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NUCLEAR DISARMAMENT VERSUS NUCLEAR WAR

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„Nuclear Disarmament Versus Nuclear War"

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I. The past and the future of the Non-Proliferation Treaty (NPT)

Since 5 March 1970 a Non-Proliferation Treaty (NPT) is in force. At that time the three depositories Soviet Union, United Kingdom and the United States of America together with forty other non-nuclear weapon countries signed the agreement in London.

The NPT-concept was to curb the spread of nuclear warheads to Non-Nuclear-Weapon States and to reduce the number of nuclear weapons of the superpowers and Nuclear-Weapon States. The Treaty was in conformity with a number of previous resolutions of the United Nations General Assembly dating back as far as 1946 and warning of the devastation all mankind would experience by a nuclear conflict. It was also believed that the proliferation of nuclear weapons would seriously enhance the dangerous possibilities of starting-off a nuclear exchange warfare.

To all signatories it was evident that the NPT had political, economic and technical aspects. Therefore in the preamble the principle was affirmed that the benefits of peaceful applications of nuclear technology derived by the Nuclear-Weapon States, when developing nuclear explosive devices, should be made available for peaceful purposes to all parties of the Treaty.

Eleven articles define the Non-Proliferation Agreement. Article 1 spells out that all Nuclear-Weapon States do not transfer to any recipient nuclear weapons or explosive devices directly or indirectly and do not in any way assist, encourage or induce any Non-Nuclear-Weapon State to manufacture or acquire nuclear weapons. Article 2 makes it clear that Non-Nuclear-Weapon States should not undertake to receive and/or control nuclear weapons directly or indirectly. Article 3 defines a safeguards system, which each Non-Nuclear-Weapon State should negotiate and conclude with the International Atomic Energy Agency (IAEA). The

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IAEA safeguards apply to virtually all nuclear materials in facilities outside the five declared Nuclear-Weapon States China, France, Russia, UK, USA. Also a number of peaceful nuclear installations in the five Nuclear-Weapon States are covered in form of voluntary agreements. All Nuclear-Weapon States are now party to the NPT, while only three started out twenty-five years ago. Articles 4 and 5 refer to non-discrimination of production and use of nuclear energy for peaceful purposes, particularly in the Non-Nuclear-Weapon States. Article 6 says that all parties of the Treaty including the Nuclear-Weapon States should pursue negotiations relating to the cessation of the nuclear arms race and undertake nuclear disarmament efforts under effective international control. The last four paragraphs define possible amendments, the mode of accession for countries at a later stage and in Article 10(2) it is explicitly stipulated that twenty-five years after the entry into force of the Treaty a conference shall be convened to decide whether the Treaty shall continue in force indefinitely, or shall be extended for an additional fixed period or periods. The decision shall be taken by a majority of parties to the Treaty. This Review Extension Conference was being held in New York from 17 April to 12 May 1995. In the course of the negotiations it became evident that a solid majority of the 178 participating countries were in favour of an indefinite extension. On the other hand 15 countries under the leadership of Indonesia, Egypt, Nigeria, Malaysia, Syria, Libya, Iran and North-Korea were driving for a time-limited extension, while a number of other non-weapon countries tried to connect their votes for indefinite extension with an agreement for further disarmament measures and security guarantees to be given by the 5 nuclear weapon countries.

A continuing global nuclear arms control now and a nuclear weapon-free world in the future seem irrevocably necessary for the furtherance of the harmony of world cultures. Nevertheless a number of countries are not happy with the NPT as it stands, as it prohibits the possession by a great majority of states of one of the most destructive weapons yet invented and on the other hand tolerating the retention of the same weapons by a handful of nations. The inequality of treaty rights and obligations of the „haves“ and the „non-haves“ has nevertheless brought a record number of adherence for an arms control agreement of about 169 nations.

The NPT regime requires nuclear trade restrictions. In particular developing countries are constantly complaining about export restrictions of nuclear materials and know-how. These obstacles can only be overcome, when exports are covered by clear and comprehensible rules,

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which both exporters and importers abide. Experience showed that trade possesses a non-vanishing risk. The present discussions concentrate on greater international harmonisation of nuclear export rules and regulations, but also measures are discussed for rules of punishment, when countries try to cheat. The IAEA will need more authority to report immediately any violation to the Security Council of the United Nations. IAEA safeguards are applied under the terms of agreements concluded between the International Agency and their member states. These agreements are generally concluded in connection with bilateral nuclear cooperation and supply agreements. At the end of 1991 180 safeguard agreements with 105 states were in force. During 1991 IAEA carried out 2145 inspections at 475 nuclear installations in 56 countries. More than 360 photographic and video-surveillance systems were in operation and approximately 1400 seals previously applied to verified amounts of nuclear material were detached and subsequently verified. About 1100 plutonium and uranium samples were analyzed at the Agency's Seibersdorf laboratory. At the end of 1991 as a result of severe budgetary constraints the Agency experienced difficulties in maintaining a safeguards program at an acceptable level of effectiveness.

The Nuclear-Weapon States agreed twenty-five years ago to pursue comprehensive disarmament negotiations. Many countries feel that this promise has not been fulfilled. Unfortunately a number of so-called „threshold states" are still outside of the NPT. Their arguments are of political nature mainly and they condemn the discriminatory character of the Treaty. In reality there are always at least two countries who mistrust each other and fear that their counterpart might acquire nuclear weapons and therefore arguing they need also nuclear explosives for counterbalancing.

Leaders for a nuclear-free world will be definitely the USA and Russia, the Western industrial world and the neutral and non-aligned countries taking advantage of the current peace situation to reinforce the already existing constraints. Over the last twenty years intensive negotiations took place between the Nuclear-Weapon States to arrive at a comprehensive test ban (CTB) agreement. Unfortunately a number of states deeply regret that the comprehensive multilateral nuclear test ban treaty banning all nuclear tests by all states in all environments for all time has not been concluded so far and this fact was brought forward at the New York extension negotiations of the NPT.

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II. Stop and run-down of the nuclear arms race

Strategic Arms Reduction Talks (START) between the USA and USSR began in 1982. Negotiations were aimed for to reduce the strategic nuclear forces on both sides. The talks were suspended in 1983 and opened again in Geneva in 1985. The START-Treaty was finally signed in Moscow on 31 July 1991 at a summit meeting between President BUSH and President GORBACHEV. The Treaty between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms is formulated in nineteen articles and a number of statements and exchanges of letters annexed. At the end of January 1992 the United States and then already Russia announced additional unilateral nuclear arms control measures.

In the preamble of the START-document the two parties stated their consciousness that nuclear war would have devastating consequences for all humanity and that it cannot be won and must therefore never be fought. They were also convinced that the measures for the reduction and limitation of strategic offensive arms will help to reduce the risk of outbreak of a nuclear war and strengthen international peace and security. Article 2 specifies the general reductions and limits. Neither side may exceed a limit of 1600 Strategic Nuclear Delivery Vehicles (SNDV), which include Submarine-Launched Ballistic Missiles (SLBM), InterContinental Ballistic Missiles (ICBM) and heavy bombers. These delivery vehicles may carry no more than 6000 accountable warheads. A maximum number of 4900 warheads may by carried by ballistic missiles and no more than 1100 warheads by intercontinental ballistic missiles on mobile launchers. Article 3 defines the counting rules. Article 4 relates to the non-deployed missiles and non-deployed mobile launchers. Each side is permitted to have only 250 non-deployed InterContinental Ballistic Missiles. Articles 5 and 6 deal with basic prohibitions, particularly on the movement of deployed mobile systems. In Articles 7 to 15 the verification principle and the verification regime are defined. In Article 16 the Treaty prohibits either side to assume international obligations that would conflict with treaty provisions. Finally Articles 17 to 19 are concerned with the conditions for entering into force and future discussions of possible amendments. The Treaty will remain in force for a period of fifteen years and can be extended successively for five-year periods. Each party has the right to withdraw from the Treaty, if it decides that continued adherence to the Treaty would jeopardize its supreme interests. Withdrawal from the Treaty requires a six-month notice and a declaration for the reasons to withdraw.

In the unilateral statements reference was made to ban nuclear tests. Despite of the fact that the number of nuclear test explosions has been drastically reduced, an overall agreement on a complete nuclear test ban does not exist yet. About 1900 nuclear test explosions in the atmosphere and underground were carried out since mid-July 1945. USA ranks first with about 950 explosions followed by the former USSR and its successor Russia with more than 650 detonations. Third is France with more than 200 test explosions followed by UK and China with roughly 50 explosions each. India has detonated one nuclear device described for peaceful ground excavation purposes.

Nuclear weapons worldwide totalling to about 55.000 warheads consist of fission weapons with ^{235}U and/or plutonium, of boosted fission warheads and of thermonuclear fusion bombs. SALT lays down a dismantling of approximately 30.000 Russian and about 15.000 US warheads within a period of seven years after entering into force of the Treaty. To meet with this time scale US is dismantling 2000 warheads a year, while Russia should dismantle approximately 4000 warheads per year.

A number of treaties like NPT, Antiballistic Missile Treaty, and special United Nation's Sessions on disarmament are counterforces against nuclear wars, but nuclear weapon technology and production of fissionable isotopes could be acquired by some thirty countries in a relative short period of time.

III. Weapongrade plutonium and highly enriched uranium (HEU) bomb materials for the civil fuel cycle

Originally weapongrade plutonium was produced in special military nuclear reactors. Highly enriched uranium for the first bomb was produced by electromagnetic isotope separators called CALUTRONS. Later on diffusion was the key method for enriching U-235. Nowadays ultracentrifuges are in use as well as laser-induced separation methods. When nuclear power

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became an economic alternative possibility for electricity production, large quantities of reactorgrade plutonium were piling-up.

From energy and electricity data of the International Atomic Energy Agency in Vienna the nuclear power electricity production at the end of 1993 was about eleven percent of the world's total electrical energy consumption (**Fig. 1**). This energy was supplied by 430 power reactors connected to the grid in 29 different countries; their total power amounted to 337 820 MWe. The nuclear share of electricity generation varies from Lithuania with 87.2 percent, France with 77.7 percent, Belgium with 59 percent to former Eastern countries like Hungary and Bulgaria with roughly 40 percent, Japan with 30.9 percent, Germany with 29.7 percent, the United Kingdom with 26.3 percent, USA with 21.2 percent and Russia with 12.5 percent (**Fig. 2**).

The world list of nuclear power plants as of 31 December 1994 is shown in **Fig. 3**. Here all reactors operable and under construction or on order with an electrical output of 30 MWe or over make 424 units operable with a net output of 337 518 MWe in 33 countries, while the total number of units was 490 with 391 549 MWe. 68 power reactors with roughly 20 000 MWe are out of service as of 31 December 1994 in 11 countries. The nuclear electricity generating costs in some of the most important countries have been compared with coal-fired stations or gas-combined cycles. **Fig. 4** shows the comparative electricity generating costs and proves the competitiveness of nuclear power.

Nine different reactor types are in service, but only two contribute to electrical power generation considerably. These are the **P**ressurized Light **W**ater **R**eactors (PWRs) and the **Bo**iling Light **W**ater **R**eactors (BWRs). 243 PWRs supply presently 213 753 MWe, while 92 BWRs contribute 75 555 MWe. From the 55 reactors under construction, 33 are PWRs and 4 are BWRs.

Nine nuclear power stations were connected to the grid during 1993, eight of them are of the PWR- or the BWR-type. Eight additional reactors started operation during the year 1994 with five PWR- or BWR-systems.

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Since the first demonstration nuclear power reactor began operating in Obninsk near Moscow in 1956, the total reactor years experience until 31 December 1994 has reached 6297 reactor years. Altogether 68 reactors were shut-down and taken out of service in the past 25 years. Adding the operating and shut-down reactors, the nuclear industry and the utilities have accumulated an operating and shut-down know-how of 7402 reactor years emanating from 506 nuclear power stations.

III. 1 World Plutonium Stocks and Surpluses

Plutonium is derived from two major sources:

a. It comes from dismantled warheads as a consequence of the two disarmament agreements in force between USA and Russia.
b. It is the result of commercial separation by large scale chemical reprocessing of spent uranium fuel coming from civilian nuclear power reactors.

There are some 55 000 tactical and strategic nuclear warheads stored in the world's nuclear arsenals. The agreed overall cuts between the two largest nuclear weapon countries to approximately six-thousand warheads each will result near to fifteen thousand warheads to be retired by the USA and roughly thirty-thousand warheads by Russia (**Fig. 5**).

Advanced thermonuclear warheads contain about 15 kg fission explosives (highly enriched uranium HEU and/or plutonium Pu), both in the primary and in the secondary compartment, the latter together with fusion fuel. It can safely be assumed that some 256 000 kilograms weapon grade Pu will be available and more than four times as much U-235, when the warheads are dismantled. While U-235 can easily be used commercially by mixing it with natural U and thus blending it down, Pu can only be removed by nuclear reactions either by irradiation in nuclear power reactors or by explosion in warheads. As a somewhat unrealistic alternative, mixing Pu with high-level radioactive waste has been proposed, for instance by vitrification and disposing it in proper geological structures. If, however, significant quantities of plutonium remain in whatever form stored on our planet, the risk of weapons proliferation will greatly increase and the diversion of only tens of kilograms of plutonium for criminal or subversive acts could cause crises world-wide. Reactorgrade plutonium can also be used for

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weapons purposes, even if it is not as effective as weapongrade material. With 7.5 kg of reactorgrade plutonium a bomb with an output in the kilotons TNT-range can be built.

At the end of 1990 the world Pu stocks and surpluses had accumulated to about 900 tons **(Fig. 6)**, the major portion in the nuclear weapons countries, but roughly 175 tons in non-nuclear weapons countries. Some 20 tons of reactorgrade Pu were accounted to countries, which had not signed the Non-Proliferation Treaty. Over 500 tons were at that time contained in irradiated fuel. The Pu-stocks inventory increases year by year **(Fig. 7)** as shown in the cumulative amount of fissile plutonium in spent fuel alone. The table shows for 1990 an amount of 531 tons in irradiated fuel. In 1995 about 750 tons will be in irradiated fuel and in the year 2000 one thousand tons of reactorgrade plutonium will have accumulated, if no Pu-burners are available.

The civilian reactorgrade plutonium contains Pu-240 between 25 % and 33 % depending on the uranium fuel type. Weapon-grade plutonium has less than 6 % Pu-240 and some 94 % Pu-239.

In the seventies the extraction of civilian plutonium by special separation plants was justified for the use in fast neutron plutonium breeder reactors. Unfortunately the experimental fast reactors encountered a number of serious problems and could in general not be operated safely. Therefore, with very few exceptions, the fast breeder reactor programs were terminated in several countries.

In order to make use of the existing plutonium stocks the use of Pu as **m**ixed **ox**ide fuel (MOX) in light water reactors was suggested. Several important countries are engaged in Light Water Mixed Oxide Fuel Reactors on the basis PuO_2-UO_2. The method requires reprocessing and produces new plutonium and therefore cannot claim to be nonproliferative. Nevertheless this is an option the nuclear industry has chosen so far for the separated civilian plutonium, even if modifications in existing light water reactors are required.

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III. 2 The Radkowsky Nonproliferative Light Water Thorium Nuclear Reactor

The concern about a massive increase of nuclear weapon materials arises from the fact that an 1000 MWe light water nuclear power reactor produces approx. 200 to 300 kg plutonium in its core annually. Therefore the present 335 light water reactors with some 290 000 MWe power have produced 58 000 kg Pu in the year of 1994. This amount would be enough to feed additionally some four to five-thousand nuclear weapons in the 100 kilotons range.

In order to overcome these problems Alvin RADKOWSKY proposed a new approach to reactor core design under the boundary condition of utilizing proven light water technology and thorium. The core should be suitable to replace present cores in light water reactor systems with none or minor alterations only. The design became known as the „Radkowsky Thorium Power Reactor".

Already in 1980 A. RADKOWSKY et al. published an article entitled „The Optimization of Once-Through Uranium Cycle for Pressurized Light Water Reactors". In this paper the authors point out that the optimum enrichment for nonproliferative U-235 is 20 %. A uranium core design under this condition leads to a reduction in core volume by about a factor two, while at the same time the safety will be enhanced as a result of utilization of metallic fuel elements. The plutonium discharge would be reduced at least by a factor seven. There is no need to employ soluble neutron absorbers for control purposes. Using the experience gained by the former studies the concept of the nonproliferative light water thorium reactor evolved. The concept provides an economic approach to the utilization of the nuclear potential of thorium in an „Once-Through Put Away Cycle".

Thorium is at least as plentiful as uranium despite of the fact that there have not been any exploration efforts so far. Thorium offers no attraction from either nonproliferative or economic standpoints, if it is used uniformly mixed with uranium of relative low enrichment. Studies revealed that the plutonium burn-up was less than in standard light water reactors, but a relative large amount of U-233 was created, which has weapon potential.

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A. RADKOWSKY embarked on a completely different core layout utilizing a special multiple-seed blanket arrangement. The seed regions are fuelled with nonproliferative uranium with 20 % U-235 in zirconium alloy. The blanket fuel elements are supposed to be thorium oxide spiked with a few percent of nonproliferative uranium oxide (20 % enriched to U-235). The seed regions have a very high water to fuel volume ratio. This leads to a good thermal spectrum and minimizes the capture in U-238 with the result of a high value of the seed multiplication constant, which in turn maximizes the fraction of core power obtained from the blanket. Another advantage is the minimization of plutonium production. Natural thorium contains no fissionable isotopes, but thorium is by neutron capture converted to the fissionable isotope U-233. The transformation of thorium goes via Pa-233. For a given neutron input the energy obtained from thorium is less than from uranium at short irradiation, but if thorium remains for a longer time in the core, this disadvantage is offset. In order to get an optimum power output from thorium, the geometry of the core arrangement is essential (seed-blanket system).

It is now planned to refuel the seeds at three-year intervals and the blankets at nine-year intervals. By use of successive seeds the blanket can be irradiated to the full metallurgical lifetime of about 100 000 MWd/T. This fact is supported by earlier Oak Ridge experiments. The importance of the concept is that the energy from thorium is obtained by burning in place the U-233 as it is formed. It is not necessary to extract the U-233 and fabricate it into fuel elements. Thus thorium can be utilized for production of nuclear energy without the need for a new fuel cycle. The inclusion of small amounts of uranium in the thorium oxide blanket rods leads to an economic gain and eliminates the need for soluble boron control during operation. Nevertheless soluble boron can be foreseen for emergency shut-down purposes. The seed blanket core arrangement has a strong negative moderator coefficient, which will simplify adjustment of load variations. The residual U-233 could conceivably be utilized for weapons. However, as stated above, the blanket fuel elements also will contain some nonproliferative uranium oxide (enriched up to 20 % U-235). As a result the U-233 will be denatured by being uniformly mixed with nonfissionable U-236 and U-238. An important difficulty in utilizing U-233 is the very high Gamma-radioactivity accompanying it. This Gamma-activity arises in a complex chain reaction from the isotope U-232. Over the Th-232 (n,2n)-reaction and a Beta-decay one arrives at Pa-231. By neutron capture of Pa-231 Pa-232 is formed and this by Beta-

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decay goes to U-232. Because of the very high Gamma activity of U-232 it would be very difficult to separate out U-233 making the whole system even more nonproliferative.

To make proper use of plutonium in connection with thorium in analogy to the 20 % U/Th-cycle an „Once-Through Put Away Cycle“ with Pu/Th was studied (**Fig. 8**).

A further important feature of the Pu/Th and the enriched U/Th-cycles is the virtual absence of transuranium elements, which are very difficult to be handled in a final storage of normal uranium spent fuel. The actinides have a high biological risk and hundred thousands years of half-life as seen in **Fig. 9**. In the absence of the actinides the final underground depository comes to the biological risk level of uranium ores contained in the earth crust after about 300 years. With actinides the risk level would be several orders of magnitude higher.

In recent publications costs for underground storage of spent fuel elements with actinides were quoted to be about ten thousand millions of US dollars. Adopting the Radkowsky Thorium Power Reactor concept would nearly save all of these quoted expenditures.

The main advantage of the thorium-based fuel cycles in thermal reactors is that is has a higher neutron yield of U-233 in comparison with the neutron yield of Pu-239 in the U/Pu-cycle. One possible approach to adjust the absorption rate in the fertile species is to alter the neutron spectrum by changing the degree of moderation. This can be achieved by adjusting the water volume to fuel ratio. The above idea is also incorporated in the RTPR concept.

III. 3 Other Work on Thorium Utilization in PWRs

Proper utilization of thorium was part of several national and international programs already in the past. Unfortunately none of the previous investigations, however, were of nonproliferative nature.

In 1969 a government agreement of cooperation in the field of science and technology between Germany and Brazil was signed and a program between KFA Jülich and NUCLEBRAS on the thorium utilization of PWRs was started in 1979. The program was

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planned to run in three phases with phase 1 from 1979 through 1983. In this period the technological basis for further work on $(Th,U)O_2$ fuel for PWRs was established and the feasibility of the chosen fuel cycle was proven in principle. In phase 2 nuclear core design and initiation of development of $(Th,Pu)O_2$ fuel as well as spent fuel treatment were the main themes. The program was terminated in 1988 after the advantageous features of a once through Pu/Th fuel cycle with high burn-up were confirmed.

Major activities in the area of thorium based nuclear fuels have been reported besides Brazil and Germany from Argentina, Australia, Canada, China, France, India, Italy, Japan, Pakistan, Rumania, USA, USSR and by the International Atomic Energy Agency (IAEA), Vienna, Austria. A number of countries terminated their efforts in the eighties, but others have still programs running directed towards high temperature reactors, heavy water reactors, light water reactors and fast breeders. The theoretical and experimental studies comprise of nuclear core design and strategy calculations, thermal and mechanical fuel rod evaluations, technological development for $(Th,U)O_2$-PWR fuel such as pelletizing ex-gel technology, transfer of $(Th,U)O_2$-fuel technology to $(Th,Pu)O_2$-technology, irradiation testing and post-irradiation examination as well as fuel storage assessment and reprocessing studies such as the THOREX process.

Between 2-4 December 1985 the IAEA convened a Technical Committee Meeting to assess „Thorium-Based Nuclear Fuel: Current Status and Perspectives". At this meeting main emphasis was given to the utilization of thorium fuels in once-through nuclear fuel cycles. In an overview of world thorium resources it was stated that reasonable assured resources (RAR) of thorium are estimated at about 1.16 million tons. About one third of this amount is available in the beach and in inland placers of India. Other countries which have sizeable reserves are Brazil, Canada, China, Norway, the former USSR, USA, Burma, Indonesia, Malaysia, Thailand, Turkey, and Sri Lanka. Thorium appears mainly in association of uranium and rare earth elements (REE). The present knowledge of the real thorium resources is poor, because there is practically no exploration effort due to insignificant demand.

As an outflow of the German-Brazilian cooperation a nuclear core design for the KWU-standard 1300 MWe PWR was performed. It was found that the KWU-type reactor can be

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operated without changes and restrictions in open and closed fuel cycle modes with all types of fissile material investigated. In the Th/Pu cycles without recycling great savings can be realized, when using Th/Pu instead of uranium fuel in existing reactors. In order to avoid the need of early reprocessing and to strive for reasonable savings, the „Once-Through Put Away Cycle“ with extended burn-ups was recommended. This means for the Radkowsky Thorium Core after remaining for about 10 years in the reactor being put away to final storage without reprocessing.

For more than ten years the Commissariat á l'Energie Atomique and the Electricité de France have jointly carried out experimental design studies for the thorium cycle in unmodified PWRs. The studies first concerned the use of plutonium with thorium to start the cycle. The French investigators came also to the conclusion that burnable poisons are no longer necessary, when the assemblies are loaded in rings. To start the Th-U-233 cycle two possibilities were considered:

a. the high enriched Uranium/Thorium/U-233 cycle and
b. the Plutonium/Thorium/U-233 cycle.

The French group proposed the solution to start the Th/U-233-cycle in unmodified PWRs in loading the whole reactor with Th/Pu-assemblies from the first core with three different Pu assembly concentrations in ring form. The use of thorium as a fertile material is also especially suited for heavy water moderated reactors. High conversion ratios are reached and even breeding might be expected. It is, however, a fact that light water reactors, not the heavy water reactors, have been commercially established in the last two to three decades.

Nine papers were presented at the before mentioned IAEA 1985 Technical Meeting exploring the following subjects in some depth:

- evaluation of world thorium resources and incentives for further exploration;
- basic research results of physical, chemical and nuclear properties of thorium;
- reactor core and blanket concepts regarding utilization of Th-based fuel;
- advanced thorium fuel fabrication technology and reprocessing of thorium-based fuel.

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The final panel discussion concluded: for a long-term fuel supply thorium could be recovered at costs less than US $ 80 per kg in the amount of about 2.4 million tons.

For a long time it was believed to be impractical to breed with light water reactors; however, since the value of η for U-233 is only slightly lower in the epithermal region, while that of U-235 and Pu-239 is greatly reduced, the thorium cycle appears to be most attractive for thermal conversion.

The Radkowsky Thorium Power Corporation (RTCP), owner of the property rights of the Nonproliferative Radkowsky Light Water Thorium Reactor, joined forces with UE&C Nuclear, Inc. (Raytheon) to fully develop and build a Thorium Power Reactor as described before. Raytheon in particular is providing engineering, construction and support services based on their experience with a great number of nuclear plants operating in the United States.

Both companies are in contact with the Russian Research Center - „Kurchatov Institute“ in Moscow. This Institute has a vast know-how in the nuclear arms development, dismantling of nuclear arms and the utilization of thorium for power reactors. The Institute has a staff of roughly 14 000 coworkers and under the leadership of the Institute's Vice-President Academician N. PONOMAREV-STEPNOI is prepared to verify the nuclear data base and reactor codes for the thorium power reactor concept in using benchmark models and experience of thorium irradiation. A further objective is a confirmation of the reactivity effects and control mechanism and validation of neutron-physical and thermohydraulic characteristics of the core design. Finally a 1000 MWe VVER-reactor will be made available to accept a full Radkowsky type thorium core. A feasibility study was submitted in December 1994 by the Russian Research Center „Kurchatov Institute“ confirming the basic Radkowsky concept.

The above relationship is also supported by efforts of US national laboratories such as the Brookhaven National Laboratory.

In Russia and the former Eastern Bloc countries about 45 light water pressurized power reactors are in operation; 14 are under construction. The total power output of these reactors

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will be more than 42 000 MWe. Seven VVER-1000 units are operative in Russia, ten in the Ukraine and two in Bulgaria (**Fig. 10**). As some of the VVER reactor types do not meet Western safety standards, a number of multimillion dollar upgrading programs are under way. A full Pu/Th or 20 % U-235/Th core of the Radkowsky design could contribute to safety improvements of Russian built Pressurized Water Power Reactors (PWPRs), but in the Western countries there are about 160 PWPRs with sufficient licensable life to justify retrofit deployment of the Radkowsky thorium reactor core concept.

IV. Consequences of a global nuclear exchange

The two atomic weapons used in warfare were dropped on Hiroshima and Nagasaki, Japan, in August 1945. The yield of the Hiroshima bomb was about 15 000 tons TNT equivalent, while the Nagasaki bomb had a yield of slightly over 20 000 tons of TNT. It is reported that the casualties were 120 000 people immediately and some 250 000 fatalities up to 1990. In Nagasaki approximately seven square kilometers were destroyed, while in Hiroshima about thirteen square kilometers of urbanized area were devastated. The two bombs were exploded in the air some 500 meters above ground. The blast damage and the damage by heat irradiation were for these heights at a maximum, but the radioactive fallout was at a minimum. The heat intensity had the most direct consequences so that people being away several kilometers from the hypocenter suffered serious skin burns. The enormous pressure waves damaged buildings and other construction works three to four kilometers away. The relative low yield nuclear explosions showed that the destructive power of nuclear weapons is immense. Nowadays weapon yields can reach million tons of TNT and thus can destroy also large cities within a few seconds. Typical strategic warheads are in the range of about 200 000 tons of TNT. The atmosphere is effected by the explosion of nuclear devices over large areas and radioactive fission products and neutron-induced radioactivity contaminate the environment and can extinct any life being plants, animals or human beings.

When a nuclear device is detonated, the fissionable materials uranium and/or plutonium become volatile within 10^{-6} seconds. The effective radiation temperature reaches about 40 million Kelvin. A blast of X-rays is the result of the intense power. Fires initiated by the nuclear explosion are mostly of secondary nature, because the blastwave extinguishes fire ignited by the primary heat sphere.

Scenarios for a global nuclear war have been discussed in a number of publications such as the US National Academy of Sciences, the Office of Technology Assessment and the National Research Council. The National Research Council published its nuclear war scenario in 1985 assuming that 6 500 megatons of TNT equivalent were detonated by 25 000 devices between 50 kilotons and 1.5 megatons plus tactical 1 500 megatons in surface bursts and the same amount in urban zones and 500 megatons of smaller tactical devices. The term „overkilling capacity" evolved from these scenarios and to the layman it is frustrating to hear that the overkilling capacity is reaching one hundred, which means that all life on planet earth could be extinguished one-hundredfold, or putting it in other terms, if only one percent of the nuclear weapons available reach their targets, life would virtually be coming to an end.

It seems needless to discuss the consequences of a global nuclear warfare, but also a local nuclear exchange would have pronounced ecological and climatic effects, in particular on agricultural productivity and the availability of food after a local nuclear exchange. To arrive at precise estimates of a limited nuclear war on humans and the duration with severe effects for humans, is difficult or even impossible. But from the energy involved it is no over-estimation to say that billions of human beings may die immediately or within a short period of time. It is known that current strategic deterrence policies imply that in an escalating nuclear conflict the majority of warheads may be targeted directly against urban and industrial centers.

In summary the effects of a nuclear war can be characterized:

1. Direct consequences:

   a. Devastation by shock-wave; 500 km^2/MT
   b. Mushroom fireball has a vertical velocity of 100 m/s; explosions over 100 000 tons reach up to the stratosphere and fire damages extend to 250 km^2/MT
   c. Radioactive fallout with lethal dosis value of 4.5 Sv:

in the first 48 hours	1000 km^2/MT
within 50 years	2000 km^2/MT

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2. Indirect consequences:
   a. Meteorological and climatic effects
   b. Ecological and biological effects
   c. Adverse effects on food production

Because fifty years have passed since the first and only use of nuclear weapons for warfare a great number of political leaders claim that the nuclear balance between the two super-powers made this possible. The large number of nuclear warheads in stock on both sides convinced their leaderships that nuclear wars cannot be won by neither party. Independent of the encouraging NPT decision to keep indefinitely in force the validity of the Treaty, it was more or less a general consensus that the present nuclear weapons states are allowed to maintain a minimum deterrence force. It must be remembered that at the time, when the NPT was signed in 1968 less than ten-thousand warheads existed. At its maximum a few years ago the number of warheads was approximately 60 000. The NPT review conference was not an end for itself. It is playing a key-role to lead to a cessation of the nuclear arms race. It could well lead to a complete disarmament under effective international control.

What is happening to nuclear weapons could be extended to other mass destruction means including chemical and biological warfare. One can only hope that a large majority of countries identifies itself and supports such ideas.

V. Nuclear weapons verifying and safeguards systems

The accumulated amount of weapongrade and reactorgrade plutonium was discussed before and summarized (see **Figs. 6** and **7**). By now the total plutonium inventory amounts to about 1100 tons. Highly enriched U-235 in nuclear warheads both in the United States and Russia exceed 1000 tons and in thermonuclear devices about 200 kg tritium is available. Not only the number of nuclear warheads but also the nuclear materials in the warheads must be safeguarded and verified from time to time. Sophisticated technical regimes have been developed for control and verification. Particular attention was given to submarine-launched cruise missiles (SLCMs), submarine-launched ballistic missiles (SLBMs), intercontinental ballistic missiles (ICBMs) and aircraft bombs and missiles.

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Already in 1962 the Government of the United States of America, in order to lend its support to building-up a safeguards system by the International Atomic Energy Agency, signed an Agreement that the Agency's safeguards could be applied for test purposes to four US reactor facilities. As a conclusion the inspectors recommended that qualified auditors, statisticians and highly qualified technical personal could assure themselves with reasonable accuracy on the situation of a given facility. It was, however, strongly pointed out that the most convincing and accurate information on a possible non-peaceful diversion of nuclear materials could only be obtained by destructive or non-destructive analysis of the fuel in question. Gamma-spectroscopy of the fission products was pointed out as one possibility, since it is possible to select an appropriate number of characteristic fission product Gamma-lines covering different half-lives. This way information on fissionable material burned could be obtained and also information of the history and the total neutron flux seen.

Modern technology has made the cruise missiles a strategic nuclear weapon able to target very precisely any location in the world over long distances. Also nuclear detector equipment was improved dramatically. A short summary for the verification of nuclear arms is given in **Fig. 11**. Portable monitors for detecting fissile materials and chemical explosives are available as well as very improved Gamma-ray and neutron detectors, which can also be operated from helicopters. Satellite observation and guiding techniques with a resolutions in the cm-range exist besides video-surveillance and monitoring electronic seals. Further control possibilities are environmental sampling to detect releases of radionuclides and detection of so-called „signatures" typical for a particular nuclear fuel cycle. Institutional control mechanisms are on hand, which involve various political, economic and diplomatic strategies to control sensitive materials and facilities up to a complete technology.

Technical arguments are not always crystal-clear proves. Negotiations on limiting the testing of nuclear weapons demonstrated, how technical arguments can be misused to promote a particular political argument. The main obstacle to reduce and stop nuclear testing was not the feasibility of adequate verification, but rather the unwillingness to address the real question, whether the nuclear weapons states should in the interest of global nuclear nonproliferation give an end to the development of new nuclear devices. As a test ban treaty did not emerge so far, the conference issue of extending indefinitely the Non-Proliferation Treaty-Agreement

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was for some time in jeopardy. Meanwhile two nuclear weapon countries have announced plans to possibly reopen underground nuclear tests, before a test ban treaty can enter into force in the middle of 1996.

VI. Outlook

If 1100 tons of plutonium must be stored, 275 000 shipping containers are required (a maximum of 4 kg plutonium in each container). Cost requirements for storing 1 gram of plutonium per year have a band-width of US $ 1 to 2. Therefore between 1.1 and 2.2 billion US $ must be provided per year. When using MOX-fuel in light water reactors twelve reactor units of 1000 MWe each would be able to burn in a ten-year period 100 tons of weapongrade or reactorgrade plutonium, but MOX-fuel will produce for each unit plutonium burned two-third units of new reactorgrade plutonium. The nonproliferative Radkowsky thorium reactor system will be able to burn about 850 kg plutonium in a 1000 MWe PWR per year. As a plutonium burning system there would be virtually no plutonium produced.

In the last decade opinion polls in favour and against disarmament inspections were taken in the United States, UK, France, India, Germany and Japan. A majority of the population - between 70 and 92 percent - supported disarmament inspections. Being asked, if mankind should drive for a nuclear weapons-free world, a huge majority find the idea desirable but believe that it is not yet feasible. An almost unanimous support was given to the proposal to undertake every effort for reaching finally a nuclear weapon-free world with the argument that otherwise self-extinction may be the consequence for mankind.

Since the Cold-War ended the risk of nuclear wars between the super-powers has become remote and this is one of the reasons, why stocks of nuclear weapons both in the United States and Russia are being drastically reduced by some 90 %. The Strategic Arms Limitation Treaty (SALT) initiated this huge weapon reduction, but in each of the two countries there are still about 6000 warheads available as deterrence force. It can be argued that a survivable force of about 2000 warheads would be more than enough to be considered a „finite deterrence force". In reality several hundreds of warheads would be enough. Under these circumstances pressures have been exerted onto the United States and Russia at the nonproliferation

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extension discussions to cut their military budgets and make the free resources available to deal with urgent national problems. In the United States alone it is estimated that over a ten-year period as much as 150 to 200 billion dollars could be shifted from military requirements to civilian purposes.

The weapon dismantling process would not be worth the effort, if it were not connected with a policy, what to do with the fissile bomb materials. The Radkowsky Thorium Reactor gives one possible answer. It gives also a positive answer to the continued need of the nuclear energy sources, because, in order to get rid of the plutonium and the highly enriched U-235 bomb materials, more than 100 existing pressurized water reactors in the world will be required for the next decades to burn the fissionable materials and eliminate these products for ever. Radkowsky Thorium Reactor Cores would not produce new plutonium and latest studies indicate that truly nonproliferative nuclear power reactors could evoke broad public acceptance of such nuclear power systems.

Only one alternative way exists theoretically, namely, to explode the bombs with all the consequences elaborated earlier.

The nonproliferation discussions were lengthy and tiresome, but because of the threads of a nuclear exchange above everybody's head, the final outcome was an unanimous agreement for an indefinite extension of the Nonproliferation Treaty. Thus we have a model on hand, how other divisive issues should be dealt with and agreed upon.

Vienna, June 1995

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REACTORS IN OPERATION AND NET ELECTRICAL POWER 1993

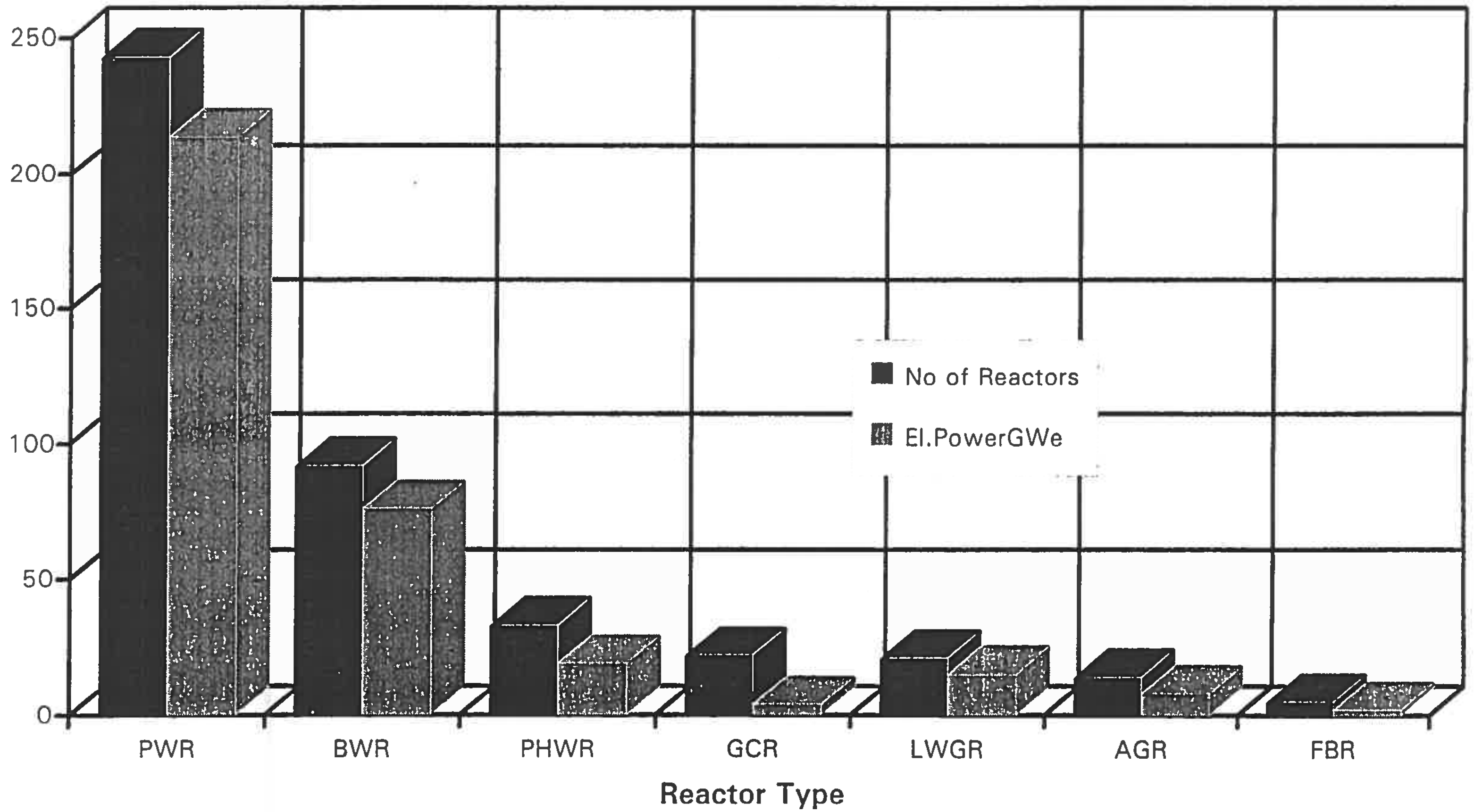
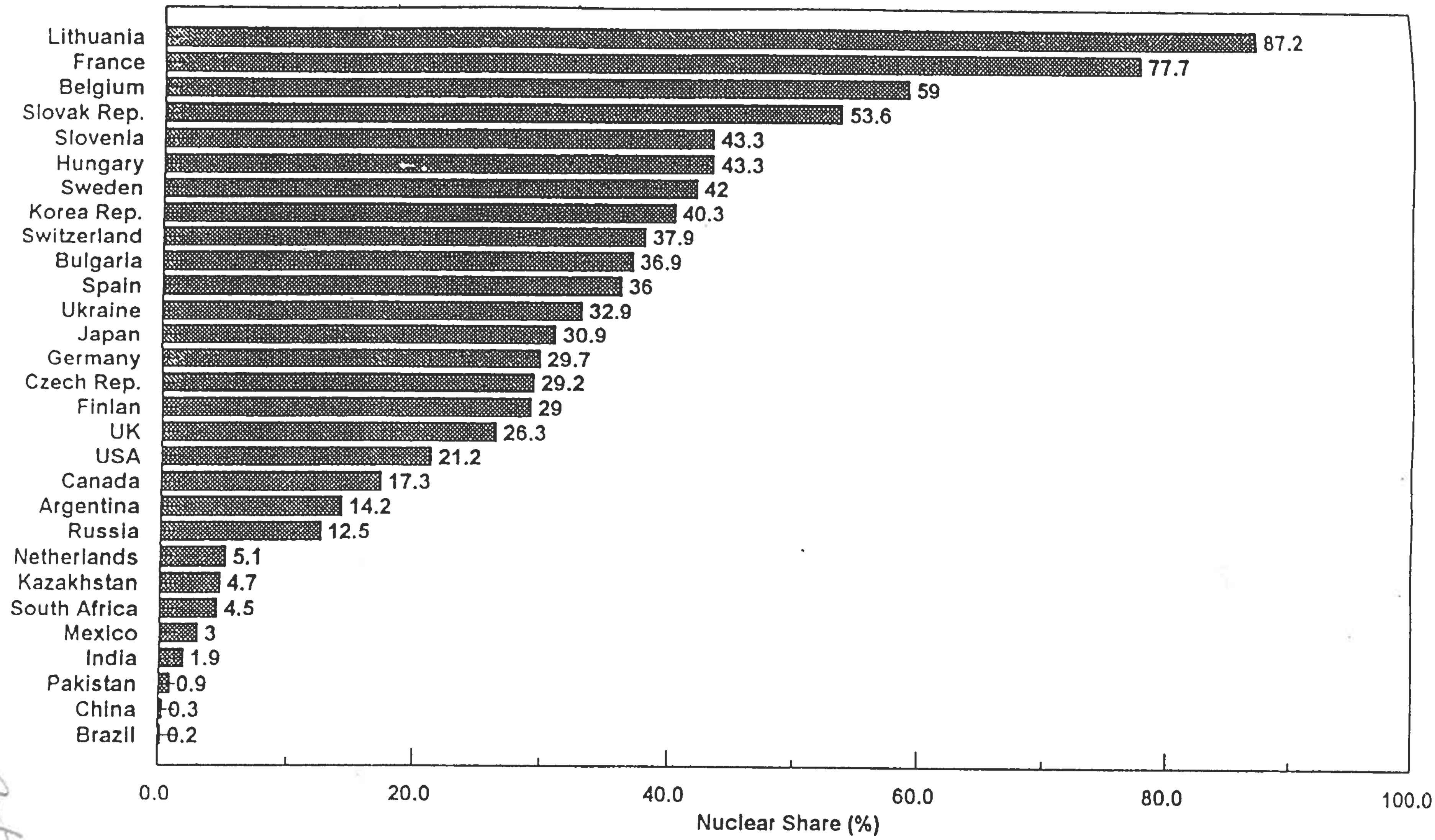


Fig. 1



Nuclear Share of Electricity Generation (as of 31 December 1993)

Fig. 2

WORLD LIST OF NUCLEAR POWER PLANTS
as of December 31, 1994

(operable, under construction or on order with 30 MW_e or over in 33 countries of the world)

Reactor Type	# Units (in operation)	Net MW_e (in operation)	# Units (total)	Net MW_e (total)
Pressurized light-water reactor (PWR)	245	215 669	284	252 461
Boiling light-water reactors (BWR)	92	75 861	98	81 891
Gas-cooled reactors, all types	35	11 699	35	11 699
Heavy-water reactor, all types	34	18 576	50	26 471
Graphite-moderated light-water reactors (LGR)	15	14 785	16	15 710
Liquid-metal-cooled fast-breeder reactors (LMFBR)	3	928	7	3 308
World total	424	337 518	490	391 540

NUCLEAR POWER PLANTS OUT OF SERVICE
as of December 31, 1994

68 Power Reactors	with 19 524 MW_e	in 11 Countries

Fig. 3

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COMPARATIVE ELECTRICITY GENERATING COSTS

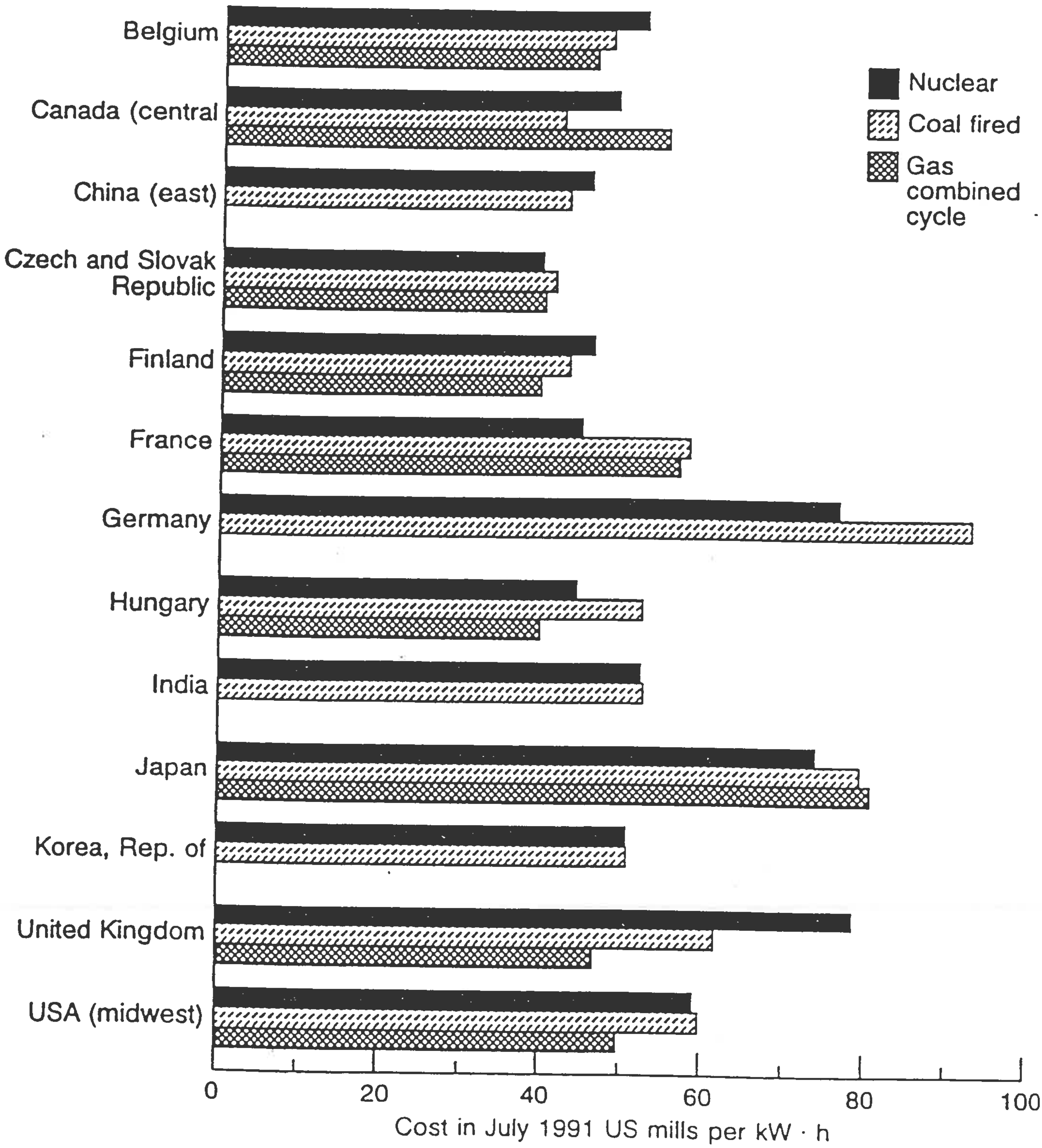

Fig. 4

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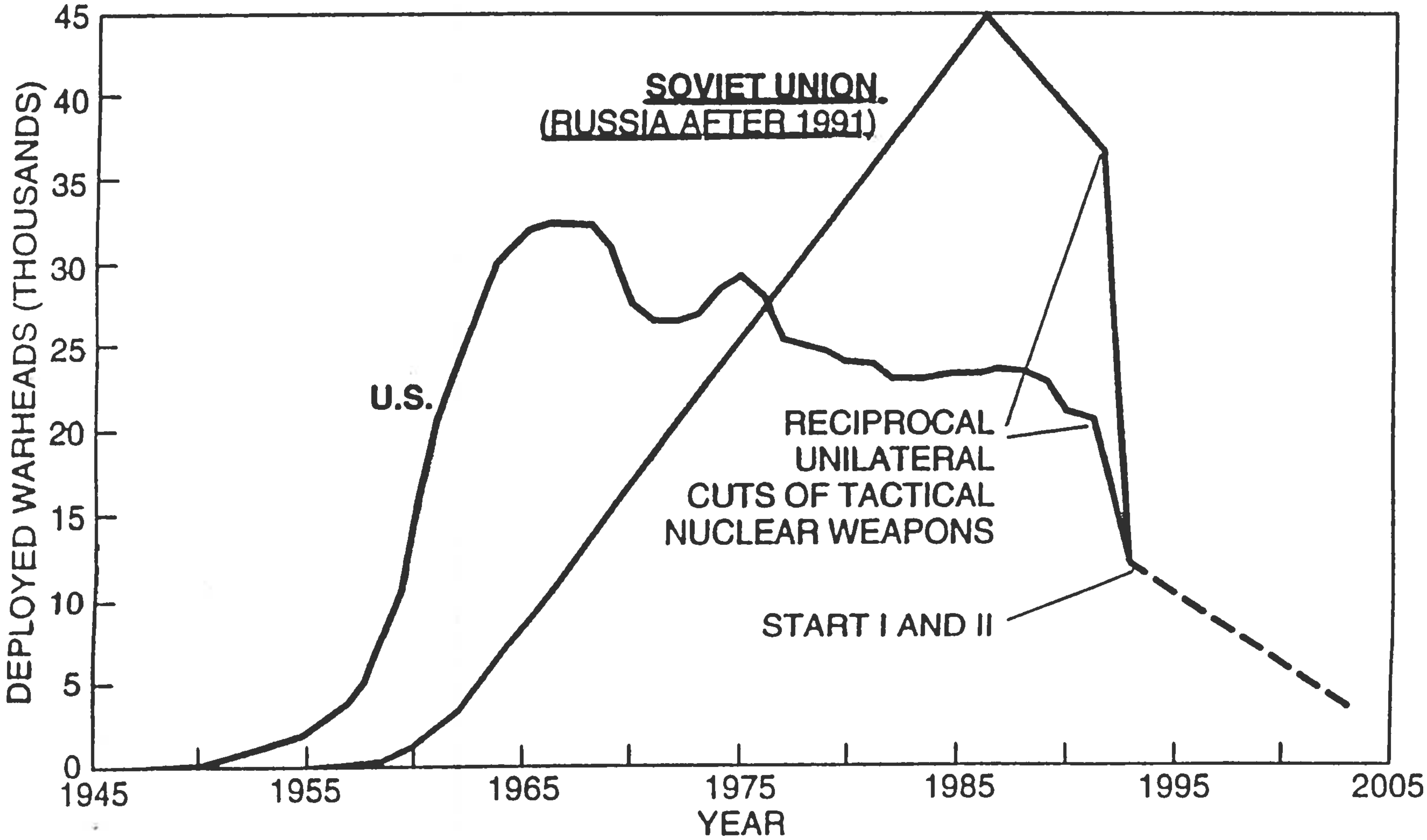
SOVIET UNION
(RUSSIA AFTER 1991)
U.S.
RECIPROCAL
UNILATERAL
CUTS OF TACTICAL
NUCLEAR WEAPONS
START I AND II
DEPLOYED WARHEADS (THOUSANDS)
0
5
10
15
20
25
30
35
40
45
1945
1955
1965
1975
1985
1995
2005
YEAR

Fig. 5

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SUMMARY TABLE OF WORLD PLUTONIUM STOCKS AND SURPLUSES AT THE END OF 1990
(in tons)

	Nuclear-weapons countries	Non-nuclear weapons countries	Non-NPT countries	Total
In weapons	260	0	< 1	260
Civil				
In irradiated fuel	296	218	17	531
	366	148		
Recycled in MOX	31	18	0	49
Stored as oxide	64	8	< 0.5	72
Total (by ownership)	651	244	18	913
Total (by location)	**721**	**174**	**18**	**913**

Fig. 6

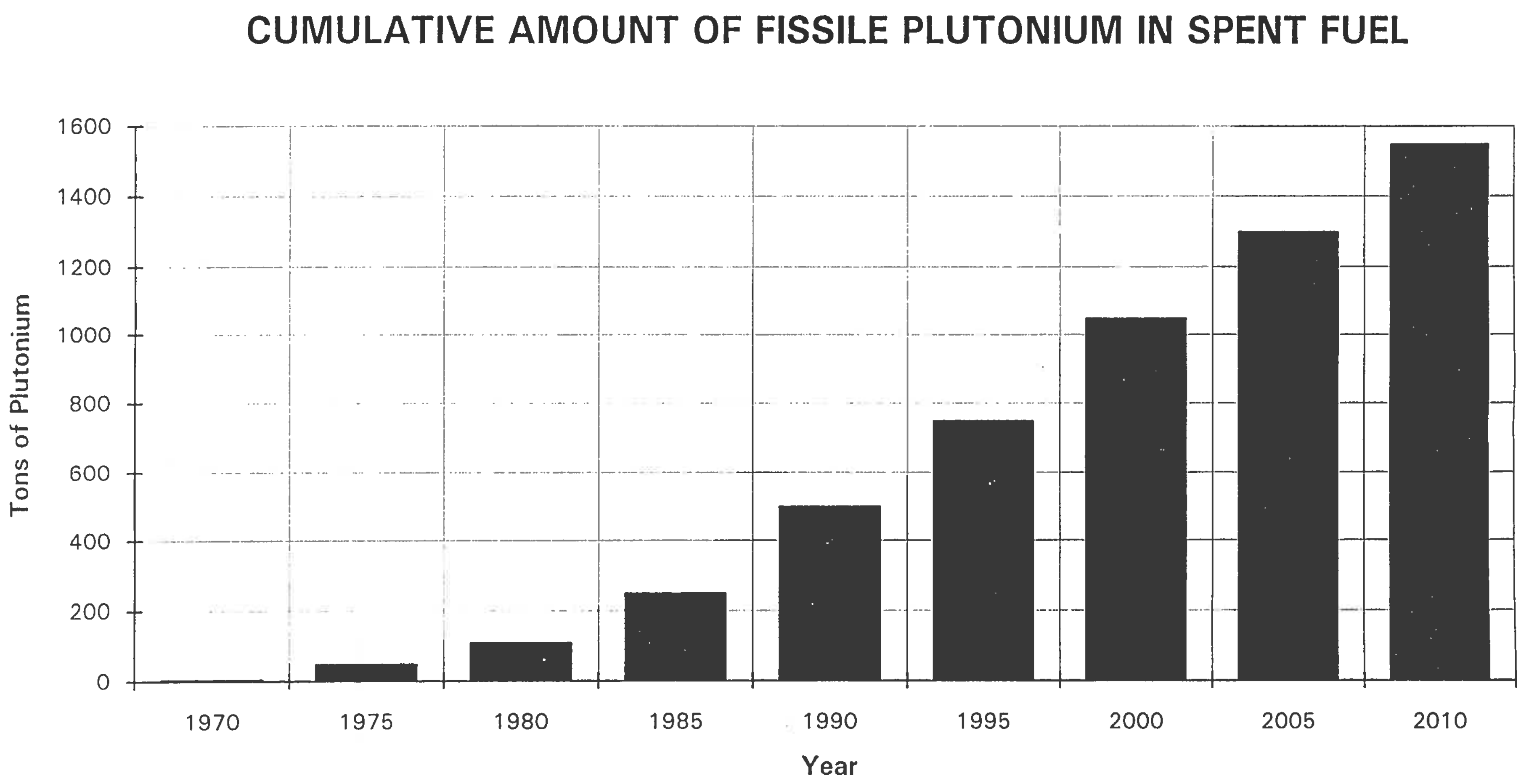
CUMULATIVE AMOUNT OF FISSILE PLUTONIUM IN SPENT FUEL
Tons of Plutonium
1600
1400
1200
1000
800
600
400
200
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

Fig. 7

WARHEAD PRODUCTION AND ELIMINATION ACTIVITIES

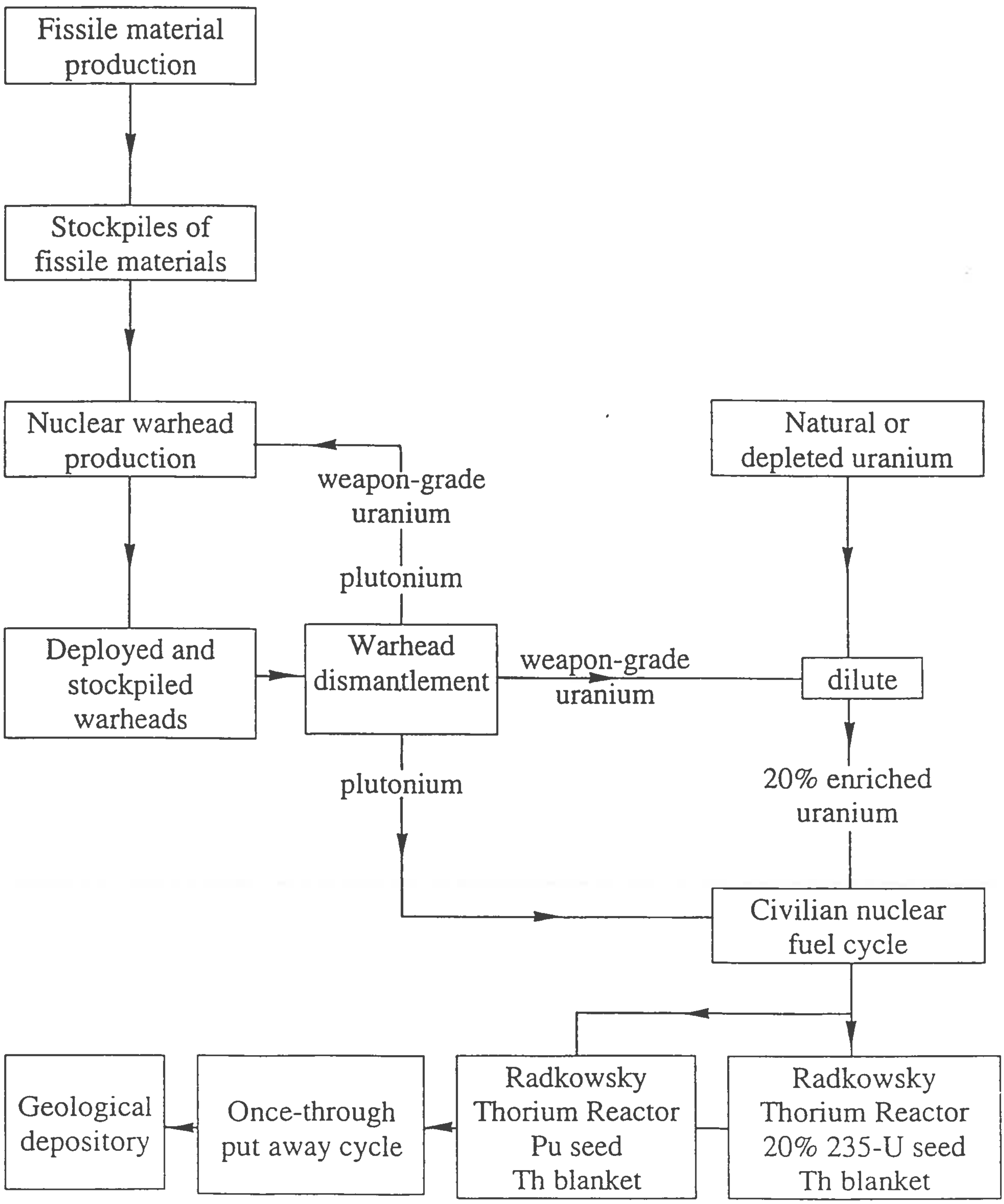

Fig. 8

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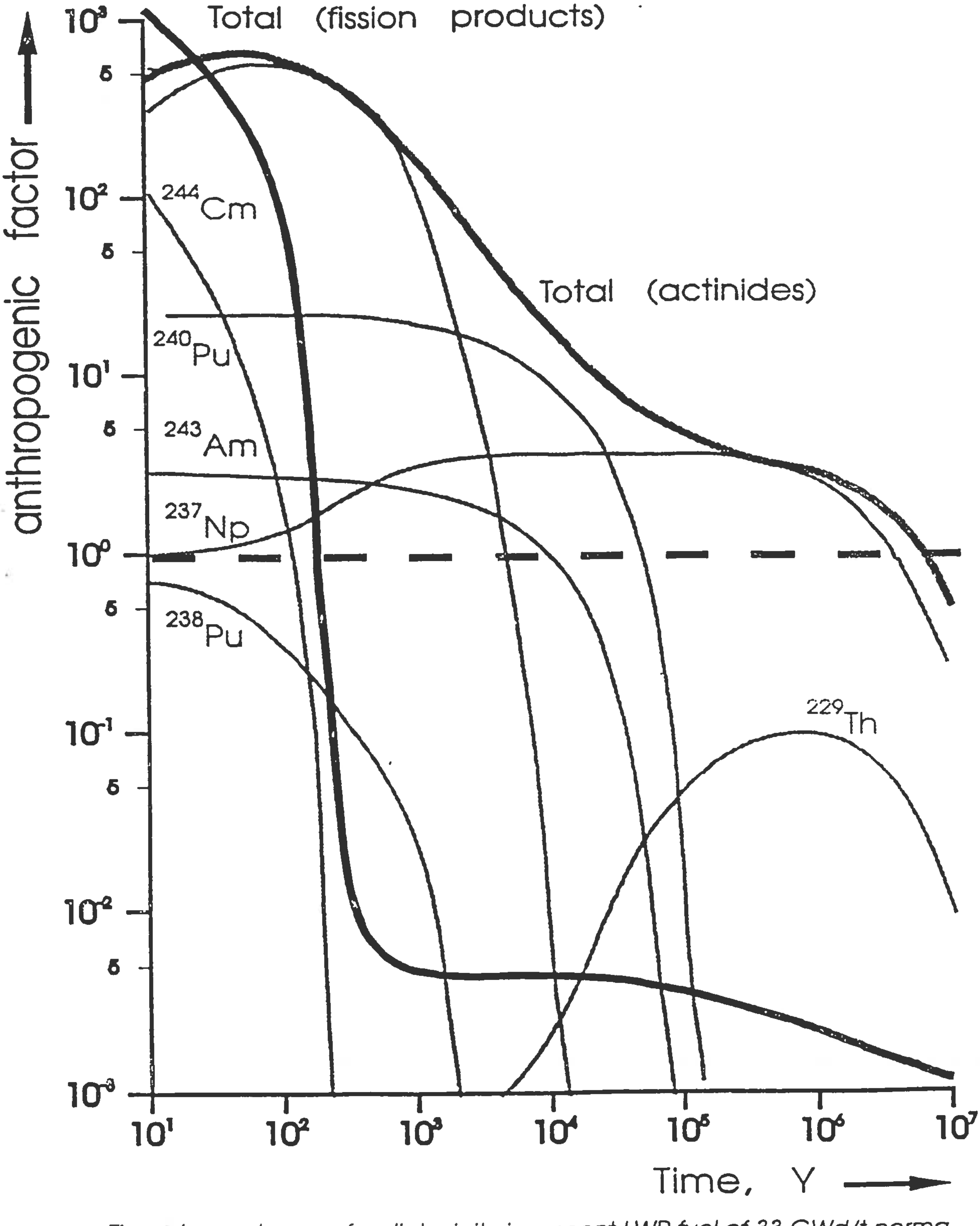

Time-dependence of radiotoxicity in a spent LWR fuel of 33 GWd/t normalised to the radiotoxicity of the uranium ore (dashed line) mined to produce the fuel.

Fig. 9

VVER REACTORS OPERATIONAL AND UNDER CONSTRUCTION IN DIFFERENT FORMER EASTERN COUNTRIES

	Operational	Under construction	Electric output in MWe
VVER 230			
Bulgaria	4	-	1.760
Slovakia	2	-	880
Russia	4	-	1.760
VVER 213			
Slovakia	2	4	2.640
Czech Republic	4	-	1.760
Finland	2	-	880
Hungary	4	-	1.760
Russia	2	-	880
Ukraine	2	-	880
VVER 1000			
Bulgaria	2	-	2.000
Czech Republic	-	2	2.000
Russia	7	2	9.000
Ukraine	10	6	16.000
Sum	**45**	**14**	**42.200**

Fig. 10

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VERIFICATION OF NUCLEAR ARMS

1. Warheads: All 55.000 warheads contain U-235 and/or Pu-239 either as fission bomb or trigger for hydrogen bomb

   HEU (Highly Enriched Uranium) 93.5 % U-235
   (U-234 1 % and U-238 5.5 %)

   WGPu (WeaponGrade Plutonium) 93 % Pu-239
   (Pu-240 6 % and others 1 %)

   Fission bomb consists of inner sphere of HEU and/or WGPu followed by 2 cm Be reflector, 3 cm temper (tungsten or uranium), 10 cm high explosive and 1 cm of Al-case).

2. Detection possibilities:

   Neutrons: HEU 1.6 N/s/kg
   WGPu 56 000 N/s/kg
   Neutron production mainly by spontaneous fission occurring in isotopes with even numbers (Pu-238, Pu-240, ...)

HEU weapon with tungsten	60	N/s
HEU weapon with depleted U	2500	N/s
WGPu weapon with tungsten	1.500.000	N/s
WGPu weapon with depleted U	1.500.000	N/s

Fig. 11

7-5 [illegible]