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AUSTRALIAN ATOMIC ENERGY COMMISSION

ILLICIT DIVERSION OF NUCLEAR MATERIALS

by

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ABSTRACT

This paper discusses the means of preventing illegal use of nuclear material by terrorists or other sub-national groups and by governments.

With respect to sub-national groups, it concludes that the preventive measures of national safeguards systems, when taken together with the practical difficulties of using nuclear material, would make the diversion and illegal use of nuclear material unattractive in comparison with other avenues open to these groups to attain their ends. It notes that there are only certain areas in the nuclear fuel cycle, e.g. production of some types of nuclear fuel embodying highly enriched uranium and shipment of strategically significant nuclear material, which contain material potentially useful to these groups. It also discusses the difficult practical problems, e.g. coping with radiation, which would face the groups in making use of the materials for terrorist purposes.

Concerning illegal use by Governments, the paper describes the role of international safeguards, as applied by the International Atomic Energy Agency, and the real deterrent effect of these safeguards which is achieved through the requirement to maintain comprehensive operating records of the use of nuclear material and by regular inspections to verify these records. The paper makes the point that Australia would not consider supplying nuclear material unless it were subject to international safeguards.

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The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12(INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

ACCOUNTING; IAEA SAFEGUARDS; NON-PROLIFERATION TREATY; NUCLEAR MATERIALS DIVERSION

CONTENTS

INTRODUCTION

Like many drugs, poisons and [illegible] in common use in our society today, nuclear materials are dangerous. As is the case with these other substances, we want to be assured that nuclear materials will only be used by competent and authorised people and that they will not fall into the hands of men of ill will. If by remote chance they do fall into the wrong hands we want to know about it as quickly as possible so that they may be recovered without delay. In this paper we consider the arrangements in operation to guard against this chance and we look at the two possible cases, i.e. diversion at sub-national level, e.g. by terrorist groups or individuals, and at a national level by governments.

SUB-NATIONAL DIVERSION

It has been suggested that a sub-national group might steal nuclear material and then use it for terrorist purposes or extortion. Presumably it would either use or threaten to use the material in one or more of three ways:

- as an explosive;
- as a biological poison; or
- as a radiation source.

The thief will not find it easy to use the materials in these ways even if he does succeed in stealing it (see Appendix A), but our prime concern is to prevent the theft in the first place. We must also bear in mind the possibility that the thief may be working within the field of atomic energy.

To prevent theft, national safeguards systems are established and the International Atomic Energy Agency has given six points of guidance to achieving an effective national system:

1. There should be a proper definition of responsibility and lines of authority, and of provisions for the application of sanctions as necessary by those responsible.

2. Nuclear material may only be held or used by those licensed to do so, and one condition for the grant of a licence must be that provision is made by the licensee to apply preventive measures prescribed by the licensing authority.

3. Preventive measures should be prescribed to match the requirements of the particular materials and the use involved.

4. In particular the measures to apply to material in transport and storage should be defined.

5. There should be arrangements to keep those responsible at the national level informed on the measures in use, and to make known to the operators of nuclear plants any changes in the requirements made of them.

6. Those responsible at the national level must make sure that the measures they prescribe are being properly carried out, and if this is not being done, that prompt and effective remedial action is taken.

These six recommendations are a useful basis for organising national arrangements for measures to prevent sub-national diversion of nuclear material.

Actual practice, taking heed of the six points, results in three main lines of defence. The first is clearly *containment*. It is directed to

(a) preventing unauthorised persons from gaining access to the nuclear materials; and

(b) preventing the unauthorised removal of the nuclear material whether by persons gaining unauthorised access or by persons having legitimate access to them.

Containment usually takes the form of physical barriers and/or guards who prevent unauthorised access or egress. Once the material is contained the protection offered by containment is reinforced by *surveillance* which is directed to

(a) forestalling unauthorised removal of material; and

(b) demonstrating that material has not been removed.

Standard forms of surveillance are guards, the use of sensors to detect the removal of radioactive material, and the use of cameras to survey areas. In this technological age sophisticated techniques of surveillance are available and are used.

Equally important, however, is *accountancy*. It inexorably records the quantities of materials, their locations and their movements. At all times the records will show the disposition of the nuclear material even though it passes through processing plants which change its form and concentration. They also show the history in terms of reactor exposure and record the extent to which uranium is burnt and plutonium created.

Records are periodically confirmed by the taking of inventories when the materials are seen, weighed, analysed and tested to ensure the correctness of the records.

As a whole, containment, surveillance and [illegible] [illegible] and physical inventories superimposed, make up what are known as safeguards. Properly operated, they make it extraordinarily difficult for anyone to steal material and further, they make it difficult to conceal a theft for any significant length of time.

It is important to appreciate that all parts of the nuclear fuel cycle are not equally attractive to thieves. In some areas the nuclear material is too dilute, in others it is so radioactive that the risks involved are unacceptable and so we can identify the attractive targets in the nuclear fuel cycle and pay special attention to them. Appendix B describes the stages of the nuclear fuel cycle in this context.

By employing proper safeguards measures, regularly reviewed to ensure their effectiveness, successful theft can be made so difficult as to be impracticable and not worthwhile in comparison with other means which the potential thief might employ to gain his ends. The nuclear power industry has never recorded a theft of nuclear weapon material, and safeguards are continually evolving and making the opportunity for theft even more remote.

A final comment on sub-national theft is that it has been suggested that to avoid the difficulties, dangers and uncertainties inevitably associated with an attempt to steal nuclear material and fabricate an explosive, the simple and sensible course for the would-be diverter is to look to a ready-made explosive from a military establishment. This would be obtained by some subterfuge such as bribing appropriate service people, rather than by attempting to steal it directly. At first glance the suggestion appears reasonable, but there is a major practical difficulty because military authorities are well aware of the potential of their explosives and they use very comprehensive fail-safe, 'defence-in-depth' measures to protect them. As a result there has been no successful theft of a nuclear weapon.

NATIONAL DIVERSION OF NUCLEAR MATERIALS

So far we have considered the possibility of theft from within a nation and the countermeasure of a national safeguards system. Now we examine the case of diversion by a nation or its representative government. Governments can overtly turn a country's efforts towards the manufacture of nuclear explosives; we recognise this possibility and if we know of their intention we can make the appropriate decisions with respect to supply of Australian uranium. Of far more concern to us would be governments, to whom we supply uranium in good faith, which covertly manufacture nuclear explosives.

Firstly we look to would-be purchasers of Australian uranium to have ratified the NPT* so that they too have an international obligation not to manufacture or acquire nuclear explosives if they do not already possess them. Secondly, if they have not ratified the NPT we want an undertaking by the importing government to the Australian Government that

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* Nuclear Non-Proliferation Treaty.

Australian material will not be used for the manufacture of nuclear explosives and that verification of this by an independent body will be permitted.

To achieve this verification we need a kind of international watch dog which would conduct both routine and spot checks to provide "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, and deterrence of such diversion by risk of early detection." The preceding quotation is actually a statement of the objectives of the International Atomic Energy Agency's NPT Safeguards System and it is of course the IAEA to which we turn to carry out the independent verifications that nations are being honest.

Australia, and many other nations, have ratified the NPT and brought into force the required safeguards agreements with the IAEA.

The Agency document INFCIRC/153, which is actually a blueprint of the NPT Safeguards agreement, sets down the principles which guide the formulation of such agreements. It requires that a safeguards agreement should contain, amongst other things:

- An undertaking to accept safeguards on *all* nuclear material used for peaceful purposes.
- A provision for the Agency's right to apply safeguards.
- A promise to cooperate with the Agency.
- The establishment, by the State, of a national system of accounting and control of all nuclear material used for peaceful purposes.
- A promise to supply information to the Agency in so far as it is needed for verification.
- A promise to permit Agency inspectors access to records and the opportunity to check material in a real, physical sense.

When an NPT Safeguards agreement is in operation the IAEA has the right, which it exercises, to verify that diversion is not taking place within a State. IAEA inspectors regularly visit Australia to confirm to their satisfaction that we can account for all our nuclear material, just as they visit other NPT countries. For further details of the NPT safeguards system see Appendix C.

If countries are not parties to the NPT it is still possible to apply an IAEA safeguards regime, as defined in Agency document INFCIRC/66/Rev. 2. In this regime the Agency and State mutually agree on facilities and materials to which safeguards will apply.

In summary, the IAEA can effectively oversee a country's national safeguards system and within limits*detect whether material is being diverted. The IAEA inspections also reinforce the national system's effectiveness against sub-national diversion. Australia will only supply uranium to non-nuclear weapon countries which will permit the IAEA to verify that our uranium is not being used to manufacture nuclear explosives.

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* Set by data quality, statistical parameters and measurement limits.

APPENDIX A

ILLICIT USES OF DIVERTED NUCLEAR MATERIAL

[illegible] national groups might use nuclear material to create threats or deliberate hazards in three ways:

1. as an explosive;

2. as a biological poison; or

3. as a radiation source.

The explosive - relatively small quantities of 'special nuclear material' (about 17 kg of the uranium isotope U-235, about 8 kg of the uranium isotope U-233, and about 6 kg of the plutonium isotope Pu-239) are required to make an explosive device. With such 'weapon-grade' high purity metal, sophisticated design, a suitable neutron source and explosive assembly device, precision manufacture and assembly of components, an explosion comparable with those at Hiroshima and Nagasaki can be achieved. But the efficiency of the explosive device depends critically on each of these factors - thus for example, reduction in the purity of the material, or decrease in design efficiency or standards of workmanship, would rapidly reduce the attainable explosive yield, and the probability of achieving a successful explosion. As an instance, uranium metal containing only 20% of the isotope U-235 requires a mass of about 350 kg to go critical, provided it is surrounded by a similar mass of natural uranium metal; however a significant change in neutron lifetime in this material markedly increases the difficulty of achieving detonation. But a crudely-made device, if it can be made to detonate, can cause a relatively powerful explosion (of the order of tons of TNT equivalent) and in addition can dissipate substantial quantities of highly radioactive materials.

The problem for the would-be diverter proposing to make and use an explosive device is to be sure that what he creates will behave as he plans. This of course does not apply if the material is stolen to be the basis for a threat.

The biological poison - plutonium, in common with other strong alpha particle emitters, is a highly radiotoxic material - some have called it the most poisonous substance known to man, - and it has been suggested that dispersion of relatively small quantities of powdered plutonium oxide or nitrate would cause widespread cancer in the affected population, and render the affected areas permanently uninhabitable because of its 24,000 year half-life.

However recent studies* have shown that while plutonium is very toxic - in common with other similar alpha particle emitters such as radium - it is certainly not the most poisonous substance known to man,

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* Cohen, B.L., 'The Hazards of Plutonium Disposal', Institute for Energy Analysis, Oak Ridge, USA, March, 1975.

[illegible] Table 1 compares the air concentrations of plutonium and some other poisons necessary to achieve 50% [illegible] after 4 hours inhalation (these fatalities wou occur within a short period after inhalation). Table 2 compares the [illegible] 50 fatalities by oral intake (in this case the fatalities from plutonium would occur from long-term induction of cancer, while the other poisons would cause short-term death).

Table 1

Poison	Concentration in milligrams per cubic metre
Nerve gas	less than 1
Plutonium-239	[illegible]
Cadmium fumes	10
Mercury vapour	30
Phosgene	65

Table 2

Poison	Amount in grams
[illegible]	10^{-7}
Botulism toxin	10^{-6}
Lead arsenate	0.1
Potassium cyanide	0.7
Plutonium	6
Caffeine	14

The studies also point out that dispersion of plutonium as proposed for contamination purposes is not particularly easy to achieve and need not necessarily have disastrous effects on the habitability of an area, because the area can be effectively decontaminated by physical and chemica means. Plutonium can be detected and measured easily even in minute concentrations and far more readily than equivalent or worse chemical poisons, thereby simplifying the determination of whether it has in fac been dispersed, or the extent to which decontamination has progressed.

Plutonium must be specially contained and handled with care to avoid exposure to its radiation and, if large enough quantities are involved, an accidental criticality incident. Meeting these conditions would involve a would-be diverter in the provision of the necessary facilities and expertise and he would have to accept the resulting complications in his procedures. The question facing him would be whether the desired toxic effects could not be achieved more easily from some o the more common, easily handled and in many cases more lethal poisons.

The radiation source - fission products and materials activated by expo sure to neutrons in reactors can produce high levels of radiation, whic could cause debilitation or death to exposed individuals. However the high levels of radiation make it necessary always to handle and transpo these materials inside massive, heavy shielding, so theft would be diff icult, handling of the material without proper shielding would be extr dangerous, while explosive breaching of the shielding to release and s the radioactive material would require very large amounts indeed of co ventional explosive.

The problem for the would-be diverter is whether the probable results would be commensurate with the risks and difficulties of the i use.

APPENDIX B

STAGES IN THE NUCLEAR FUEL CYCLE VULNERABLE TO DIVERSION

A typical nuclear fuel cycle is shown in Figure B1 and a consideration of the various stages, as in the following paragraphs, shows that there are only a few areas possible for diversion of material suitable for the uses described above.

Mining and milling - refers to mining of uranium ores and production of yellowcake. No materials are produced in this stage which if diverted, would enable terrorists to produce either a nuclear explosive or a radiation hazard. This stage may therefore be excluded from consideration.

Conversion - refers to the production of uranium hexafluoride from yellowcake. The hexafluoride is no more toxic than many other chemicals, it cannot be made to explode and so this stage too may be excluded from consideration.

Enrichment - is the process by which the percentage of the uranium isotope U-235 is increased from the 0.7% of naturally occurring uranium, to that required by the particular reactor concerned. 'Light water' reactors as exemplified by the Westinghouse & General Electric designs use an enrichment of about 3% which is produced in a plant specially designed for the purpose. This material cannot be made to explode and is no more toxic than 'natural' hexafluoride, nor can the plant produce significantly higher degrees of enrichment without substantial reconstruction. Theft from such a plant for terrorist purposes may safely be discounted.

Some research reactors, and a high-temperature gas-cooled power reactor (HTGR) being developed in the USA, require much higher percentages of U-235 in their fuel, typically between 80 and 90%. This material can be made to explode but is produced in different plants. The possibility of attempted theft from such plants for terrorist purposes has to be considered.

Fuel fabrication - refers to the operations of converting the enriched hexafluoride to oxide and incorporating this into reactor fuel elements. Theft of 'light water' reactor fuel for terrorist purposes may be dismissed as unlikely, except perhaps if plutonium were being used in place of some of the uranium. This recycling of plutonium is under investigation as a means of relieving the demand for enriched uranium and if it were introduced, sub-national groups might contemplate theft of such fuel if they had access to the chemical extraction facilities with controlled atmosphere and fully-filtered ventilation that are required to enable recovery of the plutonium from the fuel. The fuel itself cannot be made to explode. The same considerations apply to fast breeder reactor fuel which is a mixture of plutonium and uranium oxides. However in assessing the likelihood of an attempt at diversion of such plutonium-bearing fuels, it should be noted that as plutonium is progressively recycled, amounts of americium and californium associated with the plutonium also increase and these are important because, being strong emitters of spontaneous fission neutrons, they increase the radiation level of the plutonium - and hence the difficulty of handling it - and they also markedly reduce the probability [illegible] could be successfully constructed from such plutonium.

HTGR fuel may also be considered a probable target for diversion attempts because it contains uranium with a high percentage of the isotope U-235 or the isotope U-233, combined with thorium. The fuel itself cannot be made to explode, so once again the would-be diverter faces the necessity of extracting the uranium isotopes from the thorium and the fuel matrix. This is a comparatively simple chemical process but is not easy in practice because of the great difficulty of dissolving the fuel to enable chemical separation, and also because the high levels of radiation from products of the spontaneous radioactive decay of the U-233 require the use of substantial heavy shielding during processing, as well as in transport and storage.

Reactor - fuel in a reactor may be stored prior to insertion into the core, in the core itself, or in so-called cooling ponds after use in the core. Theft from store is essentially the same as from a fuel fabrication plant. Theft from the core may be discounted as altogether too complicated. Theft from the ponds would also be difficult and dangerous because of the very high levels of radiation from the used fuel and the necessity to use massive, heavy and cumbersome shielded transport containers.

Chemical reprocessing plants - recover plutonium and the uranium isotopes U-233 and U-235 (the latter isotope at percentages generally unsuited for explosive manufacture). Theft of such materials would involve using suitable shielding against the radiations associated with them as already described, and would thus be hazardous and comparatively difficult. But the materials offer possibilities of use for explosives or contaminants, so attempts at diversion must be considered.

Transport - it is generally simpler to apply effective measures against theft in a fixed establishment, than to a moving transport vehicle. Consequently those parts of the fuel cycle where material suitable for explosive or contaminant use is being transported between stages must be regarded as generally more attractive to the would-be diverter.

Summary - relatively few stages in the fuel cycle are probable targets for attempted theft. The most likely are: new fuel production (including supply of materials) shipment and storage; less likely stages are used fuel storage or shipment.

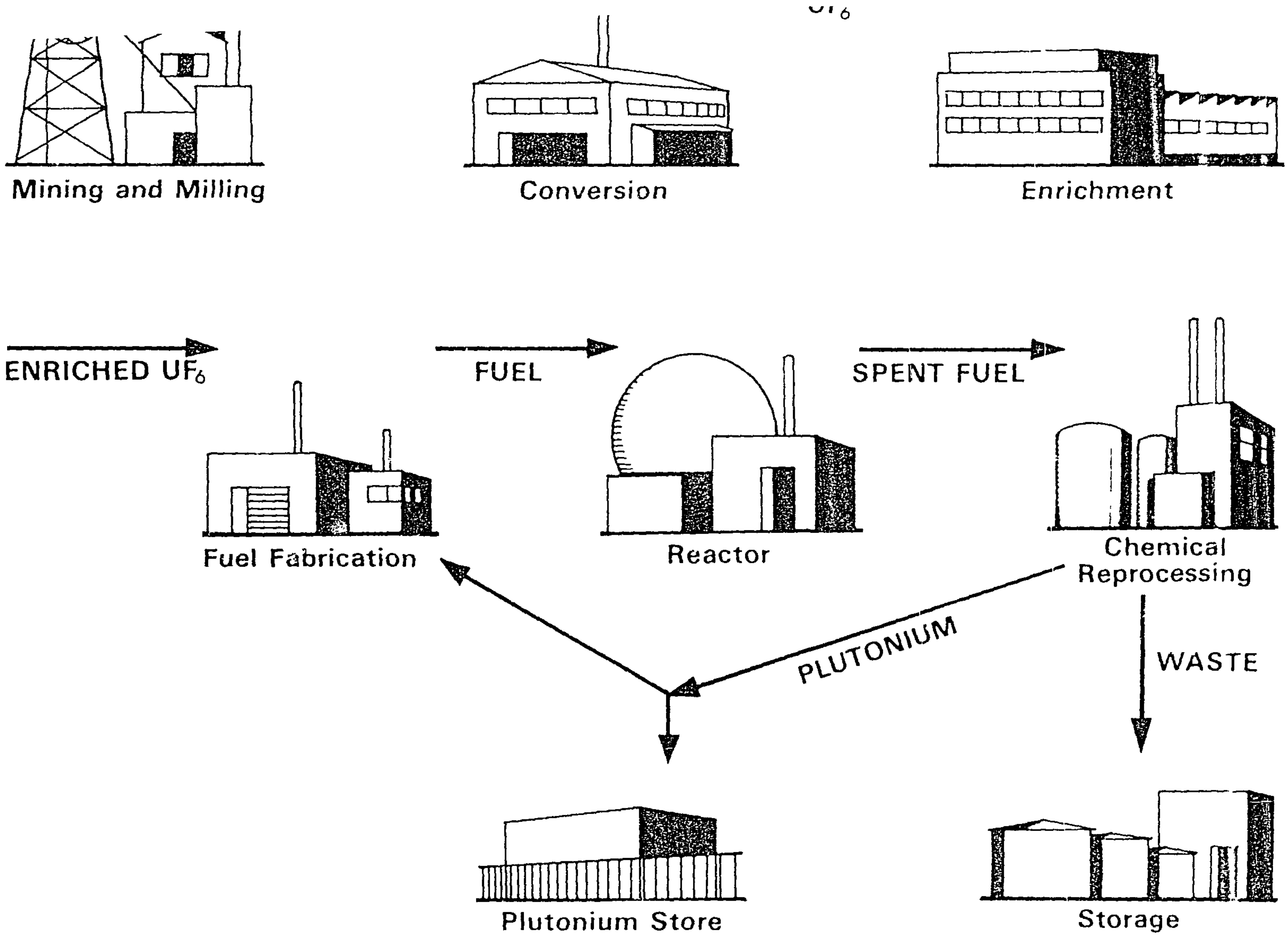

FIGURE B1. TYPICAL NUCLEAR FUEL CYCLE

APPENDIX C

THE INTERNATIONAL ATOMIC ENERGY AGENCY'S

SAFEGUARDS SYSTEM

The system builds on an initial inventory of safeguardable nuclear material declared by a state, using regular reports of changes in the amounts and distribution of nuclear material in a country to maintain a 'book inventory' which is periodically compared with a physical inventory or stocktaking by plant operators which is verified by IAEA inspectors.* The uncertainty associated with the closing of the material balance and which is caused by the attainable limits of accuracy on analysis, sampling, weighing, as well as unexpected losses, is a measure of the effectiveness of material control.

Verification by the IAEA of the material balance and the associated analysis of the uncertainty in the balance are the critical safeguards measures. By properly chosen sampling plans, independent measurements of samples, and analysis of operating procedures, the IAEA is able to determine what limits of uncertainty in a material balance are associated with normal operation in a given plant. Should the uncertainty obtained in a particular balance exceed the limit for normal operations, the Agency will investigate the reason, and if a diversion of a significant quantity of material has occurred, the Agency would then be able to determine, within the confidence limits associated with its statistical sampling and analysis, that this diversion had occurred.

The Agency can only detect a diversion after it has occurred, so the frequency of its inspections is set to enable such detection to occur before the diverted material could be converted into an explosive device. The Agency has no power to prevent a diversion, the action taken following the Agency's detection of a diversion being for the Agency's parent body, the UN, to decide.

The projected increase in world nuclear power generation and the associated increase in inventories of nuclear materials suitable for weapon manufacture would be expected to increase the cost and physical impact of safeguards, perhaps to unacceptable levels. To avoid this the IAEA looks to improved inventory and control techniques to improve the quality of basic data, and ease its collection, and also to 'graded safeguards' - a concentration on materials in proportion to their strategic significance, which, for example, will reduce the effort expended on say, natural uranium (which has relatively little direct interest for explosive manufacture) in comparison with weapon-grade uranium, but without reducing the overall effectiveness of verification activities. It also looks to co-location of facilities and international ownership to reduce the effort required to achieve effective safeguards.

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* The IAEA inspectorate consists of some 50 people including support and analysis services. The staff are described by Feld in Bulletin of the Atomic Scientists, May 1975, as technically competent and devoted to their task. The budget for 1975 is US$4.8 m, and anticipated expenditure for 1976 is around US$7 m.

GLOSSARY

The following definitions are provided for the reader not familiar with some nuclear terms used in the appendices to this paper. The explanations are drawn from standard glossaries.*

alpha-particle	A helium 4 nucleus emitted during a nuclear transformation. *Alpha-decay* is radioactive decay in which an alpha-particle is emitted; whence *alpha-radioactivity, alpha-activity, alpha-emitter.*
breeder	A reactor which produces more fissile material than it consumes.
critical mass	The minimum mass of fissile material which can be made capable of sustaining a nuclear chain reaction; whence *criticality*, the condition of being critical; *criticality accident.*
fast reactor	A reactor in which fission is induced predominantly by fast neutrons, that is, neutrons moving at high speeds; whence *fast breeder reactor*; see *breeder* above.
fission	The splitting of a heavy nucleus into two approximately equal fragments. This is accompanied by the emission of neutrons and release of energy; whence *fission products*, the atoms formed in the fission process.
half-life	The time taken for the activity of a radioactive substance to decay to half its original value. The term is often extended to other processes.
exafluoride	The gaseous compound uranium hexafluoride (UF_6), used in diffusion and centrifugal uranium enrichment plants. (Abbreviated 'hex'.)
sotope	Varieties of the same element having different masses; whence *isotopic.*
ight-water reactor	A reactor of the general type cooled by ordinary (light) water.
utron	A nuclear particle having no electric charge and the approximate mass of a hydrogen nucleus.
diotoxic	Having toxicity due to radioactivity.
llowcake	The uranium oxide concentrate produced by a uranium treatment plant.

(continued)

* Sources :

British Standards Institution : Glossary of terms used in nuclear science and technology, BS 3455:1973.

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