises the danger they pose and puts them clearly above the threat posed by conventional weapons. The requirements on a verification system are high according to this assessment

In the opinion of opponents of total nuclear disarmament, the only potentially effective response to a nuclear threat, or to the deployment of nuclear weapons, is with nuclear weapons.[19] If the present nuclear weapon states disarmed to below a certain level, they would no longer be in a position to deal adequately with a treaty violator, and could also no longer protect their allies. Once they had totally disarmed their existing arsenals and the infrastructure necessary for their construction, the time required to rearm would be prolonged to such an extent that it would endanger their survival as states. If this argument is adopted, then the following must apply here, too: the more advanced the disarmament of nuclear weapons, the higher the demands on a verification system. From this point of view, total abolition can provide security only with a perfectly functioning verification system.

The attraction of Wiesner’s model is fatal, not because his assumptions were fundamentally wrong, but because they are applied without further reflection, thus leading to the erroneous conclusion that a nuclear weapon free world is only acceptable subject to perfect verification. This is due to the fact that even the modified version of Wiesner’s model which is in use today fails to consider important aspects of the states’ risk calculation.

The first error occurs in the defining of the threat posed by a certain weapon arsenal – a political process which always contains a strong subjective element. In the course of this

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18 We assume that a nuclear-weapon-free world cannot be achieved in a single step, but rather stands at the end of a whole series of disarmament steps. This is mentioned here because there are also other opinions on how and, above all, how fast nuclear disarmament should be carried out.

19 This assumption is wide spread. See z. B. William J. Perry, Desert Storm and Deterrence, in: Foreign Affairs, vol. 70, no. 4, 1991, pp. 66-82. This has, however, been surpassed in view of the present possibilities in the conventional area. Even if high demands are put on the defence capabilities, these can be fulfilled by the conventional armed forces. A more detailed examination of the issue of conventional defence / deterrence capabilities is to be found in Alexander Kelle, Security in a Nuclear-weapon-free World – How to Cope with the Nuclear, Biological and Chemical Weapons Threat, Frankfurt/M. (PRIF Report no. 50), 1998; and Charles T. Allan, Extended Conventional Deterrence: In from the Cold and Out of the Nuclear Fire?, in: Washington Quarterly, vol. 17, no. 3, 1994, pp. 203-233.

process, a government will always include the relationship to the other states participating in the agreement in their considerations. This means that the tenser the relationship, i.e. the greater the mistrust between the negotiating parties, the lower the probability may be that a treaty violation will remain undetected, and vice versa. According to Wiesner's model, the trust between the negotiating parties declines as the degree of disarmament advances since the threat posed by each single weapon rises as the total number of weapons falls. This conclusion is erroneous. Nuclear disarmament is a process during which the contracting states gather experience which they apply to their calculations. This experience also covers the sequence and results of verification measures. If the outcome is positive on a continuous basis, the trust in the participants of the disarmament process. Indications of a positive verification outcome are, for example, a constant rise in the level of transparency, no perceptible attempts to refuse data transfer or inspections, and no detection of non-compliance.

The second error occurs in the evaluation of the potential reactions to a nuclear threat. Conventional deterrents against nuclear weapons are now regarded a realistic option.[20] If this is the case, a state can abandon nuclear weapons without being provided with one-hundred percent certainty by the verifications system. The issue of the feasibility or non-feasibility of non-nuclear deterrents or defence cannot be dealt with in more detail here.[21] In no way, however, does total nuclear disarmament lead to states being incapable of defence.

Despite the criticism given here, the Wiesner model is of importance for the discussion of the verification issue. The requirements that are made on verification will actually rise in the course of the disarmament process. Particularly in the final phases, when arsenals fluctuate to below one hundred, the verification procedure will have to satisfy extremely high requirements, both in terms of quality and quantity. The reduction of nuclear weapons to below the threshold regarded as essential for a minimum deterrent is not only a drastic step in terms of military strategy, but it presupposes the surmounting of a psychological barrier. Although nuclear weapons lose their importance as the fundamental component in the deterrent system, the perception of the high potential threat posed by nuclear weapons and the assessment of the feasibility of alternative defence methods play a n important role in the analysis of the permissible "margin of tolerable non-verifiability".[22] However, it is important to oppose the determinism which is derived from Wiesner's model and which degrades the idea of a nuclear weapon free world to an unrealistic utopia. Even in the last phase of nuclear disarmament not a "perfect" verification system is needed, but one which takes the security needs of states into account. The nature of these security needs does not

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20 See e.g. Marc Dean Millot/Roger Molander/Peter A. Wilson, "The Day After...", Study: Nuclear Proliferation in the Post-Cold War World, vol. 1, Summary Report. Santa Monica, Calif. (Rand), 1993, p. 19.

21 Op. cit. (fn 19).

22 Bettina Wieß, Verifikation und "compliance issues". Die amerikanische Diskussion um strategische Rüstungskontrolle (1977-1985) und der INF-Vertrag, Studien zur Friedensforschung, volume 1, Münster/Hamburg (Lit), 1994, p. 6.

only depend on the number of nuclear weapons still available, but also, to a substantial degree, on the mutual awareness of the states involved and of their aims and motives.

3 Tasks and Methods of Verification in a Nuclear Weapon Free World

3.1 Disarmament and Verification of Former Nuclear Weapon States

A series of steps in the nuclear disarmament process could be implemented already before the decision has to be made as to how far-reaching this process should be in end-effect: whether it should really be heading towards zero, or whether it should stop at reductions only. In the case of reductions, the requirements on verification are lower than in the case of total nuclear disarmament, since it is only necessary to ensure that a certain number of warheads has been destroyed. In the case of total nuclear disarmament, however, there is a shift in tasks. On one hand, it must be verified that to a high degree of probability no more hidden arsenals remain in existence – a rather different and more difficult task compared with the verification of disarmament of declared warheads. On the other hand, in a nuclear weapon free world, no special warhead factories and warhead material storage sites will exist anymore, which would make nuclear rearmament technically more difficult and increase detection probability of illegal activities.

A first move towards applying verification of nuclear reductions that can now realistically be expected, could be implemented in a future START-III Treaty. In contrast to the verification of START-I and START-II, which is limited to the destruction of carrier systems and does not verify the disarmament of warheads, transparency and verification measures for the destruction of nuclear warheads themselves would probably be implemented in a START-III Treaty. This was already discussed at the Helsinki summit, and is to be part of future START-III negotiations.[23] A series of additional disarmament measures also seems to be a realistic option for the near future; for example, other START treaties, a treaty on the disarmament of tactical nuclear weapons, measures for extending early-warning times or the verified disposition of weapon-grade nuclear material. [24]

The transition to a nuclear weapon free world presupposes the successful implementation of these interim steps and their verification. This would lead to the gaining of realistic experience in the handling of technical and organisational verification procedures and would strengthen the confidence of the contracting parties in one another and in these procedures' functional capability and reliability. This is an essential prerequisite for taking

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23 President Clinton and President Yeltsin, Joint Statement on Parameters on Future Reductions in Nuclear Forces, White House Fact Sheet, Helsinki, 21. March 1997, printed in full in: Disarmament Diplomacy, April 1997, p. 32. In concrete terms, a START – treaty should contain, among other things, "Measures relating to the transparency of strategic nuclear warhead inventories and the destruction of strategic nuclear warheads … "

24 Harald Müller, Far-Reaching Nuclear Disarmament, Unidir Newsletter, no 31, 1995, p. 31; Lewis, op, cit. (fn 17); Harald Müller/Annette Schaper, Vollständige nukleare Abrüstung – Wunschtraum oder konkrete Möglichkeit?, in: Bruno Schoch/Friedhelm Solms/Reinhard Mutz (eds.), Friedensgutachten 1998, Münster (Lit),1998, p. 289.

further steps. In addition to the verification implemented up to that point, the verification of the transition will then require further, more intrusive measures which are based on and developed from previous ones. This particularly includes verification of the absence of any remaining hidden or “forgotten“ nuclear weapons – the reliability of which would rest on the trust which had developed in the meantime. Following the completion of the disarmament process, the majority of the verification procedures will become obsolete. However, some will have to be applied continually in order to pursue the search for left-over warheads as a deterrent on a random basis. This is explained in more detail in the following sections.

The technical process of nuclear disarmament encompasses many individual measures. Some of them are already being implemented as part of the INF Treaty and the START treaties, namely deactivation measures, separation of warheads from the carriers, destruction or conversion of the carrier systems and destruction of the silos.[25] Some others are taking place without any prior contractual stipulations, for example, the destruction of warheads. Up to now, these have not been verified, but they could be integrated into future disarmament treaties. One of the last steps would be the non-military disposition or further use of the fissile material. Table 1 gives an overview of the most important nuclear disarmament measures, their present obligation and transparency. In the first column (measure), different stages of nuclear disarmament are listed. The second column (implementation) indicates if and to what extent these measures are currently being implemented. The third column (degree of obligation) indicates if, and in what form, an obligation to carry out this measure already exists. The stronger this obligation, the more difficult it is to reverse a measure. That is, the degree of irreversibility increases. Public pressure already generates a little friction during the attempt to withdraw a measure and therefore causes a certain element of irreversibility. In the case of valid international treaties however, the obligation is stronger. The last column indicates whether the measure is being verified, or whether at least a certain degree of transparency is being created. The table provides insight into the present state of nuclear disarmament and possible future measures. In the following sections of chapter 3, the methods for verification of these measures are discussed.

3.1.1 Initial Measures

The first and most urgent steps are deactivation measures for minimising the danger of an accidental nuclear war (measures 1 – 17 of table 1). The necessity for such steps is not disputed, but it is controversial how far they have already been successfully implemented.[26]

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25 Anatoli p. Diakov (ed.), Nuclear Arms Reduction: The Process and Problems, Report des Center for Arms Control Energy and Environmental Studies at the Moscow Institute of Physics and Technology, Dolgoprudny, October 1997.

26 In recent years, the number of warnings regarding the continued dangers of , e.g., on-going alert, faulty controls and insufficient measures towards the reduction of these dangers has risen. See Alexej Arbatov, Dealerting Nuclear Forces: A Substitute or Supplement to Disarmament?, in: Background Papers of the Canberra Commission on the Elimination of Nuclear Weapons, August 1996, p. 303. Bruce G. Blair, Global Zero Alert for Nuclear Forces, Brookings Occasional Papers, Washington D.C., 1995; see also Lachlan Forrow/Bruce G. Blair/Ira Helfand/George Lewis/Theodore Postol/Victor Sidel/Barry p.

Examples of these measures are deactivation, dealerting, detargeting, or the extension of early-warning times. There are various different proposals as to which technical means can be used to accomplish this. In addition to the START-II Treaty, foreign ministers Albright and Primakov agreed to deactivate missiles intended for disarmament in advance.[27] Some technical measures are simple and could be easily verified, for example the extension of early-warning times by piling earth onto the silos, which can be verified by means of satellite pictures or on-site inspection. Others, such as detargeting, can easily be reversed and their actual implementation is difficult to control.[28] One measure which reliably extends early- warning times is the separation of the warheads from the carriers and the destruction of the carriers. This measure is already being implemented as part of the START treaties [29] and is also being verified. The most important means in this context are on-site inspections, the examination of certain carriers (bombers and missiles), surveillance of the destruction of carriers and of the conversion of silos.

3.1.2 Verification of Agreed Reductions

A prerequisite for disarmament is an overview of what is to be disarmed, that is, inventories and registers of stockpiles (measurement no. 8 in table 1) [30]. A nuclear weapon state which disarms a fixed number of warheads would issue declarations on this. The task of verification is to control these declarations. An international nuclear weapons register is, however, at present still rejected by nuclear weapon states.[31] At a session of the NATO Russian Council, the allies presented Russia with an inventory of nuclear weapons deployed in Europe with a request for reciprocity. To date, the Russian side has not got beyond statements of intention. An urgent problem is posed, above all, by tactical nuclear weapons, whose numbers and application scenarios are unknown. They have not yet been taken into account in any arms control agreement, and pose an increasing threat to

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Levy/Herbert Abrams/Christine Cassel, Accidental Nuclear War – A Post-Cold War Assessment, The New England Journal of Medicine, April 30, 1998, Vo.l. 338, no. 18.

27 Letters from the foreign ministers Primakov and Albright "On Early Deactivation", 26.9.1997, in the Internet at http://www.acda.gov/factshee/wmd/nuclear/start2/albrtltr.htm and http://www.acda.gov/factshee/wmd/nuclear/start2/primakov.htm.

28 The current problems of deactivation and proposals for measures and their verification are given in detail by Blair, op.cit. (fn 26).

29 Matthias Dembinski, Mit START zum Ziel der allgemeinen und vollständigen Abrüstung? Stand und Perspektiven der Bemühungen um "kooperative Denuklearisierung", Frankfurt (HSFK-Report no.3) ’93.

30 A review of all deployed nuclear weapons has been compiled by an NGO with the aid of publicly accessible sources: William M. Arkin/Robert P. Norris/Joshua Handler, Taking Stock – Worldwide Nuclear Deployments 1998, NRDC Nuclear Program, Washington, D.C., March 1998.

31 Harald Müller, The Nuclear Weapons Register – A Good Idea Whose Time Has Come, PRIF Reports no. 51, June 1998. In its "Strategic Defence Review" of July 1998 the British Government has given remarkably precise information on the number of warheads: Strategic Defence Review, Presented to Parliament by the Secretary of State for Defence by Command of Her Majesty, July 1998, in the Internet at: http://www.mod.uk/policy/sdr/index.htm (August 1998). The proposal of a nuclear weapons register is, however, also rejected by the new British Government.

security.[32] Verification is simpler in the case of quantitatively agreed reductions. It is then merely a question of controlling that the declared warheads are not decoys.

Until completion of the destruction process, it must be ensured that declared warheads cannot be exchanged for decoys. This includes monitoring during various transports,

Table 1: Nuclear Disarmament Measures and their Present Obligation and Transparency

	Measure	Implementation	Degree of Obligation ("Irreversibility")	International Transparency, Verification
1.	inventories and registers of stockpiles	unknown	none, but is demanded	none
2.	reduction of the alert	partially, success disputed	none, but public pressure exists	none
3.	detargeting	partially, success disputed	none, but public pressure exists	none
4.	extension of early-warning times, e.g. by piling earth on silos	partially, success disputed	none, but public pressure exists	None
5.	deactivation measures	partially, success disputed	Letters by foreign ministers Primakov and Albright "On Early Deactivation", 26.9.1997	None
6.	separation of warheads from carriers	takes place	START treaties	START treaties provide verification
7.	destruction or conversion of carriers	takes place	START treaties	START treaties provide verification
8.	identification of warheads (measurements, seals ..)	unknown	None	None
9.	transportation of the warheads to storage sites	international technical aid	none, but public pressure and international co-operation projects exist	none, but some information emanating from international co-operation is known
10.	transportation to the dismantling factory	international technical aid	none, but public pressure and international co-operation projects exist	none, but some information from international co-operation is known
11.	destruction of the ignition mechanism	takes place	none	None
12.	separation of the primary from the secondary parts	takes place	none	None
13.	separation of the fissile material (in the form of a so-called "pit") from the other parts	takes place	none, but this will be required by the planned international co-operation	None
14.	storage of the components	planned, international technical aid	none, but this will be required by the planned international joint operation	possible controls to see if a storage site built with international financing is used according to its intended purpose
15.	destruction (burning) of the con-ventional ignition mechanism	unknown	none	none
16.	mechanical destruction of the pit (cutting up and dissolving …)	takes place only to a very small extent (experiments)	none	none
17.			none, but this will be required	cf.14, 10 tons of U.S.-

32 Nikolai Sokov, Tactical Nuclear Weapons Elimination: Next Stop for Arms Control; The Nonproliferation Review, vol. 4, no.2, 1997

	storage of the fissile material	as Pits (cf.13)	by the planned international co-operation (cf.14)	material under voluntary IAEA safeguards, more is expected and demanded
18.	Non-military utilisation or disposition of the material	planned, international technical aid	none, but this will be required by the planned international co-operation	condition of many international co-operation partners: IAEA safeguards
19.	shut-down and destruction or conversion of all plants	out-dated plants are being shut down	a Cut-off would prevent the use of Pu and HEU to produce explosives	a Cut-off would imply a corresponding verification, otherwise none

particularly from the place of deployment to an intermediate storage site, and from there to the factory in which they are to be dismantled. It is probable that some of the measures necessary for this are already scheduled for inclusion in a future START-III Treaty. The main difficulty when identifying declared warheads lies in the fact that sensitive information must not be allowed to transpire, for example the construction principles of a warhead (cf. section 5.1.2 Secrecy versus Transparency).

Verification methods are of a technical nature. Since this concerns a step the implementation of which seems realistic in the near future, there are already a great number of studies which deal with the subject of methods concretely.[33] Some already focus in great detail on the technical realisation, i. e., on the construction of a technical application.[34]

In this instance, it is assumed that a warhead is located in a sealed container.[35] Since a warhead contains radioactive material, it emits radioactive radiation. The type of radiation that penetrates to the outside depends on the radiation and absorption characteristics of the materials used, the additional shields and their geometric distribution, i.e., on the type of explosive. In the simplest case, this radiation can be measured despite the shield (so-called “passive detection“). In certain cases, this is not sufficient, and nuclear reactions which can

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33 Examples include: S. Fetter, Verifying Nuclear Disarmament, The Henry L. Stimson Center Occasional Papier no. 29, October 1996; a collection of various technical contributions in: F. v. Hippel/R. Z. Sagdeev, Reversing the Arms Race — How to Achieve and Verify Deep Reductions in the Nuclear Arsenals, New York 1990; earlier versions of these contributions are to be found in Science and Global Security, Bd. I (1989-90); Christopher E. Paine/Thomas B. Cochran/Robert p. Norris, Techniques and Procedures for Verifying Nuclear Weapons Elimination, Background Papers of the Canberra Commission on the Elimination of Nuclear Weapons, August 1996, p. 167, Natural Recources Defense Council, Report on the Third International Workshop on Verified Storage and Destruction of Nuclear Warheads, Moscow and Kiev, December 16-20, 1991; Federation of American Scientists and Natural Recources Defense Council, Report on the Fourth International Workshop on Verified Storage and Destruction of Nuclear Warheads, Washington D.C, February 26-27, 1992. Sutcliffe, W.G., Warheads and Fissile Materials: Declarations and Counting, Report UCRL-JC-108073, CTS-27-91, Livermore, August 5, 1991; Chinese examples are contained in the volume of the Institute of Applied Physics and Computational Mathematics, Program for Science and National Security Studies (Arms Control Collected Works), Beijing 1995.

34 W. Rosenstock/J. Schulze/A. Tüchsen/T. Köble/G. Kruzinski/G. Jaunich/J. Peter, M. Diedrichs, Entwicklung und Untersuchung von transportablen Meßsystemen zur Verifikation von Kernwaffen, INT-Bericht no. 162, Euskirchen, December 1995; W. Rosenstock/A. Tüchsen/T. Köble/G. Krzinski/M. Jeske/A. Herzig/J. Peter, Aufbau einer transportablen Detektoranordnung zur Verifikation von A-Waffen, INT-Bericht no. 169, Euskirchen, April 1997.

35 Source of the following: Steve Fetter/Valery A. Frolov/Marvin Miller/Robert Mozley/Oleg F. Prilutsky/Stanislav N. Rodionov/Roald Z. Sagdeev, Detecting Nuclear Warheads, in: v. Hippel/Sagdeev, op. cit. (fn 33), p. 265.

be measured from the outside must be induced by “active“ measures such as neutron bombardment. X-raying is also regarded as one of the active detection measures. The radiation penetrating to the outside is characteristic of a certain type of warhead. A measured spectrum is thus also known as a so-called “fingerprint“. Fingerprints of all types of warheads can be recorded once and can then serve as a comparison for additional measurements. In this way, it would not only be possible to distinguish real warheads from fake ones, also the type could be identified without revealing proliferation-relevant features. On 5th July 1989, a joint Russian – American experiment, the so-called “Black Sea Experiment“, was carried out to detect a cruise missile warhead by using such passive methods.[36]

However, the objection is risen, namely by a number of Chinese experts on close terms with their government, that experts were still able to gather too much information from such a spectrum.[37] The authors refer directly to the results of the Black Sea Experiment. With the aid of the spectrum measured there, they succeeded in drawing some conclusions on the construction of the Soviet warhead which had escaped those involved in the experiment. Although this data is not proliferation-relevant, the authors consider it too transparent. In this instance, a principle political problem of the verification of nuclear disarmament becomes obvious: the tradition practised in all nuclear weapon states of keeping data relating to nuclear weapons secret, even if its publication would pose no danger of proliferation or threat to their own security. This political problem is revealed by technical secrecy regulations and is explained in more detail in section 5.1.2 (Secrecy Versus Transparency). The Chinese authors themselves offer a technical solution to this problem. They are of the opinion that the identification of warheads would also be possible if a major part of the spectrum was hidden and only a small part revealed. A further possibility would be to largely automate the process with the aid of “sealed“ computer programs. First a fingerprint would be taken for reference. This is fed into a computer and then does not need any further monitoring by inspectors, provided the software and "barring" measures ensure that the program cannot be manipulated. Later, it can automatically be established whether a warhead is of the same type.[38]

3.1.3 Discovery of Undeclared Warheads

The task of verifying the destruction of warheads is more difficult if all are to be recorded. In this case, it would not only be necessary to check whether declared warheads are real, as

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36 Steve Fetter/Thomas B. Cochran/Lee Grodzins/Harvey L. Lynch/Martin S. Zucker, Measurements of Gamma Rays from a Soviet Cruise Missile, in: v. Hippel/Sagdeev; op. cit. (fn 33); p. 379; S. T. Belyaev/V. I. Lebedev/B. A. Obinyakov/M. V. Zemlyakov/V. A. Ryazantsev/V. M. Armashov/S. A. Voshchinin, The Use of Helicopter-borne Neutron Detectors to Detect Nuclear Warheads in the USSR-US Black Sea Experiment, ebd. p. 399.

37 Tian Dongfeng/Xie Dong/Liu Gongliang, High Energy Gamma-Ray "Fingerprint" – A Feasible Approach to Verify Nuclear Warhead, in: Institute of Applied Physics … ; op. cit. (fn 33), p. 63.

38 Software for the authentication and coding is far developed. One example is PGP ("Pretty Good Privacy").

described in the previous section, but it would also have to be ensured that the declarations are complete, i.e. that no additional, undeclared warheads remain in existence.

There are two reasons why, in violation of a disarmament treaty under international law, it would be at all possible for warheads to remain in existence after complete disarmament. The first reason is simply that they had been forgotten and is accounted for in terms of slipshod book-keeping and chaotic division of responsibilities. In this case, the state concerned would itself initiate the subsequent verified disarmament.[39] The other possible reason is that a nuclear weapon state had planned to cheat right from the start. In this instance, it is safe to assume, however, that in a political arena in which the complete abolition of nuclear weapons had been seriously contemplated, the intention to cheat would be relatively improbable, and mutual trust would already be very high. Nevertheless, this possibility cannot be entirely ruled out. The more precisely the inventories of existing warheads were previously made, declared and made transparent to the international community, the more difficult it will be for a nuclear weapon state then to develop defraud strategies in which a specific number of warheads or warhead components remains undetected.

In case there is any suspicion of the fact that undeclared "leftover" warheads can be found at a certain location, this can be clarified by means of measurements and on-site investigations. The methods are the same as described in the previous section. Hiding places can be detected at short distances using technical means. However, these are restricted to a few metres. In order to fully exploit this possibility, it must be possible for challenge inspections to take place, which must not be allowed to be rejected.

There is, however, no guarantee that suspicions will actually arise. There are no technical methods available for tracking down nuclear weapons if the location to be searched is not known with some degree of accuracy. Suspicion is aroused as a result of documents found, circumstantial evidence, informers, and the activities of the secret service. To maintain a high probability of the emergence of suspicions, it must be allowed to use all data for triggering a challenge inspection, especially those from unnamed sources, from the verification results of other treaties, and from NTM.[40] Maximum transparency on all past activities is also crucial. The greater the degree of transparency and the further-reaching the right of access for inspections, the stronger the growth of international confidence in the honesty of all declarations. Frauds will be deterred by a sufficiently high probability of detection.

Over and above the inclusion of suspicious indications, it would also be desirable to control the declarations in order to ensure they are complete, since there remains the slight uncertainty that they may have been submitted with a fraudulent intention. The greater the mutual trust, the less this assumption is made (cf. section 2.2 The Relationship between Verification and National Security in the Case of Total Nuclear Disarmament).This inspection would require a reconstruction of the production history of the warheads. The

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39 A disarmament treaty would require a face-saving procedure for this eventuality .

40 NTM is, in the meantime, a recognised element in almost all arms control treaties. The S3 reform also implemented the possibility of using all kinds of information as trigger for challenge inspections.

more transparency regarding production history has been previously achieved, the more credible declarations are, too. A verification of the completeness of a nuclear weapons register would only, if at all, be possible with the aid of historical documents. This would be a costly and time-consuming undertaking since not only production, but also "loss rates", for example, due to the destruction of warheads, utilisation in nuclear tests and other experiments, or due to the sinking of submarines would have to be included.[41] Full transparency regarding the history of every single warhead and every production plant in all nuclear weapon states would be a prerequisite for this. A great deal of sensitive information, for example, the amount of plutonium used in a certain warhead type, would have to be revealed to the verification authority or the partners. Even then, uncertainty would remain regarding the completeness of the documents. In addition, it is probably impossible to reconstruct and calculate an initial inventory of all plutonium and uranium, without significant discrepancies, since the production histories are simply too extensive and complex (see section 3.1.5 Disposition of Nuclear Material).

Despite these difficulties, the attempt should be made. In this way, a process will be implemented, which will constantly raise the level of transparency, and which contributes to the creating and clarifying of suspicious indications. It is a prerequisite that trust must then be so great that a few inaccuracies and discrepancies can be tolerated provided that, at the same time, a co-operative effort is made to achieve transparency and clarity.

3.1.4 Dismantling of Warheads

A nuclear warhead consists of various different components (for a more detailed explanation, see Appendix: Functioning of Nuclear Weapons). An indispensable part is the fissile material, either plutonium or high enriched uranium (HEU). In state-of-the-art warheads, it appears in the shape of a hollow sphere known as the “pit“.[42] This is part of a warhead whose effects are based on nuclear fission, the so-called “primary“. In addition to the pit, the primary also contains conventional explosives, an electronic ignition device, a pipe for inserting tritium-deuterium gas and a neutron generator. All warheads now deployed in the arsenals of nuclear weapon states are so-called “Hydrogen bombs (H-bombs)“ which, apart from nuclear fission, also rely on nuclear fusion. In addition to the primary, they also contain a so-called “secondary“, which consists of fusion material. Primary and secondary are contained in a casing of heavy metal, e.g., uranium.

During the dismantling process, primary and secondary are first of all separated from each other. The electrical ignition mechanism, the casing and the secondary can then be dismantled into their separate components. These can be stored, destroyed, or used for non-military purposes. The primary is dismantled in an additional step. The conventional explosives and electronic parts can also be stored or be disposed of. The pit is the most

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41 Fetter, op. cit. (fn 33).

42 The mass of the pit varies from warhead to warhead and is secret. Estimated averages and working figures in studies lie at a few kilograms. The warhead selected for the South African nuclear weapons program (gun assembly principle) was an exception. It is to be assumed that all existing warheads are based on the implosion principle, including those of India, Pakistan and Israel.

complex component in terms of production. If this part is destroyed, for example sawn apart or chemically dissolved, the disarmament process has achieved a certain degree of irreversibility. Pits from warheads destroyed by the USA and Russia have so far been stored intact. In September 1998 however, the demonstration of the destruction of pits and the conversion of nuclear material is to start in Los Alamos. Following this demonstration phase, which, it is estimated, will run for approx. three years, the construction of a dismantlement factory is due to start.[43] The process will consist of nine steps, including the separation of various different impurities in plutonium.[44] In Russia (Mayak), a storage site for nuclear weapon components is to be built with western aid. In Russia, the destruction of pits has not yet begun, predominantly because Russia values reciprocity. [45]

At present, there is no verification of the destruction of warheads. The necessity for the introduction of verification and transparency measures is not only seen by observers; it is also at least discussed by decision-makers in the USA and in Russia, as is made clear by the joint statement issued at the Helsinki summit. Bilateral technological co-operation on the subject of verification of the destruction of nuclear warheads has been taking place since 1996, and the results were also used during the Helsinki consultations.[46] The results of this technological collaboration have not yet been published.[47]

The task of verification is to ensure that real warheads are destroyed and not decoys. For this purpose, it is not absolutely necessary to verify the many intermediate steps (measures 11 – 16 in table 1). Instead, it must be guaranteed that warheads which have been identified are delivered to the dismantlement factory in sealed containers, and that no warheads can be removed intact from this factory.[48] The exit must also be checked. If all non-nuclear components have been destroyed as far as possible, the original parts no longer divulge any sensitive information. Additional measures could consist of measurements of the

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43 Nuclear Fuel, LANL wins Pu pit demonstration; Pnatex, SRS fight for big project, vol. 23, no. 17, August 1998, p. 24.

44 Gallium is included to stabilise the crystal structure of metallic plutonium.

45 U.S. General Accounting Office (GAO), Weapons of Mass Destruction: Status of the Cooperative Threat Reduction Program, Letter Report, 09/27/96, GAO/NSIAD-96-222.

46 The partners in this co-operation are the Sandia National Laboratory (SNL) and the Russian Federal Nuclear Center – All Russian Research Institute of Technical Physics (RFNC–VNIITF). The latter is a research laboratory in Snezhinsk (previously known as Chelyabinsk-70). This research institution was, until now, responsible for research and development on new nuclear weapons. See N.F. Rubanenko, Nuclear Weapons Transparent Dismantlement, Paper presented at the International Pugwash Workshop, September 11-13, 1997, Snezhinsk, Russia.

47 There is a conference volume with approx. 50 technological contributions from a conference of both research institutions from August 18-22, 1997. To date this has, however, only been made available to the American and Russian governments.

48 There are various, partly very cheap methods of sealing. Many are being applied and further developed by the IAEA and Euratom. One example is a forgery-safe method according to which characteristic optical samples are created by means of fibre optic bundles: IAEA, Safeguards Techniques and Equipment, International Nuclear Verification Series no. 1, Vienna 1995; see also Japanese Atomic Energy Research Institute (JAERI), Research on Safeguards Technology, http://inisjp.tokai.jaeri.go.jp/ACT95E/12/12-1.HTM; Zheng Yu Tian/Shi Hong Ju/Gongh Xia Bi/Deng Jun; The Study of Fiber-Optic Seal Technology for Arms Control; Paper for the 8th International Summer Symposium on Science and World Affairs, Beijing, July 23-31, 1996.

composition of the emissions. That way it would be controlled whether, for example, components of conventional explosives have been burned. If the pit is still intact, it could be transported in a sealed container to a high-security storage site. This can be verified in the same way as the identity and transportation of entire warheads – a realistic scenario in terms of a transitional solution. If also the pit is destroyed in this factory, which is the long-term plan, the amount of "loose material", i.e. uranium and plutonium must be recorded at the exist. As long as strict monitoring ensures it can be controlled that no pit and no loose material is misappropriated, it is not even necessary to know the amount of material contained in a specific warhead. An average figure would, however, be helpful. If this amount and its composition can be divulged, the chemical dissolution of a single pit can also be verified without knowing the exact geometrical construction. For this purpose, the procedure is performed in a sealed container. It is verified that a pit is inserted, and the out-flowing Pu or uranium solution is recorded.

If intact pits are to be stored initially, there is a simple and verifiable method of preventing their reuse:[49] Each pit has a hollow space and a narrow opening for inserting the tritium – deuterium mixture necessary for boosting. A bent wire could be stuffed through this opening in a way which cannot be reversed, and which prevents compression of the pit. With the aid of the methods described above, e.g. gamma-spectroscopy, the presence of such a wire can be verified. This would modify the fingerprint, but the possibility of automation and protection of sensitive information remained unaffected.

These methods can be used to verify that a specific number of warheads has been destroyed, but not whether all were recorded. The probability of the detection of undeclared warheads must therefore be kept high (section 3.1.3).

In a nuclear weapon free world, this process must have been brought to a conclusion. The final step is therefore the deconstruction of all plants, including dismantlement factories and intermediate storage sites. Here, too, proliferation-relevant information could still be revealed, for example due to the type of tools used. Their owner must therefore destroy them past recognition inside the plant, and then open the former plant for international inspection.

3.1.5 Disposition of Nuclear Material from Disarmed Nuclear Weapons

Many schemes and studies already exist on the disposition of the loose material, i.e., technical procedures which lead to other non-military uses or final storage. This is because large amounts of surplus material are already accruing as part of the START process. The most advanced schemes plan to dilute the HEU to weapon-grade low enriched uranium and to use it as reactor fuel. These schemes also plan to process and use plutonium either as reactor fuel, the so-called "mixed oxide" fuel (MOX), or to mix it with radioactive waste,

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49 Matthew Bunn, 'Pit-Stuffing': How to Disable Thousands of Warheads and Easily Verify Their Dismantlement, Federation of American Scientists Public Interest Report, vol. 51, no. 2, March/April 1998, pp. 3-5.

which would then be vitrified and put into final disposal.[50] However, none of these plans has, as yet, been implemented, and the estimated periods required stretch over many decades.

The material will, in any case, be put into intermediate storage beforehand, and the task of verification will be to ensure that it is not re-used for military purposes. The amount of plutonium used for nuclear weapons is estimated at over 200 tons, and the amount of nuclear-weapon HEU at over 1700 tons.[51] The technical methods for this kind of verification have been tested and improved by IAEA and Euratom safeguards for decades.[52] However, only a few tons of American material have so far been placed under IAEA safeguards. The USA and Russia have the intention, however, to increase this amount, although the concretisation of these plans is making only slow process. There are several reasons – technical and political –for the delays. One reason is the technical effort necessary for freeing this material from sensitive information (cf. section 5.1.2 Secrecy versus Transparency).

The negotiations between the USA, Russia and the IAEA to subject disarmament fissile material to IAEA verification measures ought to be evaluated as progress.[53] Although there has as yet been no consensus on the introduction of international safeguards, an unequivocal trend towards internationalisation of the control of and security for nuclear material also inside nuclear weapon states can be observed.[54] Declarations of intent or pledges in terms of individual measures can be found, for example, in a statement issued at the G8 summit in Moscow 1996[55], in various international co-operation projects with

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50 Influential studies on the disposition of weapons plutonium have been carried out by, e.g., the U.S. National Academy of Sciences: National Academy of Sciences (NAS), Committee on International Security and Arms Control (CISAC), Management and Disposition of Excess Weapons Plutonium, Washington 1994; NAS, CISAC, Management and Disposition of Excess Weapons Plutonium: Reactor Related Options, Washington 1995. A German – French – Russian project for the building of a MOX pilot plant for Russian disarmament plutonium and an American – Russian agreement on the non-military use of Russian disarmament uranium are among the most advanced plans. See Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Siemens Aktiengesellschaft und Ministerium für Atomenergie der Russischen Föderation (MINATOM): Basisauslegung für eine Pilotanlage zur Produktion von Uran-Plutonium-Brennstoff aus waffengrädigem Plutonium und zum Einsatz dieses Brennstoffs in Kernreaktoren, Abschlußbericht, 28.02.1997; R. A. Falkenrath, The U.S.-Russian HEU Purchase Agreement: Achievements, Problems, Prospects; Report of the Center for Science & International Affairs, Harvard University, July 1995. Details of further projects can be found in: A. Schaper, A Treaty on the Cut-off of Fissile Material for Nuclear Weapons – What to Cover? How to Verify?, Frankfurt/M. (PRIF Reports no. 48), July 1997, chapter 2.4.1.

51 David Albright/Frans Berkhout/William Walker, Plutonium and Highly Enriched Uranium 1996 – World Inventories, Capabilites and Policies, SIPRI (Oxford University Press), 1997.

52 Tom Shea, On the Application of IAEA Safeguards to Plutonium and Highly Enriched Uranium from Military Inventories, Science & Global Security, vol. 3, 1993, p. 223.

53 Department of Energy, Press Statement: Trilateral Initiative on Verifying Excess Weapon Origin Fissile Materials, November 8, 1996; B. Pellaud, International Verification of US and Russian Materials Released for Storage and Disposition, Paper presented at the International Policy Forum: Management & Disposition of Nuclear Weapons Materials, Landsdowne, Virginia, 12 February 1997.

54 A. Schaper, The Case for Universal Full Scope Safeguards on Nuclear Material, The Nonproliferation Review, vol. 5, no . 2, Winter 1998, p. 69.

55 Moscow Nuclear Safety and Security Summit Declaration, April 20, 1996.

Russia, in the implementation of the 1997 IAEA safeguards reform known as "Strengthened Safeguards System" (S3),[56] or in the guidelines on the handling of plutonium, which were agreed between the most important plutonium-using states in 1997[57]. In a 1993 transparency initiative, the USA started to publish data on its plutonium stockpiles. However, the point at which international controls are to be employed has not yet been determined and depends on the readiness of the governments concerned. In 1998, also the British government published data on its stockpiles of nuclear material, and expressed the intention of making its disarmament plutonium accessible for IAEA inspections.[58] Nevertheless, the British government wishes to retain its surplus HEU for its submarines.

An important strengthening of this trend will result from the Fissile Material Cut-off Treaty (FMCT), the decision for the negotiations thereof having been taken during the Geneva disarmament conference in August 1998.[59] It is not clear whether this treaty will also take into account material produced before the treaty came into force, or how extensive the verification measures will be. What is certain, however, is that this treaty will put an end to the idea that the control of nuclear material and plants is solely the concern of nuclear weapons states. In the meantime, the FMCT is increasingly regarded as an “instrument of a process which is developing into a comprehensive regime for the international control of nuclear material“.[60] The universalisation of full scope safeguards, even if not connected with comprehensive nuclear disarmament, is increasingly regarded by the German government, among others, as an aim worth striving for.[61]

During the disarmament phase, it would be unrealistic to suppose that transitional rules and regulations could be avoided. Thus, the technical and legal precondition for the

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56 Determined in model protocol INFCIRC/540. The obligations of some nuclear weapons states were expressed in: French declaration: *Measures that France Intends to Apply for the Implementation of the 93+2 Programme*, 13 May 1997 (unofficial English translation from French); British declaration: *Implementation in the UK of Measures Provided for in the Programme 93+2 Model Protocol*, 13 May 1997. The elements of the reform are described in detail in: Suzanna van Moyland, Verification Matters: The IAEA’s Programme ‘93+2’, Report VERTIC, January 1997. For the state of the implementation, see: Suzanna van Moyland, Progress on Protocols: The IAEA's Strengthened Safeguards System, Disarmament Diplomacy, June 1998, p. 9.

57 Guideline on the handling of plutonium , translated by AA, 2. February 1998.

58 Strategic Defence Review, op. cit. (fn 31).

59 In August there were advances in the CD towards the realisation of a negotiations forum which lead to the setting up of an ad hoc committee for the negotiation of an FMCT: Rebecca Johnson, Geneva Update, The CD: 1998 Round-up, Disarmament Diplomacy, no. 29, August/September 1998, p. 16.

60 This was so expressed, for example, in a paper presented to the Geneva disarmament talks on 29. April 1998 by the Australian government: Australia, Fissile Material Cut-off Treaty, Concept Paper, 29 April 1998. For possible variations on the scope of this ban and its verification, see Schaper, op. cit. (fn 50).

61 Foreign Office, Bericht zur Rüstungskontrolle, Abrüstung und Nichtverbreitung 1996, p. 56; see also Jörg H. Gösele/Hans Herman Remagen/Gotthard Stein, "A German view on safeguards beyond 1995," in: Proceedings of the Symposium on International Nuclear Safeguards, vol. II (Vienna: International Atomic Energy Agency, March 14-18, 1994), p. 701, Hartmut Blankenstein, "Political Considerations on the Future of Safeguards," Proceedings of the 17th Annual Symposium on Safeguards and Nuclear Material Management, (Aachen, Germany, 9-11 May 1995), p. 21.

introduction of international safeguards must first be created.[62] This task is on the agenda anyway, especially if an FMCT were to be successfully negotiated. An important problem is the protection of proliferation-relevant information, which must be taken into account as long as the disarmament process is not fully completed. This task is complicated by the – partly exaggerated – secrecy in nuclear weapon states. It can be assumed, however, that a rethink on this issue of secrecy will coincide with the loss of status associated with the possession of nuclear weapons, if the determination grows to achieve extensive or comprehensive nuclear disarmament (see section 5.1.2. Secrecy versus Transparency).

3.1.6 Discovery of Undeclared Materials

In the case of comprehensive nuclear disarmament, verification will have to go well beyond all these approaches. Possession and production of nuclear material outside international controls will have to be made illegal. The verification must be able to detect, with sufficiently high probability, illegal misappropriation of this material and to track down and identify any undeclared material that may be in existence. This is also verified in the non- nuclear weapon states party to the NPT. The task in former nuclear weapon states is, however, more difficult because of the long and complicated production history and the decades of absence of any international controls.

An important method is the reconstruction of past production. A prerequisite for this is maximum transparency in the production history of military material. The task of verification then consists of controlling and re-recording measurement data with the aid of the documentation, in order to establish an inventory in book form, which can then be compared with the declarations. This was also applied in South Africa (section 4.1.4). Furthermore, it is possible to draw conclusions regarding past by using radiological measurements in nuclear plants which have either been shut down or are still in operation.[63]

There will, however, be a higher rate of errors during the determination of the initial stock than in anything previously experienced by the IAEA. For example, in the data on plutonium stockpiles published by the USA, there was indication of a discrepancy between the measured stockpiles and the stockpiles calculated from the documentation, which amounted to 2.7 tons – sufficient for approx. 1000 warheads.[64] This does not mean that this amount has been put aside; the discrepancy can be explained in terms of insufficient documentation and inaccurate measurements in former times. Errors in future figures emanating from some other NWS are likely to be even higher. In the former Soviet Union, for example, material accounting was based solely on documentation but not on

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62 Details of these tasks are described in Schaper, op. cit. (fn 50), chapter 4.5.4.

63 Steve Fetter, Nuclear Archaeology: Verifying Declarations of Fissile-Material Production, Science & Global Security, vol. 3, no. 3, 1993, pp. 237-259.

64 Department of Energy, Plutonium: The First 50 Years. United States plutonium production, acquisition, and utilization from 1944 to 1994, February 1996; see also Albright/Berkhout/Walker, op. cit. (fn 51).

measurements.[65] In the meantime, international efforts are concentrated particularly on modernisation of material accounting and its adaptation to IAEA standards. In NNWS, whose nuclear industry was subjected to international surveillance at an early stage, there are also measuring inaccuracies, though on a smaller scale, the correctness of which is taken to be reliable. As a supplement, measurements must be carried out on materials and plants.

The same applies for these problems as for the verification of warhead stockpiles (section 3.1.3): we shall have to live with these discrepancies and inaccuracies. However, with maximum transparency, utilisation of the most diverse sources of information and the possibility of challenge inspections, it is highly probable that undeclared material storage sites will be detected sooner or later, which also has a deterrent effect on frauds.

3.1.7 Destruction or Conversion of Plants

The possession of nuclear weapons is not possible without regular maintenance in order to guarantee functionality, reliability and safety. The reason for this is that warheads display different effects of ageing:

1. The composition of plutonium alters as a result of radioactive decay. The isotope Pu-241 which is contained (to a small degree) in plutonium decays to gaseous Am-241 (americium), which destroys the crystal structure.[66] Depending on the level of the Pu-241 content, the pit must, sooner or later, be replaced and the old plutonium cleaned of americium. The time scale is 10-20 years. For this reason, warheads are dismantled and reassembled at regular intervals. Both activities take place in warhead factories. In addition, storage sites are required for warheads and components which have been scrapped.
   The same warhead factories and storage sites will also be used for dismantling operations during the course of disarmament. As a first step, all these plants must be declared. Most of them have already been known for a long time anyway. During verification of the dismantlement of warheads, the measures specified above will then be applied. These are the measures concerning for example the entrances and exits of these plants, or the surveillance of transportation. The last step in nuclear disarmament would then be the destruction of the plants and the conversion of the buildings, followed by on-site inspections. On-site inspections must also be possible at any random site in future, in order to make sure that no activities geared towards the production of nuclear weapons can be carried out.

2. As a result of the radioactive radiation of the pits, electronic components and conventional explosives are impaired. These must therefore be checked and replaced at

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65 A. N. Roumyantsev, Establishing a SSAC in Russia: Structural, Organizational, Budgetary and Political Problems, Conference on Fissile Material Security in the CIS, Deutsche Gesellschaft für Auswärtige Politik, Bonn, 7.-8. April 1997.

66 The half-life of Pu-241 is 14.4 years. In comparison, that of Am-241 is 433 years. The typical content of Pu-241 in American weapons plutonium counts as 0,35 %; op. cit. (fn 95). The americium enriches in such a way that one third of the Pu-241 has decayed after 10 years, and almost two thirds after 20 years.

regular intervals. As a result of further technological developments, older electronic components are often no longer produced. For this reason, newly-constructed warheads are often slightly modified and their functional capability has to be checked. This is done with the help of so-called "hydrodynamic tests" and tests on components, for which test sites are required.[67] Formerly, nuclear testing was also carried out for this purpose.
These activities must cease, at the latest, when the transition to a nuclear-weapon-free world is complete. This will have to be controlled by means of on-site inspections of former test sites. A range of these activities is ambivalent in character: testing plants for conventional explosives can be used for hydrodynamic tests as well as for the testing of conventional ammunition. In this case, arrangements for „controlled access“ must be made for challenge inspections. This verification instrument was developed as part of the Chemical Weapons Convention (CWC), which represents a milestone in the development of verification.[68] On one hand, unlimited access is stipulated for inspectors, on the other hand, plant operators are given the opportunity to protect industrial secrets by, for example, covering up devices or locking away documents. The details are jointly negotiated between operators and inspectors. By means of environmental analyses, for example, it is possible to determine which materials have been used. However, technical details need not be revealed simultaneously.

3. The tritium required for boosting decays with a half-life of approx. 12 years, and must be regularly renewed. Simple nuclear warheads can also function without tritium. Technically advanced warheads in nuclear weapon states are, however, reliant on tritium. To abandon it would require the reconstruction of warheads, which, following the conclusion of the CTBT, is only possible for very primitive models. Various different technical possibilities are available for the production of tritium, especially the production carried out with the aid of lithium-6 in reactors, the extraction from the primary cooling cycle in heavy water reactors or spalation neutron sources.[69] Most of these plants are also suitable for the production of plutonium. For this reason, it is probable that, as a result of an FMCT, they will be subjected to verification measures with the task, among others, of differentiating between plutonium and tritium production. If a decision was made in favour of total nuclear disarmament, one

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67 Hydrodynamic experiments form part of those activities which are carried out in the NWS following the test ban in order to maintain the nuclear arsenal. In the USA activities of this kind are known as “Stockpile Stewardship“. See e.g. JASON and the MITRE Corporation, Science Based Stockpile Stewardship, Report JRS-94-345, November 1994. An overview is provided by Richard L. Garwin, Stockpile Stewardship and the Nuclear Weapon Complexes, Pugwash Meeting no. 206, Moscow, 19-23 February 1995. See also: A. Schaper, The problem of definition: Just what is a nuclear test?, in: Eric Arnett (ed.), Implementing the Comprehensive Test Ban: New Aspects of Definition, Organization and Verification, SIPRI-Research Report (Oxford University Press), Oxford, 1994.

68 Alexander Kelle, Das Chemiewaffen-Übereinkommen und seine Umsetzung – einführende Darstellung und Stand der Diskussion, Frankfurt/M, (HSFK-Report no. 12), 1996. Walter Krutzsch/Ralf Trapp, A Commentary on the Chemical Weapons Convention, Dordrecht/Boston/London (Martinus Nijhoff eds.) 1994.

69 M. Kalinowski/L. Colschen, International Control of Tritium to Prevent its Horizontal Proliferation and to Foster Nuclear Disarmament, Science and Global Security, vol. 5, no. 2, 1994/95, p. 130. cf. also section 4.5.2: Tritium in Schaper, op. cit. (fn 50).

consequence will also be a ban on the production of tritium for warhead purposes, which would then have to be verified, too. [70]

4. It is also necessary to maintain the level of qualification of a sufficient number of scientists and technicians. For this purpose, regular training is required. On the technical side, the handling of special materials, production technologies and tools must be practised. On the scientific side, the trainees must intensively occupy themselves with theoretical and experimental issues relating to nuclear weapon-oriented problem areas which are hardly touched on in published literature (for further details, see section 3.3.4 Theoretical Foundations). It is also necessary to recruit and train the rising generation of qualified personnel.Continued employment of a number of nuclear weapon specialists in a nuclear weapon state beyond the point of total nuclear disarmament holds a high risk of detection. The previous activity of these experts is known to a large circle of people not easy to survey. In order to cover up the fact that an option is secretly being kept up, one would have to work for a large-scale creation of legends. The methods for this would be the same as in the case of secret nuclear rearmament which is discussed in detail in the next chapter (cf. section 3.3.8 Secrecy and Creation of Legends). The probability of detection in terms of nuclear weapon-orientated research activities can in addition be increased by the fact that large research institutions must, in principle, be open for visiting international experts in the same field.[71] Thus, for example, the operation of the NIF laser fusion plant in Livermore, USA, (as part of "Stockpile Stewardship") with the exclusion of non-American colleagues, would no longer be permitted in a nuclear weapon free world.67

As has been demonstrated, the detection probability in terms of the continuation of maintenance activities is very high. There remains the slight risk of non-detection that a nuclear weapon state might retain a number of undeclared warheads. However, it is highly unlikely that it would do so entirely without any maintenance facilities and personnel, since, after only a short time, the functional capability and safety of this arsenal can no longer be guaranteed. Thus the overall probability that incomplete nuclear disarmament will not be detected is extremely small.[72]

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70 Kalinowski/Colschen, ibid.

71 This would accommodate a natural trend within scientific professions: residencies abroad are here typical, and the personnel in large non-military research facilities is constantly internationally mixed.

72 There is the proposal of the "*virtual nuclear arsenal*" (Avner Cohen, Assessing Virtual Nuclear Arsenals, Survival, vol. 40, no. 1, 1998 (Spring)): according to this, all warheads should be abolished, but the nuclear complexes maintained in order to allow for rapid nuclear re-armament in the case of a proliferation. The verification would, in this case, be considerably less convincing, since it would be further hampered by a lack of transparency and a multitude of hardly clarifiable suspicious activities. There are also objections on grounds of political security. See, e.g., Kelle, op. cit. (fn 19).

3.2 Summary: How Reliable Can the Verification of Nuclear Disarmament Be ?

The overview outlined in this section shows that two tasks are involved. The first is the verification that declared disarmament measures actually take place, and the second is verification that declarations of stockpiles are complete.

The first task can be managed with a high degree of reliability by using technical means. The crucial element here is the identification of warheads and the reliable distinction of decoys. Accompanying methods are the secure protection of transports and the sealing of containers. Technologies and methods in this respect are so advanced that their principle feasibility and the high degree of reliability need not be doubted. One difficulty is the problem of the secrecy of many technical details. It would, however, be possible to overcome this problem with a combination of political and technical methods. An important principle is that of the closed factory with a verified entrance and verified exit. A prerequisite which would greatly simplify the task is a dramatic rise in transparency in the participating states (cf. section 5.1.2 Secrecy versus Transparency). The conclusion can be drawn that the impending further steps of nuclear disarmament, for example a START-III treaty, could be verified with a satisfactory degree of accuracy, provided that there is the political will. Verification measures can also be introduced and developed step by step in the same way as the disarmament measures themselves. Each new measure can build on previously gained experience.[73]

The second task, the verification that no warheads and no nuclear material remain, cannot be mastered solely with technical means. Technological methods can be employed in the case of a concrete suspicion: specially trained inspectors with the relevant equipment would be in a position to find and identify warheads at a concrete location. There is no guarantee, however, that suspicions will actually arise. It is only possible to raise the level of probability for this. The following factors are important in this respect:

1. The highest possible level of transparency of production histories, i.e., above all, voluntary declarations and documentation, the publication of historical documents and the possibility of interviews with former employees.
2. Full exploitation of all technological possibilities for verification, including, in particular, aerial reconnaissance and environmental measurements, furthermore, the possibility of involving National Technical Means (NTM), including secret services.
3. Freedom of the press and a democratic climate which, in the case of non-compliance with international obligations, would generate a corresponding sense of injustice in those individuals involved.
4. The possibility of forcing clarification, if necessary, in the case of suspicion, i.e., the impossibility of rejecting challenge inspections.
5. International trust, resulting in the fact that quantitative disagreements would be realistically evaluated.

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73 Diakov, op. cit. (fn 25).

Each of these factors, taken individually, is a necessary prerequisite for the verification of total nuclear disarmament. Together, they would improve verification to such an extent that we could talk about sufficient criteria.

3.3 Tasks and Methods of Early Detection of the Various Different Elements of Secret Nuclear Weapons Programs

The task of early detection of an attempt at nuclear rearmament will never, even in a nuclear weapon free world, become obsolete. Since nuclear weapons cannot be un-invented,[74] and since, as a result of the close link between non-military and military uses of nuclear energy, it would always be possible to overcome the technical hurdles for the acquisition of nuclear weapons, the world will always have to live with permanent verification, even after comprehensive nuclear disarmament. This is already the case in the non-nuclear weapon states (NNWS) party to the NPT, who have undertaken to relinquish the right to use or own nuclear weapons and to allow this to be verified by the IAEA. The IAEA safeguards have been reformed and improved on the basis of decades of experience. They have also become more intrusive.

In a nuclear weapon free world, these requirements would be even higher. As with every verification however, it is not possible to be one hundred percent certain. The remaining uncertainty has always been reduced in the course of time, but it is fundamentally impossible to eliminate it altogether. The degree of uncertainty which can still be tolerated in the case of a nuclear-weapon-free world lies below that of a world in which some nuclear weapon states still exist. In conjunction with far-reaching nuclear disarmament, the present verification system must therefore also be developed to such an extent that it will be acknowledged by the international community[75] To what extent uncertainties can be tolerated depends in this instance firstly on the degree of international trust, which states have acquired over the course of time. Secondly, it depends on the effectiveness of countermeasures which can be resorted to in the event of an attempt at secret nuclear rearmament. The aim of a further extension must be to detect potential treaty violators as early as possible rather than to increase the expenditure on verification in reliable member states.

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74 There have been considerations which assume the possibility of the disappearance of the technical knowledge of nuclear weapons: Donald MacKenzie/Graham Spinardi, Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons, American Journal of Sciences, vol. 101, no. 1, July 1996´5, pp. 44-99. In a nuclear-weapon-free world, a large number of technical skills would in fact disappear. These considerations are, however, according to our opinion only correct for the engineers‘ level and not for the basic physics. The basic principles of nuclear weapons will always be known. These can be built on, so that is future, there would be no theoretical obstacle to redevelopment. The numerous possibilities for transferring scientific and technical knowledge from non-military areas to nuclear weapons should not be underestimated.

75 At present there is a large number of critics who consider the present system to be insufficient, and who have influence on the political elites of their countries: Lü Chenxi; How High is the Threshold for Japan to Develop Nuclear Weapons?; Paper for the 8th International Summer Symposium on Science and World Affairs, Beijing, July 23-31, 1996; Paul Leventhal, Latent and Blatant Proliferation: Does the NPT Work Against Either?, Nuclear Control Institute, Washington, 1990. It is, in principle, not possible to satisfy all critics, but it is necessary to have the recognition of the majority of all political elites.

Different from former nuclear weapon states, a new beginner would first have to work out the scientific foundations for the construction of nuclear weapons. His first nuclear weapon would be based on a technically quite simple construction principle. A state cannot build a hydrogen bomb until it has not only mastered the construction of simple nuclear fission bombs, but can also exactly predict the yield. Computer simulations and part experiments are inadequate for this. It would also be necessary to carry out some experimental nuclear explosions with the prototypes for primaries, which would be detected by the verification apparatus of the CTBT (see appendix: functioning of nuclear weapons).[76] Hence verification must concentrate primarily on activities connected with the secret construction of a simple nuclear fission bomb.

Additionally, the possibility cannot be ruled out that a proliferator acquires the necessary knowledge from nuclear weapon states by way of espionage. In this case, he would theoretically be in a position to bypass some of the research and development activities and select a technically more advanced design. In the case of a nuclear weapon free world, the documents and skills still in existence would, however, in the long term be reduced to the minimum required for future arms control. But even in this case, a technical infrastructure and production would first have to be developed. Early detection of the latter is the task of verification.

A prerequisite is the universality of the commitment to relinquish nuclear weapons, and the verification thereof. The verification authorities must have the same rights in all states. In a nuclear weapon free world, the overwhelming majority of states will not develop any ambitions in terms of nuclear weapons, just as today there is no doubt about the contractual fidelity of almost all non-nuclear weapon states in the NPT. There can, however, always be a small number of treaty violators. Whether verification in a nuclear weapon free world is possible depends crucially on whether these treaty violators are detected in time. In the following, we describe the acquisition strategies for different elements of a secret nuclear weapon program and the measures needed for their detection.[77]

3.3.1 High Enriched Uranium (HEU)

For a nuclear weapons program in a beginner state, there are, in principle, two alternative lines of technical development: either the acquisition of the nuclear weapon material plutonium or the nuclear weapon material HEU.

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76 A. Schaper, Bombenstimmung in Indien und Pakistan, Spektrum der Wissenschaft, July 1998, p. 110.

77 Office of Technology Assessment, United States Congress, Technologies Underlying Weapons of Mass Destruction, OTA-BP-ISC-115, Washington DC: U.S. Government Printing Office, December 1993; A. Schaper, Kernwaffen der ersten und zweiten Generation: Forschung und Entwicklung, in: E. Müller/G. Neuneck (eds.): Rüstungsmodernisierung und Rüstungskontrolle, Baden-Baden 1991/92; John E. Dougherty, A Summary of Indicators of Nth Country Weapon Development Programs, LA-6904-MS, Informal Report, Los Alamos, January 1978; Proceedings of Symposium on International Nuclear Safeguards, vol. I, II (Vienna: International Atomic Energy Agency, March 14-18, 1994); Anthony Fainberg: Strengthening IAEA Safeguards: Lessons from Iraq, Report, Center for International Security and Arms Control (CISAC), Stanford University, April 1993; methods of technical safeguards are described in: IAEA, Safeguards Techniques…, op. cit. (fn 48).

Natural uranium, i.e., that which can be found in nature, consists of 99.3 per cent of the isotope U-238, and 0.7 per cent of U-235. It is not suitable for a chain reaction in a nuclear explosion since the content of U-235 has to be considerably higher – at least 20 per cent. For nuclear weapons, a content of 90% or more is typical.[78] The isotope composition of uranium must therefore be artificially modified. The technologies used for this are called enrichment technologies.[79] There are a number of different enrichment technologies, which are based on different principles, display a varyingly high level of technical requirements, have a varying distribution, and also have different detection probabilities in the event of a secret operation. The most important known enrichment processes are: gas diffusion enrichment, gas centrifuge enrichment, jet nozzle enrichment, chemical enrichment, electromagnetic enrichment (EMIS) and laser isotope enrichment (AVLIS) (cf. appendix B: A comparison of enrichment processes). In principle, it is not impossible, although not very likely, that a proliferator could succeed in discovering a new, previously unknown process, and be able to develop it to the point where it can be used.

Enrichment technology is not only used for military purposes, but also in the non-military production of nuclear energy. Most nuclear reactors need low enriched uranium (LEU) as fuel. This contains approx. 3 – 5 per cent U-235, less than in HEU, but more than in natural uranium. It is itself not suitable for weapons, but the same enrichment technologies are used for its production as for the production of HEU. But an LEU production plant is configured somewhat differently to one for the production of HEU: one enrichment element, for example centrifuge or jet nozzle, is normally only capable of enriching the material by a small fraction.[80] For this reason, many elements have to be connected in series, and due to the required amounts, also in parallel. The enrichment of the end product results from this arrangement. The mere construction of a plant shows whether it is used for the production of HEU or LEU. Reconstruction is possible in principle, but takes a long time. A state that has access to non-military enrichment technology is therefore in principle also able to produce HEU for military use. It is, however, extremely unlikely that an enrichment plant which is already subject to IAEA safeguards would be used for the production of HEU instead of LEU without this being detected, if inspections take place often enough. The alternative method would therefore be to build a secret plant.

A state which had no previous access to enrichment technology would first have to acquire this by developing it themselves, either with or without external help. Due to the danger of misuse for the purpose of developing nuclear weapons, important technical details are kept secret so that most processes can only be developed by industrial countries without external help. These processes also include the most wide-spread processes of gas diffusion and gas centrifuges. Both pose a considerable technical hurdle for less developed

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78 The smaller this proportion, the larger is the amount required for the production of a warhead, and the more cumbersome and technically elaborate is warhead. cf. appendix III, Glossary of technical and legal terms, in Schaper, op. cit. (fn 50).

79 Allan S. Krass/Peter Boskma/Boelie Elzen/Wim A. Smit, "Uranium Enrichment and Nuclear Weapon Proliferation" (Taylor & Francis), London 1983

80 The size of this fraction is given by the so-called “separation factor“. cf. table 3: Enrichment Processes in Comparison. The smaller it is, the larger is the number of necessary enrichment elements.

countries, so that the latter are reliant on external help such as the legal or illegal transfer of technology, smuggling, espionage or treason on the part of foreign experts. Other enrichment technologies are comparatively easy to master and can be developed by less industrialised countries without external help. One example is electromagnetic enrichment with the aid of so called “calutrons“, which Iraq had worked on as part of its program. Nevertheless, even with simpler technologies, the costs in terms of technology, finance, time and logistics that are required to produce sufficient amounts should not be underestimated. In a secret nuclear weapons program which is to use HEU, a proliferator would therefore have several options:[81]

1. **Direct diversion:** He could attempt to divert HEU directly, for example from non-military use as a fuel for special research reactors[82], from the military application as fuel for submarine reactors[83] or from a previously unknown stockpile which is not subject to safeguards.

   To detect the first scenario, diversion from a research reactor, sufficiently frequent inspections are necessary, so that the time-span between diversion and detection remains short enough.[84]

   The HEU for military submarines could prove a problem.[85] A verification regime would have to ensure that illegal diversion for nuclear weapons was discovered early enough. Due to the military character of the material, conflicts regarding the degree of transparency are likely. The same problem is bound to arise during the negotiations for the FMCT, which can therefore provide lessons for future measures. One possibility to at least ease this problem would be to relinquish the use of very highly enriched HEU (over 90%) in submarines, and to replace this with less highly enriched uranium. At least unverified stock-keeping would no longer be allowed. The same considerations apply in the case of the detection of undeclared fissile material storage sites as they do in the case of the detection of undeclared warheads (cf. section 3.1.3).

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81 Cf. Tom E. Shea, Verifying a Fissile Material Production Cut-Off: Safeguarding Reprocessing and Enrichment Plants: Current and Future Practices, Seminar on Safeguards and Non-Proliferation, IAEA Headquarters, November 16-17, 1995.

82 Such research reactors are rare. Most of them will have reached the ends of their operating lives within the next couple of years. The only research reactor to be newly built since a moratorium 20 years ago, is the planned FRM-II in Garching.

83 At present, this does not exist in any NNWS which is a member of the NPT, although, theoretically, it would have the right to possess such fuel.

84 Iraq had planned to use its HEU, which it had imported for use in research reactors, in a crash program. The inspections only took place every half year, so it would have had enough time and material to build one or two warheads. Cf. section 4.2 Iraq: Attempted Violation of the NPT and the literature quoted therein

85 See the more detailed discussion given in chapter 4.5.1: Specific verification problems – Naval fuel in: Schaper, op. cit. (fn 50). Very highly enriched uranium as is required for nuclear weapons is only used in submarines in the USA and Great Britain. Less highly enriched uranium, e.g. the 45% which is used in many Russian submarines is also legally classified as HEU. Nuclear weapons would, however, require a much greater degree of technical expenditure. The danger of proliferation is thus lower. The French submarines run on only 7% enriched uranium.

2. **Smuggling:** He could attempt to acquire this material on a potential black market. These activities can be detected by authorities such as the police, customs or secret services. There is always a certain probability of discovery, but this will never be one hundred percent. It has been increased as a consequence of several incidents in the last few years, mainly by the improved training and equipment of the relevant authorities, improved security and improved international co-operation.[86] International awareness of the problem has grown in the meantime. Countries which are in this respect poorly equipped are especially suitable as trans-shipment locations. For this reason it will be necessary in a nuclear weapon free world to extend routine international co-operations.

3. **The use of non-military plants:** He could attempt to misuse an already existing non-military plant secretly for military purposes. In this connection there are two varieties: the plant already produces non-military HEU, or it produces LEU and would have to be correspondingly converted. This is the scenario traditionally aimed at by the IAEA safeguards. The probability of detection has continually risen as a result of many technical improvements. Ultimately, it is restricted by the finiteness of the financial resources.

4. **The building of his own secret plants:** He could attempt to build his own secret plant himself without external help. In this instance, he would either use existing non-military technology, or develop his own enrichment process. The more advanced the industrialisation of this state, the greater is the selection of possible enrichment processes for its own development.

   According to the safeguards reform S3, a state undertakes to declare such plants already before they are loaded with nuclear material.[87] The reform also aims at developing as much transparency as possible regarding the relevant industries of member states. The necessity for protection of industrial secrets poses a problem here.[88] This problem is typical of verification, and not only in the nuclear area. Verification must here make use of challenge inspections with controlled access according to the CWC model (cf. section 3.1.7). In the CWC case, the aim is to verify the absence of forbidden activities. In the case of enrichment, the aim would be to verify that there are no undeclared preparations for enrichment processes, depending on the exact terms of the scope in a future treaty.

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86 As with the combating of other forms of crime, there will always be a limit in rights of access for the authorities in order to protect individual privacy.

87 This was not the case before the reform. Plants were first registered at the IAEA once they were loaded with nuclear material.

88 This was also a point of dispute during the negotiations towards S'3. Extensive transparency measures and declaration obligations were originally proposed in non-nuclear areas of technology which are relevant for enriching and reprocessing. However, these plans were cut after a group of non-nuclear weapons states complained about the competitive disadvantage as against the nuclear weapons states due to increased risk of industrial espionage, and demanded universality in this measure. The reason for this reticence was, above all, the prospect of having to introduce similar measures in the nuclear weapons states, with the probable result that there would be resistance from industry here too. This is illustrated by: Statement by the Utilities Employing Nuclear Energy and the Nuclear Industry in Germany on the IAEA Programme 93+2, 3 June 1996.

A further possibility is of course that these activities are detected by NTM. Secret service activities in this area are, however, also ambivalent since they can be accompanied by industrial espionage. Hence, the legitimisation of these activities also has its limitations.

5. **The construction of a secret plant with foreign help:** He could attempt to build a secret plant with external help. In this connection, he would attempt to minimise the extent of this help in order to minimise the probability of discovery. The typical acquisition activities for this and the chances of their detection are described in section 3.3.7 Acquisition Activities. Plants can be detected with the aid of satellites. In the case of the construction of an underground plant the excavation would arouse suspicion.

6. **Operation:** Following completion of a plant, he has to start up the operation and produce sufficient HEU. Raw materials (either natural uranium or LEU) have to be acquired or diverted for this. Stockpiles of natural uranium are to be found all over the world, and new deposits can always be discovered.

   Most enrichment processes use the chemical compound uranium hexafluoride (UF6), which is volatile. Unless elaborately shielded, UF6 can be detected by means of atmospheric measurements adjacent to a plant, or by using so-called LIDAR techniques (Light Detection and Ranging).[89] LIDAR techniques examine laser light reflected by the atmosphere using spectral analysis methods. Some of these techniques are included in the S3. LIDAR can also be operated from satellites, but at present this only takes place in the form of NTM in some states. There is no other application for UF6 apart from enrichment. Atmospheric measurements can also detect whether HEU has been enriched. Some processes, in particular AVLIS and EMIS, use no volatile materials, and it could be easier to hide them. But EMIS would require a high power and could therefore be detected by means of infrared pictures, for example from a satellite. Had Iraq's calutrons already been in operation, this would have been detected. To hide the heat production, an elaborate underground cooling system would have to be installed, or the plant would have to be built as part of another plant which also had a high power. In the latter case however, there would again be more accessories. The enrichment method which would be the easiest to hide is AVLIS, because it gives off little energy and releases no telltale gases. On the other hand, it is technically the most elaborate process, and can only be mastered by a few industrialised states.[90] However, should a proliferator succeed in stealing this technology, the probability of detection is extremely low. In principle, we cannot rule out the possibility that he invents a new process. The thing all these processes have in common however, is that traces of HEU are present in the plants, which are detectable during an on-site inspection. Initial suspicion can always be aroused, as described above.

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89 In the USA an extensive R&D-program for improvement of the NTM, is carried out: CALIOPE (Chemical Analysis by Laser Interrogation of Proliferation Effluents). See Wolfgang K. H. Panofsky (Chair), Report of the Comprehensive Research and Development Review Committee for the U.S. Department of Energy, Office of Nonproliferation and National Security, June 8, 1996.

90 After many years of R&D, the building of a demonstration plant has begun in the USA: Atomwirtschaft, volume 43, June 1998, p. 418.

3.3.2 Plutonium

The method used to produce plutonium is the reprocessing of spent fuel, as was attempted, for example, by North Korea.[91] The principle of reprocessing shall be briefly described here: spent fuel accrues as a result of normal operation in most nuclear reactors, particularly those containing LEU fuel. During operation of the reactor, the U-235 contained in the fuel is fissioned by the impinging neutrons. The U-238 cores, however, are not fissioned, but transformed into plutonium 239 (Pu-239) as a result of a chain reaction with the neutrons. If a neutron comes into contact with a Pu-239 core, the latter is either also fissioned, or the neutron combines with the core, forming Pu-240. The longer the fuel remains in the reactor, the higher the proportion of plutonium isotopes (Pu-240, Pu-241, and Pu-242 etc.) becomes. Spent fuel thus contains the following components: remains of unfissioned U-235 and unaltered U-238, plutonium which is composed of various different isotopes, and the fissile products. The latter consist of a whole range of different chemical elements which, to a larger or lesser degree, are radioactive. The aim of reprocessing is the separation of plutonium, uranium and the radioactive fissile products. The most effective and most widely used process is called PUREX (plutonium and uranium recovery by extraction). Apart from mechanical comminution methods at the outset, chemical separation processes are used. The crucial difference between a chemical factory and a reprocessing plant is the high degree of radioactivity, which poses a danger both for the workers and the environment. Not only must the fuel elements be stored for years after removal from the reactor so that the most potent radioactivity can decay,[92] but reprocessing plants must above all also implement extensive protection against radiation. Typical radiation protection technology are, for example, hot cells. The expense depends to a certain extent on the standards of radiation protection, and thus also on the unscrupulousness of a proliferator.

In principle, non-military nuclear energy can manage without separated plutonium, since spent fuel elements from almost all reactor types could be put into final storage without being reprocessed. This use of nuclear energy is known as “open fuel cycle“. If spent nuclear material is reprocessed, this is termed a “closed fuel cycle“. The nuclear weapon material plutonium only accumulates in a closed fuel cycle, that is, only here is use made of reprocessing, its production technology. Were there no non-military reprocessing, an important route for the acquisition of nuclear weapons material, i.e., diversion from non-military utilisation, would be cut off. In fact, however, plutonium and its reprocessing is used to a considerable extent for non-military purposes. In this respect, there are various different technologies, in particular the reactor type “rapid breeding“ , which can make use of fuel with a high Pu content, and fuel containing plutonium for light-water reactors, so-called mixed oxide fuel (MOX). Countries which today use plutonium for non-military purposes, or wish to keep this option, include Belgium, China, France, Germany, Great Britain, India, Japan and Russia.

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91 A detailed and easily understandable introduction to the technical aspects of plutonium is offered by: Nuclear Energy Agency, Plutonium Fuel – An Assessment, OECD, Paris 1989.

92 The radioactivity is reduced due to the fact that the elements with the highest levels of radiation decay fastest.

Although the USA operate an open fuel cycle for reasons of non-proliferation, and even pursue the declared policy of trying to win others over to this, it is unrealistic to believe in the implementation of an international consensus for the abolition of non-military utilisation of plutonium in the foreseeable future. In reflections on the subject of comprehensive nuclear disarmament, the demand can be found that it ought to be combined with the abolition of non-military use of plutonium.[93] Acceptance of the latter is, however, much more unlikely than acceptance of the abolition of only military utilisation.[94] A combination would create an additional obstacle along the route towards comprehensive nuclear disarmament. As long as it can be guaranteed that plutonium can only be used for non-military purposes, it could also be produced and used in a nuclear weapon free world. An essential prerequisite in this instance is a working verification which is able to detect any illegal diversion early enough and with sufficient probability.

If a proliferator attaches great importance to a high Pu-239 content, he will use spent fuel elements which have only briefly been exposed to radiation as his source material, i.e. he will unload a nuclear reactor early.[95] This ought to trigger a more precise control of the whereabouts of the fuel. An alternative would be radiation-exposed fuel from rapid breeders since, for reasons of nuclear physics, this has a particularly high Pu-239 content and contains almost no heavy isotopes. Plutonium enrichment is technically very sophisticated since the difference in mass between the isotopes is less than in the case of uranium.[96]

The technology of reprocessing is the same for both non-military and military uses of plutonium.[97] A state which had no previous access to reprocessing technology would first have to acquire this, by way of its own development, either with or without external help. The technological hurdle is, in principle, lower than in the case of enrichment. However, if detection is to be avoided, extremely sophisticated shielding measures are necessary to avoid the escape of telltale traces of radioactivity. The reason for this is that reprocessing

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93 INESAP, Beyond the NPT: A Nuclear-Weapon-Free World, April 1995, pp. 80ff.

94 On the subject of the acceptance of a nuclear-weapon-free world, see: H. Müller/K. Frank/A. Kelle/S. Meier/A. Schaper: Nukleare Abrüstung - mit welcher Perspektive? Der internationale Diskurs über die nukleare Rüstungskontrolle und die Vision einer kernwaffenfreien Welt, Frankfurt/M. (HSFK-Report no. 8), 1996. The acceptance of the abolition of military uses of plutonium is widespread, as is clear from the many positive statements on the issue of a Cut-off, above all from governments of countries in which plutonium is used for non-military purposes.

95 This has several technical advantages. Theoretically however, also so-called reactor plutonium with lower Pu-239 content can be used for the production of nuclear weapons. This has been demonstrated by: Egbert Kankeleit/Christian Küppers/Ulrich Imkeller, Bericht zur Waffentauglichkeit von Reaktorplutonium, Report IANUS-1/1989., then by Carson Mark, Explosive Properties of Reactor-Grade Plutonium, Science & Global Security, vol. 4, 1993, p. 111.

96 In 1994, a small sample of smuggled plutonium from Russia was discovered in Tengen which consisted of enriched plutonium. On the basis of its isotope composition, it was possible to determine that it was enriched by means of centrifuge. It is possible to speculate that Russian warheads made of this material exist. This is further supported by the fact that Russian warheads are said to be welded not screwed. This is only possible with very pure plutonium which hardly shows any ageing effects (americium construction) and can be used for many years.

97 Small variations can arise due to the fact that the critical mass is, to a small degree, dependent on the isotope composition. This can influence the tolerance limits for the avoidance of criticality accidents.

releases a much greater quantity of telltale gases than enrichment, hardly any being inert gases which can be shielded. They can be distributed and detected over great distances. [98] Methods include the taking of air samples or LIDAR from aeroplanes or satellites.[99] Shielding measures would again substantially increase the expense and, depending on the proliferator's level of development, requires the additional transfer of technology. They would also only reduce, but not totally eliminate the emissions.

In a nuclear weapons program which is intended to make use of plutonium, a proliferator would thus have several options, and there are correspondingly several methods of verification.[100] The acquisition scenarios are similar to those for HEU, i.e. direct diversion (from fuel production or from unknown storage sites), smuggling, use of non-military plants, construction of a secret plant either on his own initiative or with foreign aid (with the somewhat different kind of dependence on outside help specified above) and operation. By way of verification that no banned reprocessing takes place, there are additional methods, apart from the measurement of radioactivity in the environment, which are also applied by the IAEA, namely safeguards in the entire fuel cycle, and also, for example, in nuclear energy plants and facilities which do not directly contain weapon-grade material. This increases the probability of detecting banned activities essentially.

3.3.3 Ignition Technology

In addition to the acquisition of nuclear material, a proliferator will attempt to develop ignition technology for nuclear weapons. In this connection, there are two technological alternatives for beginners: the “gun assembly technique“, according to which, two halves of a sphere of HEU are combined by shooting them together so that an overcritical mass is created, and the “implosion technique“ in which a hollow sphere of HEU or Pu is evenly imploded and compressed with the aid of conventional explosives. For technical reasons, the gun assembly technique can only be applied to HEU, whereas the implosion technique can be used with both HEU and Pu.[101]

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98 Office of Technology Assessment, Congress of the U.S., Environmental Monitoring for Nuclear Safeguards, OTA-BP-ISS-168, Washington, D.C, September 1995; seven contributions to the convention on "Strengthened and more cost effective safeguards" of the symposium on International Nuclear Safeguards concern themselves with the measurement of radionuclines in the environment, see proceedings of this symposium,; op. cit. (fn 77), pp. 411-475, Charles W. Nakleh/William D. Stanbro/Louis N. Hand/R. T. Perry, Jr./William B. Wilson/Bryan L. Fearey, Nobel-Gas Atmospheric Monitoring for International Safeguards at Reprocessing Facilities, Science & Global Security, vol. 6, no. 3, pp. 357-379, 1997; Martin B. Kalinowski/Hartmut Sartorius/Stefan Uhl/Wolfgang Weiss, Rückschließbarkeit auf Plutoniumabtrennungen durch Auswertung von Messungen des atmospärischen Krypton-85 in Wochenproben bei verschiedenen Abständen von der Wiederaufarbeitungsanlage Karlsruhe, IANUS 3/1998. In the USA there is a range of R&D programs designed to improve the techniques. In 1996 they were promoted with the sum of US $ 194.4 m. Panofsky, op. cit. (fn 89).

99 Op. cit. (fn 89).

100 Op. cit. (fn 81).

101 The reason is that in implosion technology, the critical mass is reached much more quickly than with the gun assembly technique, i.e. within a few microseconds instead of milliseconds. Plutonium can only be used when the compression time is very short, since it has a much higher spontaneous fission rate than

The acquisition or production of material and of the ignition system can take place parallel and independently of each other up to the point of application, since they both use completely different techniques. This applies both to the gun assembly technique and the implosion technique. In the experiments necessary for their development, non-fissile material is used instead. With the use of computer simulations, conclusions can be drawn on the results in terms of whether the warhead with fissile material would have ignited. The more accurate these computer simulations are, the more accurate the prediction on the yield becomes, too.

The technical expenditure in the case of the gun assembly technique is lower than in the case of the implosion technique, but large-scale development work is still required at the engineer level. In principle, even less industrialised countries can develop this technology without external help since no high technology that is difficult either to produce or to acquire is required. However, HEU must be used as the fissile material, and its manufacture poses greater technical requirements than that of plutonium. The necessary amount is also much higher than that required for a warhead based on the implosion principle. This route will thus only be trodden by a state which has access to large quantities of HEU. An example of a case of this kind of proliferation is South Africa (cf. section 4.1). Warheads based on the gun assembly principle are so heavy that missiles are not an option as carriers. This principle has not been used anymore for decades in nuclear weapons states.

In the case of the implosion technique, the technical requirements are higher. This is particularly attributed to the fact that compression is only possible if the implosion is taking place in a perfectly spherical way. This requires a precise arrangement of spherical symmetry and the generation of spherical, inward-moving shock waves. So-called “explosive lenses“ are used for this purposes. Explosive lenses are composed of specially formed pieces of different conventional explosives. All the explosive lenses used in the arrangement must in addition be detonated simultaneously. In this instance, the permissible imprecision in terms of time may only be a matter of microseconds. The relevant techniques for this cannot simply be acquired on the world market, and the technical requirements in the case of domestic development are high. In preliminary tests, a proliferator will first of all attempt to generate even shock waves. An example of such a program is provided by Iraq (cf. section 4.2), which, after several years of research work, had still not overcome this problem. Examples of the technologies required for the generation of shaped shock waves are: flash x-ray machines[102], high energy short-time switches, or metallurgy with the heavy metals used. If these technologies cannot be produced domestically, which can be the case in less industrialised countries, they must be acquired on the international world markets.[103] Terrain suitable for experiments with explosions is also required.

HEU, and thus the probability of early detonation with only low release of energy would rise if longer compression times were used.

102 F. Jamet, G. Thomer, "Flash Radiography", Amsterdam 1976.

103 All these technologies are subject to export restrictions.

There is an important difference between the acquisition of ignition technology and the acquisition of fissile materials. If all the necessary technical expertise is available, and blue prints are in existence, an ignition device can be constructed with relatively low effort and expenditure. The necessary materials and components, for example, conventional high explosives and high-energy short-time switches are comparatively easy to acquire or produce, whereas the technical effort required in the production of plutonium or HEU is very high, even if the procedure is known. Nevertheless, acquisition activities in this direction would pose grounds for suspicion which must be taken seriously.

Whereas spherical shock waves have just one application, i.e. implosion technology for nuclear weapons, there are a great variety of applications for the preparatory experiments in terms of generation of even and other-shaped shock waves.[104] Non-military research is included here[105], and, above all, conventional military research. One frequent application is in shaped charges with an anti-tank impact.[106] It would not be possible to distinguish between legitimate experiments on shock waves and illegitimate experiments on spherical shock waves until research had reached a fairly advanced stage, i.e. when the shock waves generated take on a spherical form. In the next step, materials would be compressed. These experiments represent the hydrodynamic tests mentioned in section 3.1.7. Thus, if during an on-site inspection of this kind of test site it could be proved that experiments on spherical implosion had taken place, this would be an unequivocal indicator. After an experiment, however, the components involved are of course destroyed, so that proof of this kind would be hard to come by, even in the case of an on-site inspection. Additional documentation and test drawings or the inspection of the test construction prior to the explosion would have to be consulted. Here again, we are confronted with the problem of protecting not only industrial, but also military secrets. It is the task of more specific studies to examine to what degree challenge inspections with controlled access according to the CWC model could be applied here.

In a nuclear weapons program which is to use the implosion technique, a proliferator would therefore have several options, namely smuggling of components, recruitment of former nuclear weapons experts, and R&D, either with or without the transfer of technology with outside aid, disguised as R&D for conventional military technology. Which one he chooses depends on his level of industrialisation. If a future verification system is to take account not only of the acquisition of the ignition technology, but also of the fissile material, at least a certain probability must be ensured that each of these

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104 Flat shock waves are generated with the aid of so called “flyer plates“. See, e.g. Hans-Rudolf Kleinhanß, F. Lungenstraß und Helmut Zöllner, "Initiation Threshold of High Explosives in Small Flyer Plate Experiments", Proceedings of the Ninth Symposium on Detonation, Portland, Oregon, USA, August 28 - September 1, 1989, p., 66 and Hans-Rudolf Kleinhanß, Stoßwellen, lecture, University of Düsseldorf, summer semester 1979. Iraqi scientists also took part in the symposium in Portland.

105 E.g. for an explosive generator for the generation of short-time high current pulses which can be used in plasma physics. One example of cylinder shaped shock waves is provided by Herbert Scholes, Untersuchungen zur Stromverstärkung durch magnetische Flußkompression in einem koaxialen Explosivgenerator, PhD thesis, University of Düsseldorf, 1982.

106 See, e.g. Rheinmetall, Hohlladungsgeschosse, in: Waffentechnisches Taschenbuch, 9th edition, Ratingen 1995, pp. 474 f.

activities will be detected. As long as there is a high enough probability of early detection of the acquisition or diversion of HEU or Pu, the detection of ignition technology activities can assume a secondary role. Of course, it is desirable to achieve the highest possible level of probability. Theoretically, even smaller explosions could be detected with the aid of microphones, but due to the vast number of conventional explosions taking place worldwide, the expense would be out of all proportion.[107] The applicability of challenge inspections or random checks should at least be investigated in more detail. Although a former nuclear weapon state does not require such an extensive development program, it too would have to carry out the accompanying hydrodynamic tests in the event of secret nuclear rearmament. The extent of these tests will increase, the longer ago the disarmament phase was, and the higher the amount of documentation, infrastructure and informal knowledge is which has already disappeared or been destroyed.

3.3.4 Theoretical Foundations

The evaluation of measurement data emanating from hydrodynamic tests requires extensive theoretical work, including computer simulations. It must be calculated firstly, how the neutrons in a chain reaction would have multiplied if Pu or HEU had been used, secondly, how the material would have been heated and how the energy would have been distributed and spread, and thirdly, how the compression would have slowed and reversed as a result of the increasing energy density. All three processes mutually influence each other and can therefore not be calculated or simulated separately, although theories from very different areas must be applied in each case.[108]

All three areas also require knowledge of special material characteristics, namely those of plutonium or uranium at extremely high temperatures and pressures. Many of these parameters necessary for the calculation have only been measured in connection with research on nuclear weapons, for example, during underground nuclear tests, and have never been published.[109] Hence, approximate theoretical figures would have to be acceptable in this case. However, since a beginner is satisfied with knowing whether a concept for a warhead would actually function, and since he would not attach great importance to an accurate prediction of the yield, approximations also suffice as far as he is concerned. State-of-the-art PCs are incomparably more suitable for extensive numerical calculations than, for example, the first computers which were available in the early days of the American nuclear weapons program.

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107 To what extent conventional explosions are to be measured and checked to ensure that they are not nuclear explosions was also a theme in the negotiations for the CTBT. Due to the large number of explosions taking place every day, systematic recording was rejected. The yield here taken into account was vastly above that which would be used in hydrodynamic tests.

108 The multiplication of neutrons is calculated with the use of core physics theories, the temperature distribution and dissipation with the aid of theories from the field of astrophysics, and the implosion and expansion of the plasma by means of hydrodynamic theories.

109 These include especially cross sections for nuclear reactors, opacities and equations of state.

Although details of the calculation for nuclear weapon ignition cannot be found in published literature, here too, there are related fields of non-military science, which a proliferator could exploit, and which would enable him to develop a theoretical model of a nuclear weapon. These fields include especially nuclear physics, astrophysics, i.e., the physics of the interiors of fixed stars, high-energy plasma physics (for example, inertial confinement fusion (ICF)), shock wave physics, and fluid mechanics). The starting point for the theoretical work, i.e. the fundamental principle, has long since been published.[110]

A beginner would have several options to work out the theoretical background for his nuclear weapons program. Which one he chooses would depend on the degree of his scientific – technical development. He would initially attempt to obtain the commitment of scientists from related non-military areas for this work. He will start by recruiting people of his own nationality, and will then, if necessary, with their help be able to recruit additional foreign colleagues. He would probably minimise the number of foreign employees in order to reduce the risk of detection. It is probable that these experts will have studied or worked abroad and co-operated and communicated with foreign colleagues from time to time. For this reason, it can be conspicuous if several scientists qualified in the fields specified above withdraw from their international scientific communities. In the context of other proliferation activities, this could be evaluated as a suspicious indication. Possible additional activities include specific espionage and attempts to recruit scientists from former nuclear weapon complexes. Verification would have the task of increasing the detection probability of these operations, and of putting individual observations into context. The larger and more advanced the scientific infrastructure of a state is, the less obvious such suspicious indications become. Methods include the observation of international scientific communities and secret service methods. Last but not least, any attempt to recruit a scientist runs the risk that he will inform a foreign secret service or the verification authority (cf. section 3.3.6).

3.3.5 Nuclear Testing

In principle, a simple nuclear weapon can be developed without any nuclear tests. The R&D methods specified in section 3.3.3 Ignition Techniques, e. g. hydrodynamic testing, suffice. A beginner is not interested, at least not initially, in an accurate measurement of the yield or of the physical parameters of the explosion. But there are, nevertheless, two reasons for nuclear tests: a state could be interested in further developing an already existing capacity, for example, to bridge the gap in the direction of hydrogen bombs, which is impossible without a few nuclear tests[111], and he may be politically interested in demonstrating his capabilities to the world. The former assumes that previous activities have not been detected.

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110 Robert Serber, The Los Alamos Primer, Berkeley (University of California Press), 1992.

111 Op. cit. (fn 76).

The task of verification is to detect and identify a nuclear test. This is accomplished by the verification of the CTBT, for which a department is currently being established in Vienna.[112]

Furthermore, in a nuclear weapon free world, even the preparation for a test must be detected in the early stages. NTM, and satellite pictures in particular, are suitable for this.[113] In the long term, as many of the methods which are today still under the direction of NTM ought to be internationally organised (cf. section 5.2 Organisational Form of the Verification System).

3.3.6 Decision-making Procedures, Infrastructure and Logistics

In every nuclear weapon program, a scientific, technical and logistic infrastructure has to be established. Initially this involves the recruiting and training of specially qualified personnel and the development of a research and production complex including buildings, entrances, catering, technical equipment, workshops, maintenance, recruiting department, acquisition department, housing, management, administration, co-ordination of external activities and much more. All these activities and facilities must be protected from verification measures and the risks of detection. The American Manhattan Program, for example, was hidden in the remote mountain village of Los Alamos.[114]

The staff of over one thousand and their families had to comply with extremely strict secrecy terms. Even the postal address consisted solely of a PO box 30 km away in Santa Fe. External employees and supplementary staff were, with a few exceptions, left in the dark as to the purpose of the enterprise. Similar extreme secrecy measures were in force in all other nuclear weapons programs. The bigger a complex grows, the greater is the probability of detection. In those days, the most likely detection mechanisms were espionage and treason.

It is to be assumed that a state which wishes to acquire nuclear weapons secretly in a nuclear weapon free world is likely to be undemocratic and have a pronounced espionage and intimidation apparatus in place which is useful to it in terms of internal disciplining.[115] It can be assumed that the transparency of political decisions is considerably underdeveloped. In contrast, decision-making processes in a democracy involve more protagonists, and it would be hardly possible for a small group to establish a hierarchically-organised project that requires massive resources, without this becoming known in some

112 Joachim Schulze, Atomteststopp-Verifikation I: Struktur des Verifikationssystems, Spektrum der Wissenschaft, Juli 1997, p. 94.

113 In this way, e.g. in December 1995, Indian test preparations were detected with the aid of commercial satellites: Vipin Gupta, Frank Pabian, Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert – A CTB Verification Exercise Using Commercial Satellite Imagery, Science & Global Security, vol. 6, no. 2, 1997, .pp. 101-188.

114 Richard Rhodes, The Making of the Atomic Bomb, New York 1986.

115 Hair-raising details of the intimidation methods used by Saddam Hussein have recently been reported by a turncoat: Khidir Hamza, Inside Saddam's secret nuclear program, Bulletin of the Atomic Scientists, September/October 1998, p. 26.

way. It could be objected that the Manhattan Project also took place in a democracy. However, there is one crucial difference: those involved considered their work to be necessary and legitimate, and perceived it as a contribution to the rescue of democracy. A nuclear weapons program in a nuclear weapon free world, however, would be a breach of international law, a fact which, in a democracy, most participants would be aware of, and which would be a contradiction in terms of their sense of injustice (cf. section 3.3.8 Secrecy and Creation of legends).

To build up an infrastructure and the logistics for his nuclear weapons program, a beginner would, in principle, proceed as follows:

1. **Decision-making phase:** In the first phase, the political decision for a nuclear weapons program is taken. In this connection, there are many stages. Examples of the different levels are: - a study on the exploration of the technical possibilities – the provision of technological possibilities, which keeps an option open, - the manufacture of a few single warheads or – the manufacture of a strategically important arsenal. A decision-making process can drag on for years and advance from level to level. It is also possible that the maximum level, the quickest possible building-up of an arsenal, is planned from the outset.
2. **Preliminary studies:** The proliferator will first conduct preliminary studies, including initial planning, further recruitment and logistics, with a few scientists and actors whose loyalty he has tested in advance. His secret service and domestic espionage authorities will be involved from the beginning in order to provide maximum security from detection.
3. **Infrastructure:** In the next phase locations will be selected and the infrastructure constructed. In this respect it is probable that existing facilities will be converted and used, inasmuch as they are available. Now, at the latest, other specialist and additional unqualified personnel must be employed, apart from the academics. It will not be possible to leave all of these people in the dark as to the genuine purpose of the facilities.

These plans can only be discovered by chance, i.e. by turncoats and secret service methods. The probability of detection increases in line with the progress of the project.

3.3.7 Acquisition Activities[116]

In order to build up its production industry, the proliferator needs technologies, components, tools, materials, technical skills, people in authority, training and consultancy service. The less industrialised the state is, the greater the dependence on foreign help will be. If he gains no access to a technology, he will try to acquire appropriate production technology, and if this is not successful, he will procure the production technology for the production technology. One example is HEU. It is produced by means of, for example

116 Harald Müller/Matthias Dembinski/Alexander Kelle/Annette Schaper, From Black Sheep to White Angel? – The New German Export Control Policy, Frankfurt (PRIF Report no. 32), January 1994; cf. also section 4.2.3..

centrifuges. For the production of the centrifuges, machine tools, storage sites, balancing machines and many other things are required. The further down this chain is tracked, the more pronounced the dual-use character becomes. Technologies clearly intended for use in nuclear weapons production are on export check-lists, whereas tools and components almost always have several uses. The transfer of knowledge and the help of experts also play an important role.

Typical acquisition activities could be observed in the case of Iraqi proliferation. There are legal and illegal strategies. This includes the acquisition of goods or components which were not listed, tools for their own production, the use of middlemen, dummy corporations, transit through countries with legal loopholes and weak implementation, false declarations of whereabouts, smuggling, exploitation of diplomatic status, industrial espionage, on-site consulting of foreign experts and bribery of such experts.

Lessons have been learned from the experience in Iraq which have lead to the comprehensive reform of export controls in many industrialised countries.[117] The aim of these reforms is primarily to prevent these exports.[118] Another important function is the early detection of acquisition activities. How quickly suspicions are aroused on the basis of acquisition activities depends largely on national export control systems and the level of international co-operation and transparency. For this reason, there are now international efforts being made to set up databases on both a national and international level in which all data regarding suspicious operations and transfer of technology is to be collected.[119] In addition to data from export control authorities, data from customs authorities, police forces and secret services also plays an important role. The IAEA will also set up a database of this kind which will collect data from member countries on the import and export of sensitive goods[120] and with the aid of which country profiles are to be compiled.[121] Transferred goods can only be tracked down if all countries participate in the compilation of information, especially nuclear weapons states, or, in a nuclear weapon free world, former nuclear weapon states.[122] In a nuclear weapon free world, the world-wide

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117 H. Müller (ed.), Nuclear Export Controls in Europe, Brussels 1995; op.cit. (fn 116).

118 Above all by means of stricter obligations with regard to the application for licences, e.g., also when the mere suspicion of intended use in an acquisition program for weapons of mass destruction exists, even when the goods transferred are not on any lists, by building up the control authorities, by extending criminal offences, by determining responsibilities or by means of deterrence through higher punishments.

119 E.g. at the Bundesausfuhramt (Federal Export Authority) (BAFA).

120 Infcirc/540 contains a list of these goods: Annex II: List of Specified Equipment and Non-Nuclear Material for the Reporting of Exports and Imports According to Article 2.a.(IX).

121 Richard Hooper, The System of Strengthened Safeguards, IAEA Bulletin 39/4, December 1997, p. 26. To date, nothing is known about the exact concepts and methods of these country profiles.

122 This was a point of dispute during the S3 negotiations, since the nuclear weapons states at first hesitated to apply these measures to themselves. They have now given statements specifying which measures should apply to them, although, the statements from Russia and China are still unsatisfactory. French declaration: *Measures that France Intends to Apply for the Implementation of the 93+2 Programme,* 13 May 1997 (unofficial English translation from French); British declaration: *Implementation in the UK of Measures Provided for in the Programme 93+2 Model Protocol*, 13 May 1997; Chinese declaration: *Statement by China on its Contribution to the Implementation of "Programme 93+2"*, 15 May 1997

monitoring of the transfer of technology and acquisition activities would have to be systematically implemented.

3.3.8 Secrecy and Creation of Legends

One crucial interest of a proliferator is secrecy, which is threatened by international safeguards, foreign secret services and turncoats. For this reason, all secret nuclear weapons programs will contain systematic planning designed to deal with this threat. Part of this will take the shape of counter espionage with its characteristic methods. This includes the meticulous selection and checking of staff. Furthermore, social and psychological methods such as indoctrination, intimidation, rewards and honours are applied in order to guarantee the reliability of employees and to prevent treason.

Another element would be the systematic analysis of existing verification measures and safeguards and the consistent creation of a legend to conceal the real nature of the activities. This legend would largely be of a technical nature. In this way, it must for example be explained how the composition of radioactive samples has originated. The North Korean violation of the NPT was uncovered not least by inconsistencies between analysis results and North Korean explanations. Institutions such as existing non-military research institutes, non-military nuclear energy, conventional military R&D and industrial facilities all provide potential camouflage (see previous sections). In all cases, technical alterations and extensions are always required, and personnel will be employed who must not be informed of the true purpose. Secrecy and security provisions could be justified with conventional military research and security measures within the nuclear industry. An important element in the Iraqi program was the systematic analysis of the IAEA safeguards and the identification of loopholes in existence at the time. The creation of a legend was also systematically conducted and trained.[123]

The legends must be co-ordinated between all participants and the employees must be trained in such a way that they too believe as much of it as possible. Practice in dealing with inspectors are one probable method. In certain aspects, the fact that key employees will become aware that they are violating national legislation will be unavoidable. This legislation will exist in a nuclear weapon free world because states will be committed to its implementation. In a democracy, this violation requires criminal energy. In non-democratic states, a corresponding sense of injustice could not be expected to the same degree, and typical social and psychological methods could be more easily applied to persuade also those people to participate who would lack any mentality of criminal energy in a democracy with tradition.[124]

(translation from Chinese), Russian declaration: *Statement by the Delegation of the Russian Federation at the Special Session of the IAEA Board of Governors*, 15 May 1997 (unofficial translation from Russian).

123 Op. cit. (fn 115).

124 As an illustration of this argument, we refer to the social mechanisms which led to participation in institutions such as the Stasi in the former GDR. These would be unimaginable in a country with a democratic tradition. In a democracy, the originators of a secret nuclear weapons program would have

Another element would probably be plans regarding how to react in the case of international suspicion. Typical scenarios would include denial of access during inspections, as happened in North Korea and Iraq, delaying tactics by means of protracted diplomatic negotiations, in order to allow time for the removal of telltale clues (Iraq).

Again, such plans can only be discovered by chance. The more often observations of this kind are made, the stronger the suspicion becomes. This should then trigger additional, more intrusive verification methods. One instrument for uncovering such legends could be interviews with staff at suspicious plants and establishments. In addition, mechanisms could be implemented which would offer protection to whistle blowers. This protection could range from legal support in conflicts concerning industrial law, to the creation of an international relief fund, and typical secret service methods of hiding fleeing informants. The former is more relevant in democratic states, the latter in states where basic rights are not observed and where a threat to life and limb exists. These measures should, as far as possible, be organised on an international level.[125]

3.4 Summary: How Reliable Can the Early Detection of Secret Nuclear Weapons Programs Be?

The same applies to the early detection of secret nuclear weapons programs as to the verification of disarmament (section 3.2). There are two tasks, namely, verification that declarations are correct and early detection of secret, non-declared activities related to the acquisition of nuclear weapons. Prior to the S3 reform, the IAEA safeguards concentrated on the former task and neglected the latter. The reform introduced many measures which strongly increase the chances of early detection.

The validity of declarations can be verified using a number of technological methods which have been tested and improved over decades. There is no doubt that a theoretically extremely high degree of accuracy can be achieved. It is, however, limited by financial restrictions.

Technical methods for the early detection of secret nuclear weapons programs also exist, for example, long-range measurements of atmospheric radioactivity or measurements from satellites or aeroplanes. However, they are insufficient by themselves, since there are various scenarios in which they would be ineffective. The synergy of many additional measures is necessary, in particular also the involvement of NTM, since this would increase the probability of detection.

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to find people who not only fulfil the very high requirements in terms of scientific and technical capabilities, but who are also devoid of a sense of injustice.

125 The protection of informants and the observation of scientific – technical activities by social groups, e.g. professional associations, could be taken up in a future nuclear weapons convention. See here: Frank Blackaby, Societal Verification, in: Background Papers of the Canberra Commission on the Elimination of Nuclear Weapons, August 1996, p. 264.

The role of satellites must not be underestimated[126]: with their help, changes in landscapes can be monitored, for example, buildings, streets or excavations in the case of the construction of an underground plant. Furthermore, it is possible to detect energy flows, for example in the case of the operation of an enrichment plant or a reactor. Finally, various different emissions can also be analysed which occur, for example, as a result of secret reprocessing or the use of uranium hexafluoride for enrichment. Suspicious plants can also be monitored in order to determine whether an above-average level of activity is taking place, for example, traffic and transportation. Mining of uranium can be detected with the aid of satellites. Satellites also play an important role in the preparation of nuclear tests.

Of crucial importance is the possibility of using all the information in order to establish suspicion, including that from whistle blowers, secret services or from the free press.

If all the methods of verification mentioned in the previous sections were applied, an undiscovered program leading to the construction of several warheads would be extremely improbable.

Which measures would be how important in the synergy depends on a number of different features: in this respect, it is important to distinguish between beginners and former nuclear weapon states where documents, experts and materials could still exist, which would make certain developmental work superfluous. One important difference is the difficulty of recording initial inventories of former nuclear powers in comparison with all other states, i.e., of checking whether declarations were correct and complete from the outset, as described in O. The reason for this is the late implementation and the complexity of the task. The illegal acquisition scenarios would, however, be the same as in non-nuclear weapons states. If the declarations given in the disarmament phase were correct, and sufficient transparency had been gained at the time of their recording, then a later government will find no more undeclared stockpiles.

Another distinguishing feature is the degree of development in the nuclear industry. The bigger the industry is, the more expensive is the verification. This is already the case today. All states with a nuclear industry apart from NWS and India, Pakistan and Israel are subject to comprehensive IAEA safeguards. A purely mathematical adjustment to the size of this industry has in the past led to the situation where the majority of activities in terms of routine inspections were devoted to only a few countries such as Germany, Japan and Canada. In Iraq, however, inspections took place too infrequently. The reforms therefore had the aim of not only adjusting the scope of activities to the nuclear industry, but also of more strongly taking the already grown level of trust between states into consideration.

Other distinguishing features are this trust and the criteria listed on p. 29. It will have to be accepted that there will always be countries in which not all of these conditions are fulfilled. On the contrary, it is probable that secret nuclear weapons programs will take

126 Wolfgang Fischer/Wolf-Dieter Lauppe/Bernd Richter/Gotthard Stein/Bhupendra Jasani, The Role of Satellites and Remote Data Transmission in a Future Safeguards Regime, in Proceedings of the Symposium on International Nuclear Safeguards, vol. I (Vienna: International Atomic Energy Agency, March 14-18, 1994), p. 411; Space Applications Institute – Advanced Techniques, EC-Joint Research Centre, Minutes of the Informal Meeting on the Use of Remote Sensing Data in Support to Non-Proliferation, Ispra, Italy, 28 May, 1997.

place in undemocratic and less transparent countries such as, for example Iraq, North Korea or South Africa prior to its fundamental change. It is precisely in such countries that early detection must be effective. The following examples are intended to examine the historical experiences with these examples with regard to the question how effective the verification was and whether the programs would have been detected earlier had better methods been available.

4 Three Examples and Some Lessons to Be Learned

There are a few historical cases of nuclear weapons programs which illustrate the typical approaches adopted by proliferators and display the possible limitations of verification. In the following, three examples are analysed in detail. These examples include the nuclear programs of Iraq, North Korea and South Africa. In the case of South Africa, suspicion had existed for some time, but could not be confirmed since it was not a member of the NPT and did not allow comprehensive inspections. The case of South Africa is also of interest, because a subsequent verification took place here, verifying that nuclear disarmament had been achieved. In the Iraqi case, verification also took place to establish whether a nuclear weapons program had been reversed. This case was characterised by, on the one hand, the extreme rights of access for the inspectors, and on the other hand, (in stark contrast to the verification of disarmament in South Africa) the total lack of co-operation on the part of the Iraqis. In North Korea, too, co-operation was lacking, but there was also a lack of possibilities for forcing access to suspicious plants. It was nevertheless possible to uncover a violation of the NPT.

All three examples have in common that the protagonists developed secrecy strategies and that co-operation and transparency were lacking while the programs were being carried out. The key issue is whether despite this lack of co-operation, early detection would have been possible. Here it is necessary to examine how the activities were discovered, and how and with which methods it would have been possible to track them down earlier. Particularly inspections, secret services and international monitoring of acquisition activities play an important role here.

4.1 South Africa: Nuclear Armament and Disarmament[127]

4.1.1 When and How Were the Activities Discovered?

The first suspicious indication was South Africa's refusal to join the NPT and subject all its nuclear plants to IAEA safeguards. The CIA had a concrete suspicion that South Africa was operating a secret nuclear weapon program as early as the mid seventies.[128] This suspicion was largely based on South Africa's efforts to establish its own capacity for HEU production. Its intentions became clear in 1977 at the latest when the Soviet secret service, using surveillance satellites, discovered preparations for a South African nuclear test. The question now was no longer whether South Africa was working on a nuclear weapons option, but how advanced this was. In a CIA report of 1984, it was stated that "South Africa had got together enough HEU for two to four warheads [...] depending on which design they want to use."[129] "Proof of significant nuclear weapon capability" was "considerable and compelling"[130] Satellite pictures provided an important means of clarification. In addition, there were "massive efforts on the part of the secret service community to confirm the occurrence of a nuclear explosion by means other than satellite surveillance"132s a result of satellite surveillance, it was suspected in 1979 that a nuclear test had taken place in the South Atlantic. Whether this was really the case, and whether South Africa and / or Israel were involved, is still a matter of dispute.

Several plants were subjected to IAEA safeguards, but since these were not full-scope safeguards and, most importantly, did not take place in the uranium-enrichment plants, existing suspicions could not be further confirmed by these means.

In 1991, as a result of South Africa's joining the NPT in the same year, the IAEA began with the implementation of full-scope safeguards and the recording of initial inventories (see section 4.1.4). Shortly after the commencement of inspections, the suspicion arose in the IAEA that a secret program must have been carried out. The reason was the large quantities of - declared – metallic HEU, since the only possible use for such quantities of this type of material is the production of nuclear weapons. The IAEA kept its suspicions to itself since its task is to safeguard the present and future non-military use of the material, and not to clarify past uses.

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127 Statement by South African President De Klerk to Parliament on March 24, 1993 regarding South Africa's construction of nuclear weapons; Waldo Stumpf, South Africa's Limited Nuclear Deterrent Programme and the Dismantling Thereof Prior to South Africa's Accession to the Nuclear Non-Proliferation Treaty, a lecture, South African Embassy, Washington, D.C., 23. July 1993; David Albright/Mark Hibbs, South Africa: The ANC and the Atom Bomb, Bulletin of the Atomic Scientists, April 1993, p. 32; Zachary S. Davis, South Africa's Nuclear Status, CRS Issue Brief, Updated May 25, 1993; Zondi Masiza, A Chronology of South Africa's Nuclear Program, The Nonproliferation Review, volume 1, no. 1, Autumn 1993; David Albright, South Africa's Secret Nuclear Weapons, Report, Institute for Science and International Security, May 1994; Frank V. Pabian, South Africa's Nuclear Weapon Program: Lessons for U.S. Nonproliferation Policy, The Nonproliferation Review, volume 3, no. 1, Autumn 1995, p. 1.

128 Davis, ibid..

129 Director of Central Intelligence, Trends in South Africa's Nuclear Security Policies and Programs, Report, 4. October 1984, Case Number F-1992-00809, published in extracts on 27. April 1997; here p.1.

130 CIA 1984, ibid.

The world was given confirmation when, in March 1993, President de Klerk announced that South Africa had built up and again disarmed a small nuclear arsenal. Seven warheads had been planned according to the gun assembly principle, six of which had been completed and dismantled again. Materials, plants, documentation and tools had been fully conversed or destroyed. The complete picture emerged following publications by South African authorities. The scope of the program had been small, it included the construction of two warheads per year. It ran from 1960 to 1989, the most intensive phase of which having begun in 1970.

4.1.2 Could the Activities Have Been Detected Earlier?

South Africa kept its program extremely secret. Only a few members of the government had been informed. A total of over 1000 staff had been employed, and their reliability was thoroughly checked. They were almost all given only partial information, and only five to ten had a complete overview.131 For the same reason of secrecy, a maximum degree of self-sufficiency was aimed at in order to minimise the dependency on foreign acquisitions. This goal was in fact accomplished, despite the embargo.

The technical design that South Africa had selected was the most simple possible, the gun assembly design. It did not even possess a neutron source, which would have posed a certain technical hurdle.[132] Due to these low technical requirements, the expenditure, number of employees and other informed persons, and the acquisition measures had all been kept to a minimum. As late as 1984, the CIA still did not know which design the South African program was using (see above). Although the secret services seem to have made considerable efforts, they were not able to gain this information.

However, suspicions were aroused early, by the mid seventies at the latest, i.e. only a few years after commencement of the more intensive acquisition phase. It was also known that South Africa was concentrating its efforts on the acquisition of HEU. South Africa had made no secret of the kind of enrichment technology used since it was also used for non-military purposes.[133] Further clarification was not possible since South Africa had no further transparency obligations except for a few safeguards in less relevant plants. If it had been subject to full-scope safeguards at that time, illegal diversion of the quantities required for the gun assembly design would definitely have been discovered. Today, following the implementation of S3, an undeclared enrichment plant would also have been discovered, especially since the suspicion already existed. In the meantime, the IAEA are allowed to use the latter as a reason for special inspections.

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131 Stumpf, op. cit. (fn 127).

132 Stumpf, in the discussion on his lecture 1993 op. cit. (fn 127).

133 See e.g. the detailed description of the South African Helikon-Processes in Krass et al 1983, op. cit. (fn 79).

4.1.3 Acquisition Activities as a suspicious indication

Transfer of technology also took place in the South African program. This was mainly used to gain a technical infrastructure as a precondition for later self-sufficiency and independence. One of the most important elements was training abroad and the study of open sources, including declassified documents from the Manhattan Project. South African nuclear physicists were trained as part of "Atoms for Peace" in the U.S.. In the fifties and sixties, the South African non-military nuclear program received massive aid predominantly from the USA and Europe, for example a research reactor, and for this 100 kg HEU from the USA and reactor technology from Germany, Switzerland and the USA. An incident has now become known in which South Africa managed to illegally recruit 25 American nuclear technicians.

The South African enrichment technology, the so called "Helikon process" is related to the German jet nozzle process. Some sources assume that an intensive transfer of technology took place here. The technical characteristics are, however, very different, and it is now generally assumed that there had been little German influence in this matter beyond the study of published sources.134 It has been proved that an Israeli – South African technology transfer took place regarding other military technologies, but to what extent the nuclear weapon program was involved is still a matter of dispute. An argument against it is the fact that, contrary to the South African program, the Israeli program is based on plutonium, and thus required a completely different ignition technology. A remarkable event was the purchase of an flash radiography machine from Sweden in 1986 which was designed in the fifties for the Swedish nuclear weapons program of that time.135 Although this equipment is also employed in the area of conventional military research and development and also in the non-military area, it is subject to export restrictions, and acquisition attempts represent a suspicious indication. More transfer of technology took place in the case of dual-use goods, for example, tools. All tools later found were, however, technically relatively simple and were not explicitly listed on export check-lists.

The South African Government decided, despite all openness and transparency, not to name its suppliers and partners, presumably in order to spare them any diplomatic complications.

The majority of the transfers of technology took place at a time when export controls were considerably less developed than they are today. Stricter controls were first implemented with the introduction of the Zangger list on key nuclear technologies in 1974.136 It was not until 1992, and the experience gained from the attempted proliferation in Iraq, that this was reformed and a "dual-use appendix" added to the list.137

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134 Albright, op. cit. (fn 127).

135 CNS Database of the Monterey Institute of International Studies (Doc. 605).

136 IAEA, INFCIRC/207.

137 IAEA, INFCIRC 254, Part II.

The South African strategy of first establishing a scientific – technological infrastructure with the aid of transfer of technology and then building up a concrete program as far as possible without dependency on external aid contributed to a reduction of the detection probability. The international surveillance of technology transfer is now deliberately used as an early-warning instrument. Furthermore, legal exports in the nuclear field occur less and less without comprehensive safeguards. On the other hand, in many countries nuclear industrialisation is now considerably more advanced, so that the number of countries which would be heavily reliant on technology transfer is decreasing.

4.1.4 Verification of Nuclear Disarmament

The South African example is not only interesting for studying the possibilities of detecting a proliferator, but also for the verification of nuclear disarmament. South Africa is the only country in which comprehensive nuclear disarmament has been verified.

The first task of the IAEA was to check the validity of the inventory declarations. 138 There were special problems here: the enrichment plants were not designed for safeguards, and the IAEA had no experience of the particular enrichment method used in South Africa. It was therefore necessary to develop the required technical knowledge first. For this purpose, joint seminars were held for South African specialists and IAEA inspectors. At first there was a significant discrepancy between the declared amounts and those recorded independently by the inspectors. Consequently, the production history of the plants was reconstructed in more detail. Thousands of daily operating protocols and records giving precise data on the daily state of the plants were then consulted, and the daily production rate was calculated. In this way, consistency was actually achieved.[139]

A crucial factor in this success was the co-operation of the South Africans and the extreme transparency which far exceeded the South African obligations. It was in South Africa's own interest to achieve credibility.[140]

The other task of the IAEA was to check the completeness of the South African declarations. Once the existence of the former nuclear weapon program was made known, the objectives were extended: the inspectors were now not only to ensure that all material was given back and that the information on the production history was complete, but also to ensure that all non-nuclear components were destroyed, all plants converted or closed down and the test area destroyed. To this end, the team was reinforced by nuclear weapon

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138 Adolf von Baeckmann/Garry Dillon/Demetrius Perricos, Nuclear Verification in South Africa, IAEA Bulletin, volume 37, no. 1, March 1995; Garry Dillon/Demetrius Perricos, Verification of Completeness and Correctness of Inventory, in Proceedings of the Symposium on International Nuclear Safeguards, vol. II (Vienna: International Atomic Energy Agency, March 14-18, 1994), p. 231.

139 The reason for this difficulty is that the isotope U-235 is not only contained in the enriched part of the uranium flow, but also in the depleted part, the quantity of which is considerably greater. If the proportion of U-235 is calculated with even a small error, the total error can quickly rise to a significant amount.

140 Stumpf, op. cit. (fn 127).

specialists. It also had the task of discussing future strategies to ensure the irreversibility of nuclear disarmament with the South Africans.

The inspectors sifted through official documents, records and protocols and carried out interviews with employees. An important basis was provided by South Africa's policy of full transparency. As a result, it could be declared that there was no circumstantial evidence for and no suspicion of any other, non-declared plants, although the estimations were "not free of uncertainties". The IAEA intends to accept South Africa's future invitation "to unrestricted access to all locations connected with the nuclear weapon program, and to all other locations" also in the future.

Although total certainty can never be achieved, it is by now generally accepted that the disarmament process was complete. Even with the application of more thorough technical methods, it would not have been possible to achieve total certainty. The uncompromising change of the entire South African policy, which contributed to the credibility of the nuclear disarmament and the gaining of international trust, was of crucial importance,. The policy of transparency was an important element here. Nevertheless, without the verification procedure, the new policy alone would not have been sufficient.

There are, however, limitations to the transferability of this example to the much more advanced task of verification of the disarmament of one of the five established NWS: the history and scope of the nuclear programs of NWS are considerably more complex, so that discrepancies must be expected in the reconstruction of the production history. It is unlikely that these can all be so easily solved as in the case of South Africa, especially if verification were only to be used following the completion of disarmament. The disarmament process itself will therefore not be able to be excluded from this process. The most important issue is how the expected discrepancies are dealt with. In this instance, the bond of trust established in the meantime will be a crucial factor.

4.2 Iraq: Attempted Violation of the NPT

4.2.1 When and How Were the Activities Discovered?

The extent of the Iraqi nuclear weapons program was not discovered until spring and summer of 1991 as a result of inspections by the UN Special Commission (UNSCOM).[141] There had already been several suspicious indications previously. At the end of the 1970s, it was suspected that Iraq was planning plutonium production. This suspicion was triggered mainly by the size of a research reactor (Osiraq) and a few cases of transfers of

141 D. Albright/M. Hibbs, Iraq's Bomb: Blueprints and Artefacts, The Bulletin of the Atomic Scientists, January/February 1992, pp. 30-30; David Albright/Mark Hibbs, Iraq's Quest for the Nuclear Grail: What Can We Learn?, Arms Control Today, July/August 1992, pp. 3-11; D. Albright/R. Kelley, Has Iraq Come Clean at Last?, The Bulletin of the Atomic Scientists, November/December 1995, pp. 53-64. H. Müller/A. Schaper, "Besorgnis oder Erleichterung? Was wir heute über das irakische Kernwaffenprogramm wissen", Frankfurt (Friedensforschung Aktuell, no. 32), June 1992; Leslie Thorne, IAEA Nuclear Inspections in Iraq, IAEA Bulletin; vol. 34, no. 1, 1992, p. 16; Fainberg 1993, op. cit. (fn 77); Hamza 1998, op. cit. (fn 115).

technology.[142] In 1989, the secret services expressed their suspicion of renewed efforts.[143] Since 1987, there have been indications of acquisition activities, which hinted at an interest in centrifugal enrichment and nuclear weapons.[144]

Iraq was also in the possession of 36 kg of HEU enriched to between 80 and 93%, and in part slightly exposed to radiation. This was subject to IAEA safeguards, but the activities of the IAEA were limited to half-yearly routine inspections in declared plants only. Iraq had intended to purloin this material in a crash program in 1991, and build a single nuclear weapon within a few months. According to the last inspection in November 1990, this material was still intact, with the result that Iraq was certified as complying with NPT obligations. At the same time there were several suspicious indications that Iraq was attempting to acquire centrifuge technology. However, this did not lead to any intrusive consequences, although there were concrete indications on technologies and locations, acquired mainly by the secret services.[145] The IAEA was not able to use this kind of information at that time although, theoretically, it did have the right to carry out special inspections. But even the secret service assessments of the situation underestimated the extent of Iraqi activities. If Saddam had not occupied Kuwait, the program would have continued without hindrance since there had been no other diplomatic consequences.

After the Gulf war, the UN resolution 687 instigated the use of special inspections by UNSCOM. The IAEA was commissioned with carrying out the nuclear inspections. Due to the Iraqi status as an occupied country, the inspectors have unparalleled powers and rights of access which far exceed those of the IAEA in other countries. [146] In Spring, it became clear that Iraq possessed a significantly more extensive program than had formerly been supposed. It was concentrated on the production of HEU (cf. section 3.3.1), and except for plutonium production, also contained all the other elements specified above (sections 3.3.5, 3.3.3 and 3.3.4). At times, it employed several thousand people, including an estimated several hundred scientists. The previously known attempts to gain access to centrifuge techniques were confirmed, and its astounding extent was clarified in more detail. But what came as a surprise was the fact that Iraq had also concentrated on enrichment technologies in large-scale projects using calutrons (see appendix: A comparison of enrichment processes). The first important clues in this respect were provided by an Iraqi turncoat and the analysis of radioactive traces on the clothing of hostages, whom Iraq had housed close to the plant. The clarification work was characterised by resistance on the part of the Iraqis who were totally uncooperative and harassed and threatened the inspectors. They only admitted to information which was either already long proved, or the

142 In 1981, the Osiraq reactor was destroyed in an Israeli bomb attack.

143 Leonard S. Spector, Nuclear Ambitions.The Spread of Nuclear Weapons 1989-90, Boulder/San Francisco/Oxford (Westview Press), 1990, pp. 186-202.

144 CNS Database of the Monterey Institute of International Studies; Spector, op. cit. (fn 143).

145 Zachary S. Davis, Iraq and Nuclear Weapons: Continuing Issues, CRS Issue Brief; July 15, updated, 1993.

146 Cf. the UNSCOM analysis in: Katja Frank, Antreiber der Abrüstung oder Spielbälle der Mächte? Frankfurt/m. (HSFK-Report no.8), 1998.

discovery of which was unavoidable anyway.[147] On the other hand, the rights and activities of the inspectors were so extremely intrusive that it was finally possible to convey the firm conviction that the investigation of the nuclear program could be satisfactorily concluded.[148]

The discovery of secret activities was crucially dependent on information from secret services and other sources, which some states (mainly the USA) had provided. This included satellite pictures of activities with calutrons and the evaluation of photographic material by experienced nuclear weapon specialists. Clues were also provided by statements made by suppliers and export control authorities, which led to an analysis of technology transfer. In this way, the IAEA collected information from over 182 companies in 28 countries. Turncoats also played an important role. [149] It was often possible to identify locations and procedures for more detailed examinations on the basis of their evidence alone. In addition, expensive measuring equipment was used, for example, to analyse radioactive radiation from environmental samples.[150]

4.2.2 Could the Activities Have Been Detected Earlier?

Prior to the Gulf war, the extent of the nuclear weapons program was greatly underestimated and no consequences were drawn from occasional clues and warnings.[151] The IAEA had even given the all-clear.[152] This was mainly due to the verification task at that time, which, prior to the S3 reform, was limited to the discovery of illegal diversion from declared non-military production and did not take into account parallel, undeclared production. Members were, furthermore, only obliged to declare their plants once they were loaded with nuclear material, but not during the construction or even development phases. This is also why the development of Iraqi calutrons remained undetected for so long. After all, the extent of inspections in a country was determined solely according to

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147 In this way, shortly after Hussein Kamel, Saddam Hussein’s son-in-law, defected to Jordan in 1995, inspectors were informed of the plan for a crash program. According to the information provided, in August 1990, work had been started on the building of a nuclear weapon using HEU already available in Iraq. This was intended to be completed in the spring of 1991. See Albright/Kelley 1995, op. cit. (fn 141).

148 This does not apply to the other Iraqi weapons programs which were also to be clarified by UNSCOM.

149 For example a high ranking scientist, Khidhir Abdul Abas Hamza, who defected from Iraq in 1994 op. cit. (fn 115).

150 D. L. Donohue/R. Zeisler, Behind the Scenes: Scientific Analysis of Samples from Nuclear Inspections in Iraq, IAEA Bulletin; vol. 34, no. 1, 1992, p. 25.

151 According to the opinion of many specialists, by around 1996, Iraq would have had built up a small arsenal, had the invasion of Kuwait not led to the discovery of Iraq’s program by means of the verifications measures of the IAEA and UNSCOM.

152 David Kay, The IAEA: How Can it be Strengthened?, in: Nuclear Proliferation after the Cold War, Michel Reiss/Robert S. Litwak (eds.), Woodrow Wilson Center Press, 1994, pp. 309-333; see also: D. Kay, Detecting Cheating on Non-Proliferation Regimes: Lessons From the Iraqi Experience, Paper for the Aspen Strategy Group Meeting, 10-15 August 1996

the scope of its nuclear industry, but not on the basis of the various suspicious indications.[153]

The possibilities and activities afterwards are in stark contrast to this.[154] There was an unequivocal aim to uncover all past nuclear-related activities. UNSCOM was able to operate without diplomatic complications since it was directly answerable to the Security Council only. Iraq made a number of mistakes since many of its fraudulent intentions and lies were transparent; and ultimately, UNSCOM had access to every conceivable technology, location and data.

If the IAEA had already carried out special inspections in 1990 on the basis of the information supplied by secret services and other sources, suspicions would have been confirmed and specified much earlier. The construction of a centrifugal enrichment plant would have been discovered. With the current capability of the S3, this would have meant the opportunity for additional, more precise inspections and inquiries. The compilation of information from various sources, in particular from secret services, from knowledge about acquisition activities on international markets and from the results of the special inspections would have resulted in a clearer picture much earlier.[155] It can be assumed that even in this case Iraq would have done its best to lie and camouflage. If it had nevertheless succeeded in keeping the production of centrifuges and calutrons secret, further suspicious indications would have emerged as soon as the enrichment plant was running since such plants produce heat which can be detected by satellites. If the S3 reform had been implemented before the Gulf war, several important suspicious indications would have developed earlier and more precisely. This would have sufficed as trigger for further special inspections, but we would not have achieved the same degree of precision and certainty that we now have thanks to the extreme rights of access possible with UNSCOM.

4.2.3 Acquisition Activities as Suspicious Indication

Iraq was not sufficiently developed to produce all the necessary components and tools itself without external help. For this reason, it constructed an extensive acquisition network which was intended to exploit the loop holes in export controls of industrialised countries.[156] These activities concentrated mainly on enrichment technology, but also on several other components such as electrical detonators. In addition, they carried out extensive work themselves which, however, depending on the level of technical complexity, was limited in range. For example, the domestically produced steel for centrifuges was unsuitable, and imports from Germany and other industrial countries were

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153 cf. the example sketched in section 2.1 (verification of the NPT), p. 4.

154 Kay, Lessons, op. cit. (fn 152).

155 However, mistakes were also made by the secret services: for example, the defector Hamza was turned away in 1994 – an error which was not corrected until a year later, op. cit. (fn 115).

156 David Albright, Mark Hibbs, Iraq's Shop-till-you-drop Nuclear Program, The Bulletin of the Atomic Scientists, April 1992, pp. 25-37.

used instead.[157] The same applies to a variety of other components, in particular the centrifuge technology and the tools for its production, which require high quality and precision. Foreign help was of lesser importance in terms of calutrons, which do not represent high technology and do not require the latter in production. Before the Gulf war, it was actually not suspected that Iraq could try to acquire this technology.

The role played by transfer of expertise and the help of experts should not be underestimated. This applies particularly to the centrifuge project which was essentially dependent on the advice of foreign experts. At the end of the 1980s, leading Iraqi scientists took part in international conferences on subjects closely related to the scientific principles of implosion technology.[158] Given careful observation, this could also have provided a small suspicious indication.

In fact, even before the reforms, which were implemented as a result of the experiences with Iraq, Iraq's activities provided the main causes of the first suspicious indications. For this reason, Iraq attempted to spread its acquisitions as much as possible, and used the full scope of typical strategies.[159]

4.3 North Korea: Attempted Violation of the NPT

4.3.1 When and How Were the Activities Discovered?

The exact time of the discovery of the North Korean nuclear weapons program is hard to determine. The suspicion that the country was attempting to develop nuclear weapons arose as early as the mid 1980s.[160] IAEA inspections between May 1992 and March 1993 reinforced the suspicion that a nuclear weapons program existed. A plant declared as a radiochemical laboratory was in fact a reprocessing plant in construction. The analysis of plutonium samples which North Korea handed over to the IAEA showed that North Korea had made false statements regarding its production history. As the result of a tip-off from the USA, the IAEA stumbled upon two undeclared buildings near Jongbjon which were believed to contain tell-tale nuclear waste. The USA had developed this suspicion on the basis of satellite pictures, i.e. NTM. The analysis of this waste could have led to further conclusions regarding the nuclear activities of North Korea, however, the IAEA were refused an inspection. On 1st April, the Board of Governors of the IAEA declared North Korea's non-compliance with the security agreement, and informed the Security Council of the UN. This did not happen on the grounds of unequivocal evidence of a nuclear weapons program, but because the agency was unable to rule out the existence of such a program with any sufficient degree of certainty. To date, no complete inspection of the nuclear

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157 Important suppliers were Germany, France, Italy, Switzerland, Great Britain and the USA; op. cit. (fn 145).

158 E.g., the Ninth Symposium on Detonation in Portland,; op. cit. (fn 104).

159 cf. section 3.3.7 .

160 Arms Control Reporter, B.9, 15, 17, p. 457.

complex has taken place.[161] Contrary to the Iraqi case, the inspectors were unable to find any written documents on the program, and only rough estimations can be made as to its level of development. However, due to the circumstantial evidence available, it is an undisputed fact that a nuclear weapons program did exist.

4.3.2 Could the Activities Have Been Detected Earlier?

The North Korean nuclear weapons program was discovered due to the combination of on-site inspections and data analysis by the IAEA, as well as information from the intelligence service of a third state. The S3 safeguards reform introduced following the experience with Iraq had already had an impact on the implementation of inspections. The IAEA controls were carried out much more thoroughly, even distrustfully. Due to the more accurate analysis of plutonium samples and on-site measurements there was evidence of the existence of contradictions in the North Korean declarations. North Korea had claimed to have first separated plutonium in 1990, but the analyses showed that such activities had taken place much earlier.[162] However, had the North Koreans told the truth about the time-span of their production history, an important suspicious indication would not have materialised.[163]

The first use of information from intelligence services in the history of the IAEA was of great importance for reinforcing the initial suspicion. They supplied information regarding the presumed location of non-declared, telltale material, and thus facilitated the first concrete demands for special inspections. These demands, although already part of the rights of the agency, were also claimed for the first time.

Even without the use of these new measures, initial suspicions would still have been aroused, because of the false information given by the North Koreans regarding their reprocessing history which would also have been detected with the aid of traditional measures. But it is debatable whether the IAEA would also have carried out such precise on-site measurements at that time.[164] Before the reform however, information from intelligence services would not have been used, and thus, it would not have been so easy to be more precise about the initial suspicion. If, in addition, the North Koreans had made more consistent statements, no substantial, and, above all, no legally usable initial suspicion would have arisen without the use of information from NTM.

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161 The USA has, however, succeeded in bringing the program to a halt by means of a co-operation agreement with North Korea on the peaceful use of nuclear energy.

162 See Matthias Dembinski, Testfall Nordkorea. Die Wirksamkeit des verbesserten IAEA-Safeguardssystems, Stiftung Wissenschaft and Politik, SWP-IP 2849, July 1994, esp. pp. 34-36; and David Albright, North Korean Plutonium Production, Institute for Science and International Security (ISIS), Washington, D.C., June 3, 1994 (updated June 24, 1994); Katja Frank, Das Nordkoreanische Atomwaffenprogramm and das Nichtverbreitungsregime: Regimestabilität unter Streßbedingungen, dissertation in the subject area social sciences at the Johann Wolfgang Goethe University, May 1996.

163 Due to the radioactive decay of various isotopes, the age of samples can be precisely determined. The North Koreans made the mistake of not adjusting to this technical possibility. Samples can, however, give no information on the quantities produced.

164 E.g. by taking samples from used glove containers. See Albright, op. cit. (fn 163).

It is not clear whether the nuclear weapons program could have been identified so rapidly without the use of the new measures. At least the false declarations regarding the reprocessing plants would have been recognised immediately, even prior to the reform. The main obstacle in terms of early detection was initially the lack of adequate authority on the part of the IAEA to actually apply the safeguards.[165] North Korea has been a member of the NPT since 1985. According to the text of the treaty, it was committed to finalising a safeguards agreement with the IAEA within eighteen months after entering the treaty. North Korea did not meet this deadline. It did not sign the agreement until January 1992, with the effect that the first inspections could not be carried out until May of that year. Even state of the art technologies and procedures can have no impact if basic contractual commitments are not complied with. The special inspection has, to date, not been carried out, either. More precise details of the North Korean activities are therefore not known, but it is not the task of a verification agency to enforce inspections.

4.3.3 Acquisition Activities as Suspicious Indication

The foundation stone of the North Korean nuclear program was laid in the 1960s by means of imports from the then USSR, and its initial aim was peaceful utilisation of nuclear energy. A 5-MW reactor was completed in 1986 in domestic production. North Korea did not need to import fuel for this gas-cooled, graphite-moderated reactor since it was operated with natural uranium, and the country had its own resources of uranium and graphite.[166] This meant that the acquisition of enrichment technology was not an issue.

North Korea tried as far as possible to become independent of imports. However, due to an insufficient level of technological development, it was unable to achieve this goal. It obtained parts of its nuclear technology from socialist countries, and it can be assumed that North Korea did not manage entirely without western technology. Some sources conjecture that western companies often used the former GDR and Rumania as a channel for deliveries to North Korea.[167] This data is, however, often imprecise, and its reliability cannot be assured. In contrast, there is more concrete information available on “dual-use“ exports from Federal German companies in the 1980s. The goods were obviously shifted to North Korea via the former GDR or India and Pakistan.[168]

In North Korea too, the transfer of knowledge and assistance from experts played a significant role. North Korean scientists were educated in the area of nuclear physics in the

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165 The IAEA was fully aware of this problem. In September 1991, clearly in view of North Korea and Iraq, the general conference of the IAEA demanded the strengthening of the organisation’s authority in the case of inspections. Comments made by John Jennekens, leader of the safeguards department, a month later were along the same lines: "The problem is that the IAEA has no muscle to enforce the safeguards". See Arms Control Reporter, B.61f, p. 457.

166 See Andrew Mack, Nuclear Proliferation: The Case of North Korea, Australian National University, (August), 1994, p. 13.

167 James Adams: South China Morning Post (Hong Kong), June 17, 1990, p. 7.

168 CNS Database (fn 144) and Joseph S. Bermudez, North Korea’s Programs, in: Jane’s Intelligence Review, (September), 1991, pp. 404-411.

1950s and 1960s in the USSR and China.[169] Once this foundation of knowledge was laid, North Korea carried out its own research, and built up its own team of scientists, engineers and technicians. The capabilities of this team were sufficient to rearm a small research reactor. A larger nuclear reactor was completed in 1986, probably largely without Soviet help. The primitive design of this reactor was equivalent to the state of technology typical of the 1940s and 1950s. All indications suggest that this reactor is a copy of the first British reactor, the Calder Hall Magnox reactor of 1956, which leads to the conclusion that the North Korean engineers had used the declassified design information on this reactor type.[170]

In the mid 1980s, North Korea obtained the know-how to fuse uranium, and possibly also for its enrichment. This information is supposed to have originated in German companies, and made its way illegally to North Korea via Switzerland and Pakistan. However, this information obviously found no application in the military nuclear program, which was based on plutonium.[171]

Finally, according to South Korean press reports, North Korean scientists were allowed to take part in Chinese nuclear tests in the 1960s, although it is not clear, to what extent China allowed their then allies to share its nuclear weapon technology. In addition, the reliability of the source should not be overestimated.[172]

Better export controls would most probably have been able to prevent a major part of the illegal exports. For this, an increased inclusion of “dual-use“ goods as well as better end use controls would have been necessary. On the basis of the information known, however, it has to be assumed that improved controls would only have contributed minimally to the delaying of the North Korean nuclear weapons program or its earlier detection. Those deliveries from Federal German companies (zirconium and special furnaces) were not of great significance for the plutonium-based nuclear weapons program, and the supply of the relevant basic technology from the 1960s was no secret.

5 On the Road to Verification

5.1 Possibilities and Limitations

5.1.1 Two components: NTM and Implemented Verification Methods

There are a great many different kinds of verification methods. They range from objectifiable and potentially automated measurements, to organisational methods, and subjective judgements based on ambiguous suspicious indications. The measures which are

169 Alexandre Y. Mansourov, The Origins, Evolution, and Current Politics of the North Korean Nuclear Program, in: The Nonproliferation Review, vol. 2, no. 3, 1995, pp. 25-38, esp. pp 25ff.

170 CNS Database,; op.cit. (fn 168).

171 Mark Hibbs: “Agencies Trace Some Iraqi Urenco Know-how to Pakistan Re-export“, in: Nucleonics Week, vol. 32, no. 48, (November), 1991, p. 1.

172 Op. cit. (fn 143), pp. 118-140.

discussed in this report include global and local measurements of environmental radioactivity, satellite surveillance on various frequencies, specialised on-site measurements or the sealing of objects and measuring devices, routine and challenge inspections – which can include measuring, surveillance and interviews, the use of verification apparatuses from other treaties, in particular the CTBT,[173] the methods used by national authorities, such as the police force and customs, for the detection of criminal transfer activities, reporting commitments and transparency measures on the part of member states (in a nuclear weapon free world, all states), international monitoring of the transfer of technology and scientific communities, the use of secret service information and random information from turncoats, and, not least, collection, comparison and interpretation of all this information. Extensive coverage, a high detection probability and the possibility of localisation or refutation of initial suspicions can only be assured by means of a synergy of different methods. Each method by itself is not sufficient.

An indispensable element in any verification system is the highest possible degree of probability that activities can be detected, in other words, the use of secret service information and corresponding secret service activities. This applies equally to the verification of the complete destruction of all warheads and to the additional early detection of secret rearmament. As also discussed in the previous sections, secret service measures, turncoats or random discovery by chance for the purposes of detection are important elements for almost all activities such as, for example, the hiding of warheads or the secret recruiting of scientists for a development program.

Although the element of NTM has initially proved controversial in negotiations, it is increasingly becoming a vital part of international treaties, as for example in the CBTB. This element has also been introduced into the S3 by the possibility of using "all information", not least due to the experience in Iraq, whose proliferation attempt would have been uncovered earlier if the IAEA had been able to use and apply this possibility. NTM also played a crucial role in the establishing of suspicion against North Korea. In the case of South Africa, secret service activities alone would did not suffice to confirm a general suspicion. Had more inspections been carried out, the South Africans would not have succeeded in keeping the program secret.

NTM encompass more than just secret services. It is used as a collective term for all activities which are not regulated by an international organisation. This can include the use of satellites or measurements from aircraft. Uranium mining, energy and gas releases caused by the operation of enrichment plants, and nuclear reactors or reprocessing plants can be detected with the aid of satellites.[174] There will always also be satellites which states use only for their own military purposes. The utilisation of pictures from these satellites then counts as NTM. Efforts should, however, be made to organise as many as possible of

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173 Op. cit. (fn 112). Other treaties, such as the Open Skies Treaty, offer verification measures which could be of use in a nuclear-weapon-free world, too.

174 Wolfgang Fischer/Wolf-Dieter Lauppe/Bernd Richter/Gotthard Stein/Bhupendra Jasani, The Role of Satellites and Remote Data Transmission in a Future Safeguards Regime, Proceedings of the Symposium on International Nuclear Safeguards, vol. I (Vienna: International Atomic Energy Agency, March 14-18, 1994), p. 411. See also Panofsky, op. cit. (fn 89).

these activities on an international level. Thus it would be conceivable, although relatively expensive, that a verification authority would operate satellites itself. One variation of this would be the use of commercial satellite pictures and measurements. The opportunities provided by satellite verification depend largely on their technical equipment.

One problem with NTM is the possibility of misuse, which always has been and always will be a cause of conflict during negotiations and in their application. Here too, there are both unjustified and justified accusations (see section 5.2 Organisational Form of the Verification System).

Most methods reach their limits as soon as a state refuses to co-operate and co-operation cannot be enforced. Although the North Korean intentions could be uncovered, a more accurate production history could not be reconstructed since North Korea refuses to allow special inspections of different plants. Iraq is also uncooperative, but in this case, special inspections were enforced and the history of its activities could largely be clarified and reversed.[175] In contrast, the completeness of South Africa's nuclear disarmament could be established with a high degree of credibility. The crucial factor was South Africa's readiness to co-operate, which meant that a high degree of transparency was possible.

In the long term, global co-operation and transparency are the crucial prerequisites for the verification of both nuclear disarmament and a nuclear-weapon-free world. NTM and the collecting of information and data on an international level also function without the co-operation of the states concerned, but, as the example of South Africa shows, they do have their limitations. As soon as suspicion is aroused, verification measures must be used also in the country itself. It must be possible to clear up or clarify a suspicion. In the case of states such as Iraq or South Africa refusing to co-operate, mechanisms must exist to compel compliance. As was the case in North Korea, it must at least be possible to prevent the continuation of a nuclear weapons program for an interim period of time, prior to final clarification.

5.1.2 Secrecy versus Transparency

The principle of maximum transparency is a prerequisite for the acceptance of the verification results. This applies both to disarmament and to further verification of absence of nuclear weapons. Especially where the verification of the dismantling of warheads is concerned, there is the principle problem of the contradiction between the disclosure of technical details and their being kept secret. To make this contradictory connection between secrecy and verification possibilities clear, a few concrete examples are given in the following table. In the first column, several examples of sensitive information are listed, the disclosure of which could be controversial. In the second column, verification activities are given, which would reveal the information. The third column gives the source

175 This only applies to nuclear activities, not in the area of biological or chemical weapons. In August 1998, it became known that the USA had supposedly requested UNSCOM to abstain from certain special inspections. The motive is said to have been the avoidance of military escalation: Barton Gellman, U.S. Repeatedly Blocked UN Inspections in Iraq, IHT, Paris, August 28, 1998.

and the state from which the example is taken. The last column shows how this disclosure is judged by the state, or the point at which no more importance is attached to its secrecy.

Secrecy has several reasons:

1. The disclosure of technical details poses consequent dangers for non-proliferation and could conflict with the commitments of nuclear-weapon states, in the sense of Art. 1 NPT.
2. The level of the technological development of a state should not be revealed to the other side. Here the motive can be to hide technological weaknesses, or an interest in protecting technological superiority.
3. Secrecy traditionally has a special status in the nuclear complexes of nuclear weapon states. The divulgence of technical information is seen as being on a par with the surrender of status, and is often viewed as defeat.

Especially the first two reasons must be taken into account in the construction of verification and transparency measures. The third might become void with time, especially if suitable political measures are put in place. However, continuous resistance from scientific and military circles in nuclear weapons research, development, production and maintenance must be expected over a long period. Clear variations in the degree of secrecy can be observed in all nuclear weapon states, which can largely be explained in terms of such traditions. The highest degree of openness and effort can be observed in the USA. At the end of 1993, as part of the policy of “openness“, the American Department of Energy (DoE) began an initiative aimed at the reform of transparency in government. To this end, various advisory panels investigated the principles on which secrecy and disclosure were based.[176] At the end of June 1998, a new directive on classification came into force incorporating the results of these advisory panels.[177] The aim is to give the public the opportunity for assessments, especially in the areas of environment, accident safety, health and basic science.[178] However, information which, if disclosed, could endanger “national security“ is to remain secret. This classification should be carried out according to comprehensible and transparent rules. Misuse of the secrecy regulations for reasons of competition or the covering up of crime or failure is not permissible (§1045.13 Classification Prohibitions). The criteria for decisions on secrecy also in the future can be summarised as follows (§1045.16):

- Previously disclosed information is not to be classified as secret.

176 U.S. Department of Energy, Openness Advisory Panel, Responsible Openness: An Imperative for the Department of Energy, August 25, 1997; Albert Narath (Chair), Report of the Fundamental Classification Policy Review Group, Unclassified Version, Issued by the Department of Energy, October 1997, in the Internet at: http://www.doe.gov/html/osti/opennet/repfcprg.html.

177 Department of energy, Office of the Secretary, 10 CFR Part 1045, RIN 1901-AA21, Nuclear Classification and Declassification, Action (Final Rule), Effective Date: June 29, 1998.

178 This policy is also aimed at strengthening the "Freedom of Information Act". This is a law giving citizens the right to receive all information from the government, except that which is expressly classified as secret.

- Military countermeasures and defence against U.S. weapons systems are not to be facilitated.
- The dangers of proliferation are to be minimised.
- U.S. foreign policy is not to be endangered.
- Public welfare, open and informed discussions and economic growth are to be promoted.
- The public acceptance of a program is to be promoted, and its costs minimised.

As a result of this reform, a large amount of technical information on nuclear warheads has actually been declassified in the USA, since, in line with the foregoing criteria, it was regarded as no longer posing a threat to non-proliferation, and there was no danger of an undesirable disclosure of America’s own technological state of development.[179]

The striving for objectivity and the suppression of the motivation for secrecy for subjective reasons, e.g. reasons of status, becomes clear. The suggested procedures aim at establishing the most logical, deducible path from the principle of “national security“ to a concrete regulation. This leads to recommendations such as, for example: "A weapon type, once retirement is authorized and dismantlement completed, is not a factor in military capabilities, and all information concerning production and dismantlement rates and schedules for this weapon type can be declassified."[180] Such transparency is, indeed, helpful in the verifying of nuclear material stocks, but would need to be extended on a long-term basis. It has, for example, been recommended to declassify inventory figures. Nevertheless, these still have not been released as part of the reforms. Inventory figures are, however, a minimum requirement for long-term disarmament plans. Production histories, current activities and the transfer between the authorities relevant for them, DoE and DoD, are also classified as "information of national security". It is, of course, impossible to fully objectify such classifications since, in the long run, they will always be subjective in nature and dependent on political factors such as international mutual trust. For this reason, it is an even more urgent requirement that the future process of declassification will continue to be adapted to the political situation.

In the report, for example, the continued existence of American nuclear weapons is not questioned. This alone is not an obstacle for the next round of nuclear reductions. In the wake of more extensive and total nuclear disarmament however, the term “national security“ would be re-defined, which would have an impact on the principles specified above. It is for example conceivable that the principle of prevention of countermeasures against U.S. nuclear weapons (above list, b) would cease to apply. On the other hand, the principle of the minimisation of the proliferation dangers will always have to be retained, especially in a nuclear weapon free world. What must also be taken into consideration is

179 U.S. Department of Energy, Office of Declassification, Drawing Back the Curtain of Secrecy — Restricted Data Declassification Policy 1946 to the Present (RDD-4), January 1, 1998. This document lists over a hundred pages of technical details which are now declassified.

180 Report of the Fundamental Classification Policy Review Group, op. cit. (fn 176), chapter 6.

Table 2: Examples of information which could be disclosed by means of verification

Information	Verification Activity	Country, Source	Evaluation and Classification
Fact that a warhead is boosted.	Examination of the pit container	USA:	Now
Use of Pu of the α-Phase	Observation of the drilling and cutting of the metal	Field test FT-34	known
Design of the " " warhead	Inspection of X-ray pictures	(ACDA), USA 1969, fn. 183	Still classified
Radar frequency of the MK 28			now
Use of Pu-239 and U-235 in hypoth. model warheads	Evaluation of γ spectrum	China:	Intolerable
Pu-239 interior, U-235 exterior, small amounts of either Th-232 or U-232	100-3000 keV	Institute of Appl. Physics & Math., Beijing, 1995 fn. 37	
Use of Be in warhead design	Evaluation of γ spectrum		Declassified Nov. 93
Pu and U can form compounds	Sample analysis		Declassified Feb. 93
Hypoth. critical mass, e.g. 4 kg	none	USA:	Declassified Jan. 94
Average mass of the U.S. warheads	Counting of warheads + recording of outgoing nuclear material	DoE: Restricted Data Declassification	still classified
External dimensions and weight of neutron generators	Measurement, weighing	Policy, fn. 179	Declassified Feb. 93
U, HEU, and other nuclear materials can be present in secondaries	n-, γ spectroscopy		Declassified Feb. 93
Materials for tampers in unspecified weapons	Inspection of dismantlement factory exit		Declassified
Materials for tampers in specified weapons	Inspection of the result of the dismantling of a specific weapon	USA: Draft Public Guidelines	Classified
U-233, U-235, U-238, Pu-239, Li-6, Li-7, H-2, H-3 unspecified in nuclear weapons	Inspection of dismantlement factory exit	to DoE Classification of Information, January 1998, [181]	Declassified
Fissile material for specific warheads	Inspection of the result of the dismantling of a specific weapon		Classified
Pu isotope vector of unspecific Russian warheads	Safeguards, disarmament Pu before mixing with non-military Pu	Russia: study Siemens/Minatom on MOX-pilot plant, Feb. 1997, fn. 47	Classified
Number of nuclear warheads USA, Ru, Chi, GB, F	Declarations (no verification)	All NWS: Dipl. Reactions to 1993 Kinkel proposal, Müller, fn. 31; Classification Guidelines (fn. 181)	Classified

181 Department of Energy, Office of Declassification, Draft Public Guidelines to Department of Energy Classification of Information, June 27, 1994.

that a generally accessible publication could pose a much greater danger of proliferation than confidential treatment of the same information by a few selected employees of an international authority.

The striving for objectivity and transparency of secrecy regulations on nuclear weapons could take place at an international as well as a purely national level. It is conceivable that common principles and standards for national laws and procedures could be worked out in international negotiations. In this respect there are many variations as to when individual states could participate. One of these principles should be the simplification of verification tasks and maximum possible transparency.

The transparency in the USA is by far the greatest when compared with the other nuclear weapon states, in which the status considerations of military–nuclear complexes have a great influence on the decision-making process.[182]

Despite secrecy, it is possible to work out technical compromises. In this instance, the larger the number of technical details which can be disclosed, the more convincing the verification will be. However, the lower this figure is, the higher will be the acceptance of the nuclear weapons states concerned. In 1969, the U.S. American Arms Control and Disarmament Agency (ACDA) carried out an experiment into the relationship between the amount of disclosed information and the probability of fraud.[183] The results of this experiment showed that, even then, satisfactory compromises could be found.

Although the developments to date are to be seen as positive, it is apparent that no additional international participation appears to be under consideration apart from of bilateral co-operation in the area of transparency, at least not in terms of the dismantling process. Attitudes might change here due to the following reasons: other kinds of disarmament are being internationally verified, other partial problems of nuclear disarmament are to become more transparent for the international community, as is also clear from the negotiations with the IAEA, among others, on the verification of weapons materials,[184] other states could share in the financing, and finally, for political reasons, it is advisable to demonstrate nuclear disarmament convincingly, not least in order to trigger measures for nuclear non-proliferation. Moreover, international commitments and transparency increase the irreversibility of the measures.

Although non-nuclear weapons states already provide an incomparably higher degree of transparency with regard to their nuclear activities, and although the need to catch up rests with the nuclear weapon states, a further rethink is also needed in non-nuclear weapon

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182 Russia, for example, is not prepared to disclose the isotope composition of its weapons plutonium, which also poses problems for the international co-operation on non-military applications. In comparison, in the USA, the isotope composition is only classified as long as the material is still in the form of warhead components. As soon as this is modified, the isotope composition can be disclosed. See: J.T. Markin/W.D. Stanbro, Policy and Technical Issues for International Safeguards in Nuclear Weapon States, in: International Nuclear Safeguards 1994, Proceedings of a Symposium, Vienna, 14-18 March 1994, vol. II, p. 639.

183 United States Arms Control and Disarmament Agency, Final Report – Volume I: Field Test FT-34. *Demonstrated Destruction of Nuclear Weapons (U)*, January 1969. Declassified1990.

184 cf. section 3.1.5 , and op. cit. (fn 53).

states in order to speed up this process. For instance, the example of the American attempt to objectify the decision-making process relating to secrecy and disclosure is an example which should be copied in Germany. Also, a law such as the Freedom of Information Act should provide an example for other countries.178

5.1.3 Subjectivity for More Flexibility and Effectiveness?

Prior to and during the negotiations for the S3, a discussion took place which will also play a role in the verification of a nuclear-weapon-free world. It had been criticised that too formal rules for the implementation of verification activities resulted in an ineffective distribution of work. Prior to the reforms, most of the IAEA inspections took place in industrialised non-nuclear weapon states where no suspicion existed, including Japan, Canada and Germany, instead of in Iraq, where more extensive controls would have made more sense. S3 therefore greatly increased the possibilities of carrying out special inspections and thus introduced greater flexibility. The recurring issue now is which criteria should be used for the decision as to where verification activities are to be concentrated. in the course of the discussions on such criteria, an employee of the IAEA suggested that “in carrying out its verification mandate, the Agency can only take into consideration the willingness of its partners to demonstrate transparency in their relevant nuclear activities.“[185] This wording could be used as a starting point for the development of differentiating criteria for the distribution of verification activities.

The problem which arises here, however, is that subjective judgements are thus reintroduced. Interpretations as to what counts as “willingness to show transparency“ can vary over a vast spectrum, and additionally, the danger of misuse is present. For example, an inspected state interested in protecting industrial secrets could be threatened with a “bad report“ by an authority interested in enforcing more transparency. In contrast, the volume of verification work would be much greater and less effective, if more objective, i.e. rationally more comprehensible, less conflict-loaded criteria were used. Adequate conflict-solving strategies prove crucial in this connection (cf. next section 5.2 Organisational Form of the Verification System).

5.2 Organisational Form of the Verification System

The successful implementation of verification measures depends not least also on the organisational form of the verification system and must therefore be meticulously thought out.

The currently existing agreements on nuclear arms control, disarmament and non-proliferation give a first impression of the possible tasks and organisational structure of verification. Treaties such as the Sea Bed Treaty (1971) and the ABM Treaty (1972) are solely verified by NTM. Within the framework of the INF Treaty (1987) and the START

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185 Bruno Pellaud, Safeguards: The evolving picture, IAEA Bulletin 38/4, December 1996, unofficial translation, author’s italics.

Treaties (1991 / 1993), in which nuclear weapons were disposed of or reduced for the first time, compliance with upper limits and the destruction of surplus weapons must be verified. They have essentially more extensive systems of rules which are based on the co-operation of the states party to the treaty, and include routine on-site inspections as well as inspections at very short notice. The verification of the NPT is no longer the task of the nation-states, but of an international agency. The IAEA verifies the entire fuel cycle in the member states.[186] Internationally staffed teams of inspectors have access to a great number of nuclear technology plants. Following the reform of the safeguards system in the mid 1990s, rights of access were extended, the information sources of the agency stretched, and nuclear-weapon states incorporated to a limited extent in the verification procedure. With the entry into force of the Test Ban Treaty, another organisation, the CTBTO, will be established, which will supplement the existing structures.

The verification of comprehensive nuclear disarmament will build on this widely-ramified system of instruments. Since, during the course of the disarmament process, its area of responsibility will extend beyond the scope of the present agreements, its technical and organisational structures will have to be further developed.

Challenge inspections

The procedure for the triggering and implementing of challenge inspections can be crucial for the effectiveness of the verification regime. If the enforcement of such inspections is very difficult and protracted, important information can go missing. On the other hand, challenge inspections that are carried out without sufficient reason can aggravate the political climate between treaty states and severely shake the trust in the regime. Rules must therefore be created which avoid politically motivated accusations and selective treatment, but also effectively prevent a blockade of inspections. Thus the crucial issue is who can trigger a challenge inspection and under what circumstances.

One possibility is to transfer the competence to the secretariat, i.e. the technical wing of an inspection agency. It could thus use its own data in the evaluation of a situation, and subject possible information from member states to an examination. The reaction speed is in this case relatively high, and “character assassination“ actions could largely be avoided. However, such a ruling brings with it the risk of politicisation of the organisation. Any decision in favour of a challenge inspection is politically explosive. It will often meet with resistance or at least criticism from the state concerned. If the secretariat is the initiator of the inspections, it will become the butt of criticism even if the decision-makers had acted to the best of their knowledge and belief. The risk is that the neutral status of the secretariat might be lost. This is exactly what happened in 1993 in the case of North Korea, when the Director General of the IAEA wanted to order challenge inspections due to discrepancies between the national declarations and the findings of the regular inspections. North Korea accused the IAEA of having abandoned its neutral standpoint and even went so far as to charge it with espionage on behalf of the USA. The accusation was, in this case, obviously

186 With the exception of the nuclear weapons states, which are only controlled on a voluntary basis.

fully unfounded. Nevertheless, the reputation of an organisation can be damaged in the wake of such a conflict.[187]

It is therefore better if the challenge inspections are agreed by the member states. The secretariat can, in its role as provider of information, still considerably influence the decision without itself deciding on the execution. The so-called “red light“ process ought to be used in order to reach a decision. This means that in principle all challenge inspections are to be carried out, unless a certain majority of the states explicitly speak out against the inspection. If a vote (at best within a fixed time limit) is not explicitly requested, the inspection is carried out without further discussion.[188]

There should be absolutely no possibility for formally approved challenge inspections to be rejected. If a state refuses nevertheless to allow the inspections to take place, effective sanction mechanisms must be put into motion. The enforcement of special inspections, possibly even with the use of armed forces, is, however, a tricky matter. On one hand, enforcement is unavoidable if the verification regime is to have maximum effectiveness. On the other hand, the use of force cannot be applied by any random organisation. It should not be too large, so that a decision can be reached quickly. It must, however, be representative of the community of states. From today’s perspective, the Security Council would be appropriate, though it would not be able to satisfactorily fulfil this task in its present form. The composition of the group of permanent members would have to be changed. It should no longer consist only of the official nuclear weapon states. Furthermore, it should not be able to veto decisions on special inspections. In short, a reform of the United Nations is necessary which would weaken the current permanent members of the Security Council. Due to the existing rules on amendments, such a change would require a firm determination to carry out reforms.

The Internationalisation of Verification

The verification of total nuclear disarmament should, in the long term, not remain with the nation-states. The take-over by an international authority is unavoidable. The reliability of the verification should not depend on the willingness of individual states to provide information or technology. An international organisation with its own technical staff and its own verification instruments is the best guarantee for the reliable and even application of the necessary verification measures, and would strengthen the trust in the verification process.[189]

An important example of the internationalisation of verification is satellite surveillance. At present, only a small number of states have access to satellite pictures. In a nuclear weapon

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187 See Patricia Lewis: Organizing for Effective Implementation, in: Eric Amett (ed.), Implementing the Comprehensive Testban, SIPRI Report no. 8, Oxford (Oxford University Press), 1994, pp. 86-102.

188 Using the so called “green light“ process, the inspection only takes place when a certain majority explicitly pronounces in its favour. This process makes the implementation of challenge inspections more difficult since the approval of the responsible body is always required. Usually, this results at least in a delay.

189 See Heinz Gmelch, Verifikation von multi- and internationalen Rüstungskontrollabkommen, Baden-Baden (Nomos), 1993, pp. 227-288.

free world, this is not sufficient. An organisation responsible for verification must have unhindered access to satellite data. It must have practically unlimited rights of use of satellite(s). An internationalisation of the regulations of the Open Skies Treaty is also conceivable. In this case, the verification organisation would have its own aircrafts and sensor technology with which it could verify the territory of member states.

Furthermore, it must be decided whether the various verification tasks in the nuclear area could be integrated into one “super organisation“. The advantage of a large organisation responsible for the whole range of nuclear verification tasks is, for example, that only one administrative apparatus would have to be built up, and, if desired, only one General Assembly of member states and only one Executive Council. This way, the verification machinery could, perhaps, be organised more cost-effectively. Laboratories and databases could be managed jointly. This would save costs and facilitate data exchange (for example also due to the compatibility of the records). Duplicated inspections or duplicated acquisition of verification devices could be avoided. A very large organisation does, however, also have its drawbacks. The political decision-making bodies (General Assembly and Executive Council) face a larger and increasingly complex structure of tasks. The requirements in terms of technological understanding rise, the political contexts they must master become more complex. A larger administration apparatus can, to a certain extent, reduce the duplication of tasks; however, experience shows that with the growth of an organisation, more levels of administration are introduced. This complicates and slows down the communication between the upper and lower levels. The relationship between the technical staff and the political decision-making level becomes more difficult. The recourse to several organisations seems more promising since it allows the verification process to be flexibly adapted to the immediate disarmament steps. More realistic and, at the same time, more sensible, however, is the concept of a network of individual organisations. The establishment of a joint co-ordinating body can reduce the duplication of tasks. The shared use of technological resources (laboratories, computers, means of transportation...) can nevertheless take place. The establishment and use of shared databases can also be arranged by means of such a co-ordinating body.[190] Whatever the decision, each participating organisation must be directly connected to the (reformed) Security Council. Information on possible treaty violations must be passed on to the council without diversion. This means that the leader of each verification department must have direct access to the Security Council.

The IAEA already possesses the expertise and the technical equipment needed to fulfil most future verification tasks. It verifies the fuel cycle of almost all non-nuclear weapon states, and could carry out this task equally well in the case of nuclear weapon states and threshold states. To this end, the quantitative build up of resources (for example in terms of staff, laboratories and verification instruments) is first necessary. The IAEA is also capable of verifying a future FMCT. It should therefore provide the starting point for the development of the ultimate organisational form for the verification. That means that it

190 See Marvin Miller, Verification Arrangements, in: Backgroundpapers of the Canberra Commission, 1996, pp. 181-189..

must not only be expanded in terms of size, but that it must undergo changes in terms of status, competence and its relationship to the Security Council.

The IAEA cannot take on all verification tasks. The CTBTO should continue to be entrusted with the verification of the Test Ban Treaty. For the verification of the destruction of warheads, carrier systems and the infrastructure of military nuclear programs, a third organisation, working in close co-operation with the IAEA, will probably have to be formed. The work of this organisation would, however, only be transitional since the objects of its verification will be dismantled after completion of the disarmament process.

Co-operation with Other Verification Organisations

The reliability of the verification system can be substantially increased by means of co-operation with verification organisations from other areas of non-nuclear arms control. This co-operation between various organisations, for example, from the nuclear and chemical sectors is not as yet possible. The OPCW is, for example, strictly prohibited from passing on findings. The organisation is practically subject to an information ban. If it were to come across information which was, for example, of relevance to the IAEA, it would not be able to pass on this information. The possibility of data exchange must therefore be incorporated in all arms control treaties and the corresponding statutes covering verification organisations.

“Social Verification“

In addition to the classical technical instruments of verification, the concept of social verification has been developed. This is a control system which, in contrast to traditional verification concepts, relies on the participation of the entire population of a country and is not confined to highly-specialised, technically well-equipped teams of experts. Social verification is to be carried out by the population of a country. In principle, every citizen is encouraged to pass on all information on treaty violation or attempted treaty violation which comes to his/her attention to a competent international authority. This passing on of information is intended not only as the right, but also as the duty of every citizen and would therefore have to be incorporated in the legislature of the states. The passing on of information must, therefore, not be treatable as a punishable offence in the countries concerned, either as treason or any other crime. This concept of involving the whole population is also know as “Citizens Reporting“.[191] In practice, such whistle blowers will often be people who come to know of secret projects in one way or another due to their training (engineers, specialists, scientists). It must be made possible for such informants to disclose their knowledge without incurring any risks. Thus, for example, an international fund could be set up for the support of such whistle blowers.

Universality

191 For a thorough discussion, see Joseph Rotblat: Societal Verification, in: Joseph Rotblat/Jack Steinberger/Bhalchandra Udgaonkar (eds.), A Nuclear-Weapon-Free World. Desirable? Feasible?, Boulder/San Francisco/Oxford, 1993, pp. 103-118.

The process of comprehensive nuclear disarmament can be initiated by a relatively small number of states. At the end of the process, however, all states must have committed themselves to relinquishing nuclear weapons. The system can only offer the high degree of security expected of it if all states are part of the system, and only then can sanctions against transgressors take effect.

5.3 Conclusions

This report has attempted to approach the answer to the question: “Is a nuclear weapon free world verifiable?“. It has become clear that this is a complex task. Many different methods of verification have to mutually supplement and support each other. No single method could manage to fulfil the task alone since many circumstantial evidences taken for themselves prove ambivalent. Various methods of verification take on various degrees of importance according to whether former nuclear weapon states are concerned or not, how extensive the non-military nuclear industry is, how industrialised the state is, how high the degree of transparency is, and to what extent the state co-operates with the verification authorities.

The synergy of the most vastly differing methods is thus a decisive factor. Together they can trigger suspicious indications early and with a high degree of probability, and they can provide the relevant evidence. There are many possible variations on how to implement and apply measures. It is not necessary to select the most complex and expensive variation for each technology and each process; the crucial factor is a high degree of probability of detection. How high this has to be depends largely on political factors, in particular on the degree of trust bestowed on the inspected state. There will always be many and extensive variations on which states are trusted, and to what degree. The extreme case is the establishing of concrete suspicion and the necessity for clarification. The other extreme case is that of a state which no one mistrusts. Here, the prerequisites are a maximum degree of transparency and readiness to co-operate on the part of the state concerned. The degree of transparency and readiness to co-operate must itself contribute to the reinforcement or refutation of a suspicion.

A one hundred percent successful verification will never be achieved. However, the number of possibilities for starting and bringing to completion an undetected nuclear weapons program could hover around zero, if the implemented verification measures become more and more extensive and intrusive. It has also become clear, that the political background against which verification is to take place must develop considerably. On one hand, the detection of a secret rearmament program must be possible early enough and with a high degree of probability; on the other hand, this must also be recognised by the international community.

Three case studies – Iraq, North Korea and South Africa – have demonstrated three of the most critical problems of a future verification regime:

1. The early detection of secret nuclear weapons programs (Iraq and North Korea).

2. The complete recording of stocks of nuclear weapons and their components (South Africa).
3. The enforcing of inspections in the case of uncooperative states (Iraq and North Korea).

Especially in the case of the IAEA, the technical instruments of verification and the competence, that is, the remit of the protagonists have been enormously improved and extended in the last few years in response to the cases of Iraq and North Korea. The improvements made to date, above all the S3 reform, are not sufficient to accompany the nuclear disarmament process to its conclusion, but they represent an important step towards the solution of the first problem, the early detection of secret programs.

The complete recording of stocks of nuclear weapons and their components (the second problem given above) is not a technical problem. The critical points are transparency and readiness to co-operate on the part of nuclear states and threshold states. The problem of the secrecy of militarily relevant details can be solved with the aid of cleverly-devised verification methods. It is important that transparency measures are taken as early as possible and that the rejection of information requests is largely stopped.

The main problem which will arise in future is the enforcement of inspections in uncooperative states. It is unlikely that the instruments necessary for this, especially the reform of the Security Council, will be implemented in the foreseeable future. But since the elements of a nuclear disarmament process – the development of technical verification measures, transparency, readiness to co-operate, and confidence-building – reinforce each other, the enforcing of inspections does not represent an insurmountable problem in the long term.

The following prerequisites are indispensable:

- The universal will of the international community to achieve a nuclear-weapon-free world.
- The willingness of all states to offer a maximum degree of transparency and readiness to co-operate. To this end, transparency measures and the principles and criteria on which they are based must be constantly and systematically developed. The violation of internationally agreed standards of transparency would then be an exception and would even represent a suspicious indication. This transparency is still inconceivable in important elites, especially in those states in possession of nuclear weapons. On the other hand, the movement towards a greater degree of transparency is all too obvious.
- A verification system based on two pillars: an internationally organised verification apparatus applying negotiated processes and technologies, and the additional possibility of incorporating further information in a flexible manner, including information from secret services. Mechanisms to encourage the disclosure of further information must be reinforced, above all the encouragement and protection of whistle blowers. Many of the techniques which today still count as NTM, such as satellite surveillance, should be internationalised if possible.

- International mechanisms which can be used to enforce the consequences of suspicions. This would first be further verification and clarification measures, and, in the case of the confirmation of a suspicion, measures which would reverse the nuclear weapons program.

It can not yet be determined with which details verification and transparency measures and the future organisation should be formed. They stand at the end of a long development process which has only just begun. To advance this development, on the one hand, much individual progress is required, similar to that which is already taking place (outlined in chapters 0 and 0). On the other hand, a fundamental rethink is necessary: none of the individual steps should be regarded as an end in itself, but rather as part of a process leading to more transparency and further nuclear disarmament. Even though the objective of a nuclear weapon free world is still dominated by disunity, with some voices in favour, some against, and some simply sceptical, new principles should be generally recognised. These principles should be transparency and irreversibility of nuclear disarmament.[192] The fundamental rethink includes the fact that nuclear activities in nuclear weapon states are no longer purely a national matter but that, just as in non-nuclear weapon states, the international community has a right to transparency, which, put in concrete terms, means the introduction of IAEA safeguards. The time is right for this, and the development is realistic. (cf. 3.1.5 Disposal of Nuclear Materials from Disarmed Nuclear Weapons). The FMCT will prove to be an important milestone along this path. Confidence in the fact that verification of a nuclear weapon free world is possible will grow in line with the progress made along this path, so that it can finally constitute a realistic option.

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192 William Walker, Reflections on Nuclear Transparency and Irreversibility: the Re-regulation of partially disarmed states, Background paper for the Conference on the Fissile Material Cutoff, Schlangenbad (Germany), 25-27 July 1997.

Appendix A: Functioning of Nuclear Weapons

The following illustration demonstrates the most important elements of a modern warhead.[193]

↑

14 cm

↓

Fig. 1: components of a modern nuclear warhead ("Hydrogen bomb [H-bomb]")

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193 This sketch and description contain only the information which has been published to date. Technical details cannot be taken from it. Measurements and shapes are arbitrary, and do not correspond to reality. The mode of functioning of the detonator of the secondary (the so called "*Teller-Ulam-Principle*") is the same as with inertial confinement fusion (ICF). It became known as early as the start of the 1980s through German and other publications, and was also declassified in the USA in the early 1990s. See e.g. Jürgen Meyer-ter-Vehn, Zur Physik des Fusionspellets, Physikalische Bätter, Bd. 43, 1987. p. 424.

The primary, which is solely based on nuclear fission, is a warhead which functions according to the implosion principle. A hollow sphere of HEU or plutonium , the so-called "pit", is surrounded by a neutron reflector of, for example, beryllium. The configuration is subcritical. The explosive lenses consist of specially shaped and specially assembled parts made of conventional explosive material with different detonating speeds and several igniting points. If these are ignited simultaneously (with an imprecision on the scale of a μs), a spherically inward-directed detonating wave is generated. By this wave, a heavy mass which is lying below is accelerated inwards. This requires precision both in terms of space and time in order to avoid instabilities. The detonating wave compresses the reflector and the pit so that an overcritical mass is generated. Shortly before maximum overcriticality is reached, starting neutrons for the chain reaction must be generated by use of a neutron generator (not included in the sketch). The time for this must be chosen in such a way that there is maximum compression when the energy generated by nuclear fission is just large enough to trigger an additional expansion. The chain reaction is in addition reinforced by "boosting". That is, deuterium-tritium gas (DT) is inserted into the hollow space of the pit just before ignition. When the temperature and the pressure exceed specific thresholds, fusion is triggered in this gas ($D + T \rightarrow \alpha + n + 17{,}6$ MeV) which releases further neutrons and accelerates the build-up of the chain reaction. This means that a greater proportion of U or P cores are split before the chain reaction stops as a result of the expansion. With the aid of boosting, it is possible to vary the yield.

Most of the energy of the primary is first released in the form of black body radiation in the X-ray spectrum. The primary and secondary are located in one casing. The casing and outer shell of the secondary consist of optically dense material so that thermal equilibrium rapidly develops between the primary, secondary and the casing before significant mechanical effects occur. In order not to hinder this thermalisation, all the mechanical holding material is optically thin. The outer layer of the secondary, the so-called ablator, vaporises, creating an inward repulsion (ablation). It consists of optically dense and heavy material. The internal part of the secondary consists of lithium 6 deuterid (Li-6D). The ablation generates an inward shock wave which compresses the Li-6D. The closer the compression comes to an adiabatic curve, the higher is the possible density. The ablator is thus probably constructed in such a way that several shock waves can be generated one after the other, so that as a whole, the adiabatic compression is approximated. [194] The DT is located in the centre. Here, the shock waves meet and generate a hot plasma of high entropy corresponding to the fusion conditions for DT. As a result, fusion reactions are triggered which deposit their energy in the surrounding compressed and colder material in the form of kinetic energy of the reaction products. This material is thereby also heated up to fusion conditions, and in this way, a fusion wave propagates from the inside outwards. This process is quicker than the following mechanical expansion of the plasma. In the

194 The theory of spherical compression is described in: G. Guderley, Starke kugelige and zylindrische Verdichtungsstöße in der Nähe des Kugelmittelpunktes bzw. der Zylinderachse, Luftfahrtforschung 19, p. 302, 1942; for a short summary see K.A. Brueckner/S. Jorna, Laser-driven Fusion, Rev. of Mod. Physics, 46, no. 2, p. 325, April 1974. Here: p. 347. See also: J. Meyer-ter-Vehn/C. Schalk, Selfsimilar Spherical Compression Waves in Gas Dynamics, Zeitschrift für Naturforschung, 37a, 955-969 (1982).

simplest case, the secondary and its compression are spherical. It is speculated that cylindrical compressions can also be generated. The reaction in Li-6D is a double reaction:

$$D + T \rightarrow \alpha + n + 17{,}6\ MeV$$

$$n + {}^{6}Li \rightarrow T + \alpha + 4{,}8\ MeV$$

Appendix B: A Comparison of Enrichment Processes

Table 3: A Comparison of Enrichment Processes[195]

Process	Working material (volatile materials are easier to detect)	Separation factor (the smaller the particles, the more steps possible)	Energy consumption (kWh/SWU) (detectable with infrared spectroscopy)	Development stage	Distribution	technical hurdles for further spreading
Gas diffusion: uranium hexafluoride (UF6, gaseous) is diffused through a membrane, whereby molecules with U-235 diffuse more frequently. The amount of lighter materials is thus slightly increased on one side.	UF6	1,0040 – 1,0045	2300 – 3000	matured	USA	high
Gas centrifuges: particles of different mass are diversely distributed in a rapidly rotating gas centrifuge. It is thus possible to extract differently enriched gas from different parts of the centrifuge.	UF6	1,3 – 1,3	100 – 300	matured	Europe	high
Jet nozzles: molecules of differing density display slightly different flow characteristics in a specially formed nozzle. It is thus possible to channel off parts of the gas flow leaving the nozzle which are diversely enriched.	UF6 + H2	1,05	3000 – 3500	matured	South Africa	high
Chemical enrichment: reaction rates also depend on the mass of the reacting particle. This is exploited in order to change the enrichment in solutions.	watery and organic U solutions	1,0025 – 1,003	≤ 600	test phase		
Electromagnetic enrichment (calutrons): a U-ion beam is pulled through magnetic fields in an orbit. The radius here depends on the mass.	UCl4	20 – 40	3000 – 4000	matured	obsolescent, declassified, no longer used	low
Laser isotope enrichment (atomic): U isotopes are differently stimulated in U vapour with the aid of lasers and then selectively ionised. The ionised isotope can be channelled off using electromagnetic methods.	atomic	5 – 15	≈ 10 – 50	test phase	USA, France, South Africa	very high
Laser isotope enrichment (molecular)	UF6 + N2	5 – 15	≈ 10 – 50	research	industrialised countries	very high

195 Based on: Krass et al., op. cit. (fn 79), p. 188

Appendix C: Glossary of Some Specialist Terms Used in the Verification System of the IAEA

Significant quantity:[196] the approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded. (Definition given by the IAEA)

Material	Significant Quantity	Safeguards applied to
direct-use material		
Pua	8 kg	total element
U-233	8 kg	total isotope
U (U-235 ≥ 20%)	25 kg	U-235 contained
Indirect-use material		
U (U-235 < 20%)b	75 kg	U-235 contained
thorium	20 t	total element

a) For Pu containing less than 80 % Pu-238.

b) Including natural and depleted uranium.

Detection time: the maximum time that may elapse between diversion and its detection by IAEA safeguards; according to the current guidelines it should correspond in order of magnitude to conversion time.

Conversion time: the time required to convert different forms of nuclear material to the metallic components of a nuclear explosive device. Estimations are in the order of days for direct-use material, weeks for chemical compounds not exposed to radiation, months for spent fuel and one year for LEU, natural uranium and thorium.

Detection probability: the probability, if diversion of a given amount of nuclear material has occurred, that verification activities will lead to detection. (Shortened text, further terms and formulas are used for the quantitative definition.196)

False alarm probability: the probability, α, that statistical analysis of accountancy data will indicate an amount of nuclear material missing that is larger than expected on the basis of measurement uncertainties when, in fact, no diversion has occurred. α is usually set at 0.05 or less.

196 IAEA-Safeguards Glossary, op. cit. (fn 10).

Abbreviations

AVLIS	atomic vapour laser isotope separation
CFE	Treaty on Conventional Forces in Europe
CIA	Central Intelligence Agency
CTBT	Comprehensive Test Ban Treaty
CWC	Chemical Weapons Convention
DoE	Department of Energy
EMIS	electromagnet isotopic separation
FMCT	Fissile Material Cut-off Treaty
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
ICF	Inertial Confinement Fusion
INF	Intermediate Nuclear Forces
kg	kilogram
kWh	kilowatt per hour (unit of energy)
LEU	low enriched uranium
LIDAR	Light Detection and Ranging
µs	micro seconds (10-6 s)
MOX	uranium-plutonium mixed oxide
MUF	material unaccounted for
MW	megawatt (power unit)
NIF	National Ignition Facility
NNWS	non-nuclear weapon state
NPT	Non-Proliferation Treaty
NTM	National Technical Means
NWS	nuclear weapon state
Pu	plutonium
PUREX	plutonium and uranium recovery by extraction
R&D	Research and Development
SON	State outside NPT
S3	Strengthened Safeguards System
START	Strategic Arms Reduction Treaty
SWU	separative work units (measurement for the separative work achieved in the course of enrichment)
t	ton
U-235	uranium isotope with the mass number 235
U-238	uranium isotope with the mass number 238
UF6	uranium hexafluoride
UN	United Nations
UNSCOM	United Nations Special Commission for the Iraq inspections