NUCLEAR SAFETY IN THE FORMER SOVIET UNION

What type and number of reactors are involved?
How can they be made safer?
What are the UK and other Nations doing?

POST note 51
April 1994

POSTnotes are intended to give Members an overview of issues arising from science and technology. Members can obtain further details from the PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY (extension 2840).

The explosion at Chernobyl in 1986 brought home the fact that many, if not all, Soviet-designed nuclear reactors fail to meet Western safety standards. Subsequently, an international effort has been mounted to try and raise safety standards in these reactors.

This note reviews the current position and options for further reducing reactor operating risks.

BACKGROUND

Until the break-up of the Soviet Union in 1990, nuclear plants in the USSR and Eastern Europe were controlled and regulated from Moscow. The 63 Soviet-designed civil nuclear reactors in these countries are listed in **Table 1** and are of two main types.

The **VVER design** is a pressurised water reactor (PWR) and is in three different versions. The VVER 440/230, designed in the 1960s, was superseded in the '70s by the 440/213, which gave way to the most modern design (1000/320) in the early 1980s. All designs use enriched uranium fuel (e.g. 3.2% U^{235}), cooled and moderated with pressurised water. PWR designs are common in the rest of the world, and the UK has adopted this configuration as the basis for the Sizewell B design.

The second type of reactor is the water-cooled, graphite-moderated **RBMK design**, not used for commercial generation outside the Soviet Union. The oldest operational RBMK reactors (RBMK-1000) first came into use in the 1960s before formal safety standards were applied, and it was a reactor of this type which was destroyed at Chernobyl. A more modern and larger version (the RBMK-1500) is also in use. Both use slightly enriched (2.4% U^{235}) fuel.

The reactors in Table 1 in the former Soviet Union (FSU) and Central and Eastern Europe (CEE) generate 37 gigawatts (GW). Overall, they produce around 13% of the electricity generated in these countries, though regional dependence can be as high as 80%. There are also some 18 unfinished reactors, cancelled due to new safety requirements, public opposition and a cut-back in investment following the break-up of the USSR.

Table 1 SOVIET-DESIGNED REACTORS CURRENTLY OPERATING

Country	Type	Number	Start-up Date (from)	Incomplete
Bulgaria	VVER 1000	2	1988	
	VVER 440/230	4	1974	
Czech Rep.	VVER 440/213	4	1985	2 VVER 1000
Hungary	VVER 440/213	4	1983	
Lithuania	RBMK 1500	2	1985	
Slovakia	VVER 440/230	2	1979	4 VVER 1000
	VVER 440/213	2	1985	
Russia	RBMK 1000	11	1973	1 RBMK 1500
	VVER 440/230	4	1971	
	VVER 440/213	2	1981	
	VVER 1000	6	1984	5 VVER 1000
Ukraine	RBMK 1000	2	1978	
	VVER 440/213	2	1981	
	VVER 1000	10	1983	6 VVER 1000

(In addition there are 2 experimental fast breeder reactors and 2 planned, 4 transportable nuclear heating plants, and 4 planned.)

SOURCES C POTENTIAL RISK

While the safety requirements of modern reactors are highly complex, some of the key areas of emphasis are outlined in **Box 1**. The experience of Chernobyl (**Box 2**) showed only too clearly that operating Soviet-designed reactors do not conform to current Western safety standards. The main technical flaws depend on the design and are most prevalent in the early models.

The main faults of the RBMK design are:

- The reactors can exhibit a 'positive void coefficient' i.e. if the water boils, the nuclear reactions increase, possibly leading to a run-away chain reaction.
- The control rods need power to drop in.
- The safety systems are inadequate.

The earliest of the VVER reactors (440/230) is considered not to be capable of meeting current international safety standards because, for example:

- The reactor has only a rudimentary emergency cooling system.
- There is no containment system.
- The strength of the reactor vessels (possibly embrittled by neutron bombardment) is unknown, and many pipelines are corroded.
- There is little redundancy or diversity in the safety systems, and insufficient fire protection.

Improvements were made with the VVER 440/213 design, but problems remain:

- The emergency cooling system is suspect.
- Due to poor construction methods there are doubts about the ability of the steam confinement pressure system to contain radioactivity.
- The safety systems, while improved over the 230 design, still have problems of redundancy, diversity and fire protection in some of the systems.

The latest design (VVER 1000) has solved some of the

Box 1 KEY SAFETY FEATURES EXPECTED IN NUCLEAR POWER PLANTS

The major safety concern in operating a nuclear reactor is to avoid the fuel reaching temperatures where radioactive fission products are released into the coolant and thence into the atmosphere. Some of the key components in a modern safety system are:

Reactor design and construction:

- ▲ The reactor reactivity should be inherently stable.
- ▲ There should be defence in depth - e.g.back up cooling and protection systems that do not rely on a single power supply.
- ▲ Quality assurance should be applied to all phases of the life of the plant.
- ▲ The plant should be safe from internal and external hazards such as fire or earthquakes.

Reactor operation:

- ▲ Operators should be highly trained and well motivated.
- ▲ Staff should ensure that a minimum level of protection is available at all times.
- ▲ There should be independent external supervision and regulation.
- ▲ There should be regular, thorough, and well documented maintenance of the whole plant.

problems affecting the earlier models and is viewed as being the most capable of being upgraded close to international safety standards, particularly as it has a full containment system. Indeed, the Finns operate a VVER 440/213 modified to Western standards (and insured in the West) and have commented that the design incorporates certain positive safety features.

For all designs however, there is concern that weak regulatory control and poor documentation during construction makes it difficult to predict how key components will function, and makes inspections and safety judgements difficult. The safety of nuclear power stations also depends on the ability and training of the plant operators, as illustrated by the low standards of technological training and discipline exhibited at Chernobyl. There is also concern that some countries may lack the regulatory and licensing procedures necessary to ensure the safe running of the plants. Independent inspections are essential, as illustrated by the finding in 1992 by regulatory authorities that automatic safety systems at a Ukrainian plant were shut down.

The break-up of the Soviet Union has also complicated waste management, since spent fuel was formerly transported to Russia. Currently, much of the fuel is simply stored on site, with no national strategies for dealing with the problem. Some reactors may have to be shut down if no solution is found.

INTERNATIONAL AID

Firm commitments of ~600 MECU have been made by OECD countries to a variety of projects between 1991 and 1993. This includes 314 MECU from the EU and 14.8 MECU (around £11M) directly from the UK (via the nuclear industry and various government departments). In addition, the industry funds 'twinning' projects between individual reactors - an approach promoted internationally by the World Association of Nuclear Operators (WANO), which was formed by the industry in 1989 to reduce the risk of nuclear accidents. The UK's contribution covers planned and current 'twinning' projects (e.g. twinning of Scottish Nuclear's (SN) Torness station with Smolensk and Nuclear Electric's (NE) Hinckley Point station with Ignalina), safety and waste management seminars, and grants of equipment (e.g. £130,000 of communications equipment for the Bulgaria Nuclear Safety Authority).

Box 2 CHERNOBYL

On 26 April 1986, Reactor 4 at Chernobyl was catastrophically damaged, releasing radiation over much of Europe (see POST Briefing note 45). The accident happened because operators were carrying out an experiment to see how long the coolant pumps would continue to operate if the power supply from the grid was cut and before the back-up power supply was switched on. For the experiment, the reactor was operating at less than 20% power, well within the range where the 'positive void coefficient' applies. The control rods were withdrawn, and the emergency cooling system disabled. Despite warnings from the station computer, the test was started. As the coolant pumps lost power, water turned to steam and the power generated shot up.

The operators attempted to shut the reactor down manually, but due to a serious design fault, the initial effect of lowering the control rods was to **accelerate** the reaction. This vapourised more water, bursting tubes and causing power to shoot up to 100 times full power. This blew the top off the reactor, wrecking the containment, and releasing radioactivity. The nuclear reaction was stopped by the explosive destruction of the core; however the graphite moderator then caught fire. Some 3% of the radioactive reactor core was released before the thousands of tons of sand, clay and lead dropped onto the reactor prevented the release of further fission products. The reactor has since been entombed in a concrete sarcophagus.

Experts attribute the accident to a mixture of factors. The reactor design preceded the adoption of formal safety standards and included fundamental and serious design weaknesses. Although the trigger was gross operator error, many see the design as an accident waiting to happen. The fact that this could happen owed much to the isolation of the Soviet nuclear power industry from external influences and standards (both within the USSR and from the world nuclear industry). The control rods in all RBMK reactors have since been replaced and other measures taken to reduce the positive void coefficient.

EU support since 1990 has been via PHARE[1] (78 MECU and covering CEE) and TACIS (253 MECU covering the FSU). UK nuclear utilities are involved in the TACIS projects, providing quality assurance and training under TACIS 91, as well as a review of the RBMK reactors. Under TACIS 92, NE is providing on-site assistance to the RBMK reactors at St Petersburg, while SN is in-

1. PHARE is the Poland and Hungary Assistance for the Restructuring of the Economy. TACIS is Technical Assistance to the Commonwealth of Independent States.

volved at Smolensk. Such on-site assistance is intended to include changing hardware, as well as help the safer running of the plant.

At the multilateral level, the G-7 Munich Summit (1992) expressed concern over the safety of nuclear reactors in the FSU/CEE and set up the Nuclear Safety Account (NSA) to be managed by the European Bank for Reconstruction and Development (EBRD). Total contributions amount to 118.4 MECU, of which 11.5 MECU (around £8.5M) comes out of the UK contribution of 14.8 MECU mentioned above. To date, 24 MECU have been put to supplying equipment for the Kozloduy (VVER 440/230) reactors 3 and 4, in return for which the Bulgarian authorities have agreed to close reactors 1 and 2 in 1997. 33 MECU has been granted to Ignalina (RBMK) to provide equipment to improve plant safety. In return, the Lithuanian authorities have agreed to close the oldest of the 2 units by 30 June 1998, although this is subject to the opinion of the local regulatory authority and the ability to meet the demand for electricity from other sources (which could prove difficult).

ISSUES

Can the plants be made safer?

Opinion is divided as to whether it is possible to physically upgrade (backfit) to Western standards. Risks are certainly reduced by fitting modern computers and safety systems, as well as by training the operators and establishing efficient supervisory and independent regulatory bodies. The positive void coefficient which contributed to the Chernobyl accident has also been reduced by increasing the U^{235} content of the fuel from 1.8% to 2.4% in RBMK reactors. However, problems such as re[illegible] vessel embrittlement may be difficult to assess, [illegible] cannot be cured. Backfitting emergency cooling systems to some plants may also reduce overall safety by penetrating the primary (radioactive) circuit.

Some in Russia see the Chernobyl accident as primarily an abuse of operating procedures and believe the reactors can be run safely, even if the safety levels are less than would be required in the West. However, the accident at another RBMK in St Petersburg in March 1992 (leading to some fuel destruction) supports a broader concern over the basic design. As a consequence, some governments conclude that the target should be to shutdown the older RBMK and VVER designs as soon as possible - especially the 15 RBMK and VVER 440/230 Russian reactors (total output of 13 GW) which were built before major safety standards were introduced. The German Government has already shut down the four VVER reactors which had been operating in the former East Germany.

As far as the most modern VVER1000 reactors are concerned, it is generally accepted that they could be brought close to Western standards, but the costs could be substantial - some estimate as much as a new reactor. Regarding RBMKs, visitors from the International Atomic Energy Authority (IAEA) to Smolensk (the most modern RBMK) came away reassured that it would be possible to modify the reactor to increase the safety substantially, in ways that may also be applied to the older reactors.

Of the money pledged in bilateral and multilateral projects, only a small amount has yet been spent - for example, the projects drawn up under the EU's TACIS 91 budget were not put out to tender until December 1992, and were only begun in April 1993. Much of the money spent so far has been used to fund safety studies, and some operator training. However, many have felt for some time that there are enough plans for improving the safety, both inside and outside the FSU, and that what is urgently needed is support for engineering improvements at individual plants. This, in the eyes of many observers, requires more effective coordination between the various directorates of the EU involved (external affairs, energy and environment).

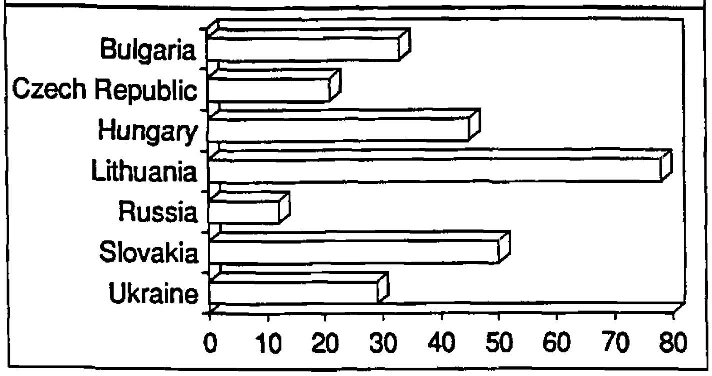
Wider progress is also limited because of industry's concern over potential liability. Western nuclear plants are covered by the 1963 Vienna Convention on Civil Liabilities for Nuclear Damage, which puts responsibility for accidents on plant operators, not the suppliers or builders of parts of the plant. The Soviet Union had not signed any of the IAEA Conventions, and most plants in the FSU/CEE are not thus covered by the Convention. Any Western company involved in work to upgrade the plant is thus unsure of the liability implications should an accident occur (irrespective of whether it was related to the company's work).

Although software studies are continuing, much of the work agreed in principle is in abeyance until countries adopt the Vienna Convention. Lithuania recently signed, and work by Swedish companies on Lithuania's Ignalina RBMK reactor is proceeding. Local waivers have also been agreed (e.g. by the Czech Republic and Slovakia for French companies), but the process of adopting the Convention is not so well advanced in other countries. This is a serious constraint and many see this as the key area where Government departments need to be active either in promoting bilateral waivers of liability or encouraging a higher priority to be given to adopting the Convention. In addition, DTI could well expand its role in coordinating the work done by UK industry and in helping raise the profile of UK industry.

Long Term Measures

In view of the slow progress reported above, some groups continue to press for the early closure of all Soviet-designed reactors without containment. However, most observers point out that this is currently just

Figure 1 % of NATIONAL POWER FROM NUCLEAR SOURCES



not possible, given the dependence on nuclear power of some regions, nor is it likely to be possible in the foreseeable future. The scale of the problem can be judged from the nuclear power distribution over the republics (**Figure 1**); some countries (e.g. Lithuania) or regions (e.g. St Petersburg) are very dependent on nuclear power. As a result, the two remaining reactors at Chernobyl (Ukraine), scheduled for closure in December 1993, are to remain open. Two reactors in Armenia, shut due to potential earthquake risks, may be restarted as electricity is rationed to a few hours daily. Even in Russia, rationing of the electricity supply began in October 1993.

The way forward appears to many to require the development of national energy policies within which each country can determine the appropriate role of nuclear power - whether existing plants should be shut down or upgraded, partially built plants completed, or new ones started. In this context, for the 1993 G-7 summit, the World Bank and the International Energy Agency (IEA) looked at three options for the reactors in Slovakia, Bulgaria, Russia, Ukraine, Lithuania and Armenia, covering from 1993 to 2000. Under consideration were a 'high nuclear' option where existing plants are upgraded to allow continued operation to the end of their envisaged life (well after 2000), 'medium nuclear' where the RBMK and VVER 440/230 reactors are retired by the year 2000, and a 'low nuclear' scenario where these plants are shut down by 1994/5 and replaced by gas-fired plants. The costs of these options were \$28 B, \$23 B and \$21 B respectively.

This report has been cited as showing that the 'cheapest' option would involve the rapid shutdown of nuclear plant and their replacement by a mix of energy efficiency measures and fossil fuel generation. However, the 'low nuclear' bill does not count either the cost of fossil fuel imports, estimated at around \$3 B per year, or the loss of hard currency to Russia (currently an exporter of gas). Another factor to be taken into consideration is that some 30% of existing thermal power stations (gas, coal etc.) are already operating beyond their design life. Moreover, replacement of nuclear power by new fossil fuel sources would have not only economic consequences (countries such as Lithuania and Armenia have no fossil fuel deposits, and cannot afford to import alternative fuels), but there would be environmental implications via the increased emissions of carbon dioxide and nitrogen and sulphur oxides. Although energy use is relatively inefficient[2] and there is clearly the prospect of reducing demand through improved energy efficiency, Western experience is that this is very much a long-term challenge rather than a short-term palliative.

A further complication concerns the future of the new but incomplete reactors (1 RBMK and 17 VVER). Some of these (e.g. at Rostov and Balakovo) are all but complete, and solving the remaining legal, social and technical problems to allow completion of these units to levels of safety comparable to the West, would create flexibility to shut down other less safe reactors.

Simple solutions are thus not available and most analysts see a need for long term measures to be flexible - providing an overall energy strategy for each country, covering the whole power generating industry. Accurate forecasts of consumption, together with realistic pricing and encouragement of energy efficiency, would allow future needs to be met, while allowing for the closure of the least safe reactors, and the potential contribution of upgraded modern plant and completed new plant assessed. Such 'holistic' reviews have been carried out by the EBRD in Lithuania and Bulgaria, and have led to policies in which the closures/upgrading of existing nuclear plant have been agreed as part of an overall energy strategy package.

In the long term, the problem of reactor safety may be most difficult to address in Russia and the Ukraine. Western pressures and assistance need to respect the greater technical independence of these countries. There is a view in Russia that their reactors are adequately safe and that the attention being given to nuclear safety is more to support the West's nuclear industry than to meet the real needs of the countries affected. Antipathy to RBMK and VVER reactors can also be portrayed as ensuring that modern Russian designs cannot develop to provide commercial competition for Western manufacturers. Russian nuclear operators have commented that they do not need Western expertise to improve the safety of the reactors, but money and hardware to allow them to do the work themselves.

This issue may well return to the G-7 and EU agendas, in which case the key questions to be resolved are how to match in the Ukraine and Russia, the progress made in Lithuania and the CEE countries, whether the international aid pledged so far (~\$600 M) is adequate to the task, resolving liability issues, and whether funds earmarked for nuclear safety assistance could be used to aid the development of long term energy policy.

2. These countries use between 2 and 8 times as much energy per unit of GDP as the average of OECD countries.