NESST:

A Nuclear Energy Safety & Security Treaty

Separating Nuclear Energy from Nuclear Weapons.

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The need to manage all radioactive materials associated with Fission and Fusion energy is matched by the need to completely separate civilian energy programmes from the production of nuclear weapons. The Nuclear Proliferation Treaty (NPT, 1968) muddles these issues together and it's politically restrained monitoring through the IAEA is clearly ineffective at regulating either. The Treaty obligations rely on trust and carry no specific or graduated penalties for breaches of the trust. Historically, the responses to breaches have all included the options of nuclear attacks, the worst possible solution. There are no requirements that weapons facilities be inspected, merely that civilian facilities with the potential to support weapons be inspected periodically by the IAEA and at their convenience. The realities of safety in nuclear plants are that 24X7 monitoring of personnel and equipment is actually essential, as it is in any large chemicals or petroleum facility, but this is not demanded in the Treaty. There is a clear case for making a new Nuclear Energy Security Treaty (NESST) which is rigorous, enforceable without violence, and separate from the political quagmire of nuclear weapons. As nuclear power is spreading rapidly around the world with 200 reactors ordered by 2020 and thousands to come by 2050 it is now urgent to open this discussion with the clear mutual intent to apply its provisions retrospectively.

Is a NESST agreement possible? The toughest element to accept is that of penalties and why they are necessary. Nuclear power stations are built with a 50-60 year service life. In the next 50 years we may expect dictators and theocracies to be replaced at least twice and democracies about 10 times. Each new government will have the option of continuing, rejecting or subverting its Treaties. Already in the 21st century, the USA set new precedents by rejecting the United Nations, the Geneva Convention, international law on invasion of other countries, and international law on torture. The rise of Islamic terrorism has included citizens of western countries in acts of violence and sabotage. A major political shift has been triggered by the Arab revolutions and challenges to dictators. Treaties on the handling of radioactive materials must transcend such arbitrary behaviour and meet a very high standard of effectiveness. Our political systems are so varied that it is unlikely that sufficient powers or enforcement capabilities could be assigned to a single world authority for this purpose. However, it is obvious that the people with the greatest interest in a country's nuclear mismanagement or attempts to divert materials to a weapons programme are its neighbours, so some devolution of responsibilities is necessary. Neighbouring countries also have the best opportunity to collaborate in the monitoring of all civilian nuclear facilities, monitor trade and travel, close borders, cut energy supplies, apply financial penalties, or take other measures using the NESST principles for such actions. The possibility that energy supplies may be cut is far more potent than any other economic or diplomatic sanctions. All facilities would have resident NESST inspectors, with appropriate international training, from several or all of the countries in a Region. IAEA inspectors would be permitted to visit at any time. The politics of penalties becomes feasible on a region by region basis. NESST members will not supply nuclear materials or services to non-members, thereby stopping proliferation.

The Baltic Region is a convenient example which fits the NESST scenario very well. All the countries would like to use nuclear power and reactor vendors have already said they cannot take back nuclear wastes and that the country or Region must handle them. Finland is building the first of a kind of the Areva EPR reactor and has also constructed a deep geological disposal site to accept spent fuel. Sweden is also contemplating a Deep Disposal facility. Poland is a major coal burner in the EU, has interest in a first round of 5 nuclear reactors, and has signed a collaboration agreement with the USA. The Baltic States would like to connect and be part of this nuclear energy group. The region would eventually benefit from an enrichment plant and a fuel recycling plant to service the 50-60 reactors in the region by 2050. The German exit from nuclear power will give these Baltic States a wealthy client for reliable and cheaper energy.

Nuclear fuels provide millions of times more energy per tonne than fossil fuels and are therefore cheap, but they are also much less abundant so supplies come from a small number of countries. The nuclear technologies are far more sophisticated than those for fossil fuels and are correspondingly expensive. Thus, not every country can have or afford a complete suite of technologies from Mining to Enrichment to Fuel Fabrication to Spent Fuel Recycling to the Burning or Management of radioactive wastes. The geographical spread of resources and facilities therefore provides many choke points where penalties and restrictions can be imposed. Global trade, finance and banking, and migration of people have already diluted sovereignty. The NESST agreements would place separate responsibilities on every part of the civilian nuclear enterprise.

This is quite different from the protectionist times of the cold war when the NPT was created. The terms of the NPT are directly opposite to the earliest view that all knowledge of nuclear technologies should be kept secret, even though it was already too late. Somewhat absurd rights were declared as follows:

NPT Article IV: Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with Articles I and II of this Treaty.

So, any country could sign the Treaty and claim the inalienable right to any or all of the materials and technologies of nuclear energy. A later administration, which feels threatened or has been attacked on all sides, may set up secret weapons facilities and deny it as they will. This is the scenario unfolding in Iran today.

The NESST agreement, primarily among neighbouring countries, would replace such rights by **permanent responsibilities** to keep any and all components of nuclear energy systems completely secure using any surveillance measures agreed for that region. Nuclear energy is good for many thousands of years, so 'permanent' implies this timescale. We should not litter the planet with polluted sites, so tight control of nuclear materials is needed to keep sites active for thousands of years. NESST is needed to meet this level of diligence.

Let us examine some of the possibilities for diversion of civilian nuclear materials throughout the fuel cycles and the NESST penalties for infringements:

Uranium Mines

Mines are the start of the Uranium fuel cycle. Up to 1 million tonnes (1Mt) of rock may have to be moved to extract the 85,000t of 1% Uranium ore needed for the initial fuel load for a 1 Gigawatt (1 million kilowatts of electricity) nuclear reactor. The

Uranium is extracted from the rock and turned into a Uranium Oxide, or 'yellow cake' as the final product. The 850t of ore finally yields 72 tonnes of 5% low enriched Uranium (LEU) for reactor fuel. The scale of mining activity is substantial and, in these days of satellite surveillance, is hard to hide. However, only 2.7 t of natural Uranium are needed by a country like Pakistan to use centrifuge enrichment to extract the 90% pure U-235 for making one nuclear weapon. This is quite a small amount and so Security is needed at the mines for the production and sale of yellow cake and its transport to NESST enrichment facilities.

Mined Thorium has only one isotope, ^{232}Th, with a fission cross section less than 100 millionth that of ^{235}U, so no nuclear weapon can be made from Thorium. However, when irradiated in any reactor, ^{232}Th can capture a neutron to make ^{233}Th which quickly decays to the fissile ^{233}U. This can be used as reactor fuel or, with some difficulty, to make a bomb. Even though Thorium is a big step away from becoming weapons material it should still be a controlled and monitored material.

The NPT allows any compliant country to hold up to 10 tonnes of natural Uranium without special safeguards, which is already far too much. Nothing is said about the mining or use of Uranium deposits from a country's own resources, but NESST would put all known and discovered Uranium sources into the regional agreement. Failure to report new resources be a breach of the agreement with potentially severe penalties by the neighbours. The price of Uranium is set to rise strongly with any strong rise of nuclear energy. Several countries are stockpiling Uranium at the low price, but the only valid destination for fresh Uranium is a NESST Enrichment or Fuel Fabrication Plant. Stockpiles should be held by the mines.

If material from a mine has been diverted then a chain of penalties would begin. All shipments en route around the world from this mine would be impounded for inspection. Regional and international inspectors would close and inspect the offending mine and expand the audit within the offending country or region as appropriate. The client for diverted materials would be identified and the Region of the offender would begin local proceedings against the client or client state.

Enrichment

Natural Uranium Oxide is converted to Uranium Hexafluoride, UF_6 , which is solid at room temperature and sublimes at 56.5^{o}C. This vapour is spun through a chain of centrifuges and recycled till the final enrichment is at the desired 4.95% for fuel fabrication. It takes 11t of natural Uranium to produce 1t of enriched fuel along with 10t of Uranium depleted to 0.275% ^{235}U, using 25MWhrs of electricity to drive the centrifuges

Depleted Uranium is now one of the world's largest energy stockpiles. Like Thorium, is only a neutron away from being reactor fuel and should be held Securely. It is ridiculous to divert it for use in munitions, wing weights or other such applications which would not be permitted by NESST.

A typical new enrichment plant is American Centrifuge's \$3.5Bn Piketon facility with 1400 centrifuges able to produce 760t of fuel for 38 x 1GW reactors per year. The plant will process almost 700t per month of fresh Uranium. Fast reactors and High Temperature reactors (HTRs) would need 20% enrichment. Now consider a scenario using the short trains of centrifuges for High Enrichment, separated from the main operation, to divert and further enrich materials into a weapons programme in a 5 year plan: Only 4.54t of LEU at 4.95% are needed to produce 1t of legal HEU at 20% ^{235}U and put 3.54t depleted to the natural Uranium level of 0.7% back in stock. Beyond that, a tonne of HEU can be enriched to 177kg of weapons grade (90%) Uranium and 823kg depleted to LEU grade at 4.95%. At the end of this secret operation only 177kg of material is missing, a 21cm^{3} volume of weapons grade Uranium, and the rest looks like natural Uranium or HEU. This illustrates the accuracy needed to monitor accounting procedures and material flows to detect any diversion.

Plant Safety requires 24X7 monitoring and Security is achieved with automated reporting to a central database. Corporations and employees cannot, in principle, be trusted any more than countries, politicians and generals, so all enrichment plants need this level of surveillance and reporting. NESST would require that any plant suspected of diversion would be shut down for an audit. All shipments to and from this plant would be impounded, wherever they were in the world, as a first step. Internal investigations would be made into the possibly criminal actions of the regional NESST inspectors. Several regions could become involved, expanding the responsibilities from country to Region to Regions to the IAEA level of world authority.

Fuel Fabrication.

Enriched Uranium Hexafluoride may be used directly in advanced reactors such a Molten Salt Breeder or a Fusion-Fission Hybrid reactor, or must be converted back to Uranium Oxide for PWR reactor fuel or to metal, Uranium Carbide or Nitride for Fast Reactors or HTRs. The movement of materials through the plant is not a continuous flow so there are many interim storage steps at which diversion become possible.

Recycled Plutonium fuels to be fabricated as MOX will be quite radioactive. Robotic handling of materials is necessary for safety. Remote monitoring for Security is again a small addition. A similar range of inspections and penalties as used for enrichment plants would be applied in the event of any breach of NESST.

Spent Fuel Recycling

About 20t of spent fuel is extracted per year from each reactor. It is cooled for 5-10 years at the reactor site before it can be moved on to recycling in robust radiation, fire and collision proof caskets. The materials are still a security hazard as they could be wrapped around conventional explosives to make a crude radioactivity bomb. NESST requires that spent fuel in transit should have an armed escort. The NPT has no such rules.

Recycling is essential to the long term future of Nuclear energy. Disposal of entire spent fuel rods in Geological Depositories is the wrong solution and led to overfilled cooling ponds and the cancellation of the Yucca Mountain project.

Present day recycling plants chemically separate spent fuel into three primary streams: (i) unused Uranium isotopes (93%) (ii) Plutoniums and higher Actinide fuel components (2%) (iii) Fission Product (FPs) isotopes (5%). Only the Fission Products, which poison the reactor, need further treatment, the rest being usable as fuel.

The 1 tonne per reactor year of Fission products is about 50% radioactive isotopes. About 200kg decays rapidly in the cooling ponds. Another 200kg consists of isotopes which decay very gently over 1000s or 100s of thousands of years. These can be greatly reduced by burning in Fusion or long burn Fission reactors. This leaves 100kg. of isotopes like Strontium-90 and Caesium-135 with

~30 year half lives. They are resistant to burning in reactors but will decay by a factor of a million in 500-600 years. These are the only ones we need consider for Deep Disposal, but not on geological timescales. The recycling plants offer the best opportunities for diversion of weapons grade materials or highly radioactive wastes and require the most stringent Security.

The latest recycling plant was designed by AREVA and Japan for their Rokkasho site. It could process 800t per year, including legacy spent fuel from 40 years of nuclear power. By 2050, some 90 recycling units around the world would be needed, region by region, to maintain 3500 reactors. The scale of Security for recycling will grow with the reactor fleets, so NESST agreements are essential.

Since there would be no more than one or two recycling plants in a Region a breach of NESST by a recycling plant would affect the whole region with penalties. All incoming Uranium, fuel, or even electricity could be stopped by bordering Regions. A full investigation of the Region and all the NESST inspectors may be triggered.

Tiny amounts of long lived wastes can diffuse into the structural materials of a PWR reactor and some structural metals can be activated by neutron absorption. Decommissioning of each nuclear plant therefore leaves a legacy of mildly radioactive materials which would decay below natural radioactivity levels in a hundred. In a more highly robotic age such materials could be re-used without harm to mankind. Again, permanent disposal is not necessary.

The Role of Fusion

Fusion produces almost 20 times as many neutrons per tonne of fuel as fission. The neutrons are as useful as the energy they carry and can be used to burn long lived nuclear wastes or generate fissile material from Depleted Uranium or Thorium at 10 times the rate of a Fast Reactor. The UK, for example, already owns enough Depleted Uranium to support an all electric Britain this way for 500 years. These capabilities could now support the Fission industry through the coming period of rapid growth in nuclear power and solve the long term waste disposal problem. Moderate size Fusion plants will be able to work in hybrid fashion as a Fusion core to a liquid fuelled Uranium or Thorium blanket reactor which would be far more efficient than a Fast Reactor. This implies that such Fusion applications must be included in the NESST agreements with the same levels of 24x7 monitoring. The multiple advanced technologies used in a fusion plant of any kind are hard to acquire and difficult to implement, presenting a high technology barrier to secret usage.

Nuclear Weapons

What about the control of nuclear weapons? For existing weapons states, NESST would only apply to facilities which are declared to be for civilian purposes. The NESST goal is to separate the management of nuclear energy from nuclear weapons programmes and would include clauses to forbid new weapons programmes. Internal diversion of materials from any facility would provoke the NESST penalties on that country or region. Penalties would be immediate and beyond appeal till the breach was resolved. This stops Proliferation by members.

Under NESST no facility would supply or support any facility which is not part of a NESST agreement. This means that no NESST mine would supply Uranium and no NESST fuel factory would supply fuel. NESST recycling plants may accept spent fuel or decommissioned weapons grade materials from military facilities but all the materials would be retained and nothing returned. This stops Proliferation by non-members.

NESST countries would also prevent shipments of any nuclear materials from entering their territory from a non-NESST supplier. All such materials would be declared illicit and impounded. This will not shut down secret deals between countries but will raise further barriers to weapons development or to the build up of weapons stockpiles.

NESST in Difficult Regions

The Baltic region described earlier has members who are already partners within the EU, so NESST appears as just an efficient nuclear management process. It could be an excellent stage on which to develop all the details of NESST.

How would it work with a group of neighbours with many disputes? Let us contemplate an East Mediterranean Region (EMR) defined as Turkey, Syria, Jordan, Lebanon and Israel. They are all actively pursuing nuclear energy in various ways. Israel is a nuclear weapons state which has refused to sign the NPT, has bombed actual or suspected research reactors in Iraq and Syria, and frequently threatens Iran with similar attacks. Nevertheless they are showing increasing interest in nuclear energy. Israel is still in conflict with all these neighbours and the best early concession which may be sought is for them to agree not to bomb civilian nuclear facilities in neighbouring countries that are fully compliant with a NESST agreement. In return they may be offered membership of the regulatory services of the local NESST agreement to ensure that the agreement is effective. There is no NESST requirement that Israel disarm, only that all civilian programmes are completely cut off from existing military ones in Israel or anywhere else.

Meanwhile, Jordan has signed the NPT and is planning a civilian nuclear energy programme based on the fact that it has significant Uranium ore deposits and also extensive Phosphate deposits with 0.1% traces of Uranium. This is enough to supply the Region with 50 GWy-e for 600 years. Israel has objected to Jordan opening Uranium mines and has gained support from the USA, who is not a neighbour in this region. Under NESST, Jordanian Uranium mines would be unable to supply Israel with Uranium if it remained a non-member. Turkey is an NPT signatory, is seeking EU membership and is negotiating to build several nuclear power stations. The region may well trust Turkey to establish a recycling plant and disposal sites as part of the regional facilities. Syria is now facing revolution and could not be included till that is resolved. However, their oil production is now falling rapidly, though they have significant gas production. Syria has no high tech industry. Enrichment and fuel fabrication plants may be best placed in separate countries in the region or even outsourced to Eastern Europe.

Self interest in the need for secure and reliable energy, without threats from neighbours, may be sufficient for even such a fractured set to finally become neighbours in a NESST agreement. The EMR is very much poorer than the Baltic region and even Israel is highly dependent on US aid. Social conditions are also quite different and many Inspectors may be susceptible to bribery or corruption. In the interests of neighbouring and other Regions it would be necessary to have an IAEA inspector as a permanent member of every NESST team. In such a region the inspectors may even have expanded powers to shut down plants without further discussion. Restricting or otherwise interfering with the work and role of inspectors would be a NESST breach and would trigger a chain of sanctions such that reactors could be out of fuel within a year.

REACTOR ACCIDENTS

For historical reasons most of the world's reactors use a water coolant**.** This means that any lapses in Safety measures can lead to a reactor meltdown as at Three Mile Island or Fukushima. In neither case have any deaths been attributed to the radiation leaks, though some Fukushima workers may be at risk. The loss of the old reactors at Fukushima was due to one of the largest earthquakes every recorded and a prompt tsunami which killed about 30,000 people and devastated the northwest coast of Japan. In Japan, Nuclear power survived the worst disaster scenario in a century without widespread impact on the land or population. However, in both cases, and at Chernobyl, Safety was compromised by company failures to follow required procedures and by tacit collusion or failure by government regulators.

Under NESST the onsite inspectors would have the power to enforce safety and maintenance procedures with a system of warnings, notices and finally closure of affected facilities for remediation. This is not part of the NESST Penalty system on Security, but endemic safety failings in a country may have a similar impact. All such action would be reported automatically in real time to the other Regional members. The NESST regime would separate the loyalties of the Safety and Security inspectors from companies and countries.

Much Safer Reactor Technologies

A better approach is to build safe reactors. A truly safe reactor should not melt down, go on fire or release any radioactive substance into the environment, even with total loss of all power, a natural disaster, employee mistakes or sabotage, or an external attack on the system. Versions of the systems should be able to breed their own fissile fuels and burn over 90% of their radioactive wastes. Several such systems have been designed over the last 30 years but have not been funded to the level of commercial demonstration.

Uranium-Plutonium cycle reactors based on tiny TRISO fuel pellets meet all the requirements. The TRISO pellets can retain all their fission products for a million years. Thorium-Uranium cycle reactors using molten salt fuels meet the requirements and produce 10,000 times less radioactivity than the Uranium-Plutonium fuel cycle. Small Fusion Reactors using Deuterium-Tritium plasma fuel and surrounded by liquid fuel blankets meet all the requirements and could serve as Fusion cores for a sub-critical Hybrid Fusion-Fission system. These are very effective at breeding other fuels and burning Fission Product wastes.

All these systems have a very strong technical base today, share many technologies, and are seeking funding for prototypes and commercial demonstrators. They could start to phase out water cooled reactors by 2030. The NESST protocols can readily incorporate these new technologies.

Concluding Remarks

It was widely known in the mid 1970s that Libya, Syria and Pakistan had secret nuclear programmes, though the Libyan effort was always negligible in its capabilities. These proliferation efforts were clearly part of the ongoing 'real politik' games of the time are now stuff for think tanks. Should the Taliban win or otherwise take power in Afghanistan then the probability of them winning office in Pakistan would be great. The prospect of a nuclear armed Taliban is the ultimate outcome of the ill considered foreign policies of the US and EU over the last 40 years.

These are the same policies of support for pliant dictators and despots, at the expense of their economies, which have now erupted as revolution in the Middle East. A matching revolution in how the West works with the new administrations is absolutely required and Proliferation will be one of the critical issues.

The Gulf States all have plans to use nuclear energy because their oil and gas will be much more valuable for export than the continually low cost of nuclear. United Arab Emirates leads the group and has now ordered 4 reactors from South Korea to be installed by 2020. Many other countries who have never had nuclear power are following the same path.

Nuclear energy has proved to be reliable, safe and cost effective when operated well. Human behaviour is not nearly so reliable and requires multiple checks and balances and overriding penalties for proscribed activities. Only a highly cooperative security regime can meet all the requirements. NESST will clear the way for nuclear disarmament negotiations in a world of real mutual security for nuclear energy. NESST could have a tremendous impact on public perception and understanding of nuclear energy.

Author

Brendan McNamara worked on Fusion Theory with AEA Technology, Culham (1961-71) and at the Lawrence Livermore National Labs in California (1971-85). He also ran a series of Plasma Colleges at the International Centre for Theoretical Physics,Trieste, 1974-84. He was Exec. V.P. of the Von Neumann Supercomputer Center in Princeton (1985-88) and now operates Leabrook Computing from the UK as an Energy Consultancy. Many of his works on Fusion and Fission may be found on www.ralphmoir.com.