Public Understand. Sci. 1 251–259. Printed in the UK

Chernobyl: the inevitable results of secrecy

Alexander Shlyakhter and Richard Wilson

The Chernobyl accident was the inevitable outcome of a combination of bad design, bad management and bad communication practices in the Soviet nuclear industry. We review the causes of the accident, its impact on Soviet society, and its effects on the health of the population in the surrounding areas. It appears that the secrecy that was endemic in the USSR has had profound negative effects on both technological safety and public health.

The accident on 26 April 1986 at Unit IV of the V. I. Lenin atomic power station near Chernobyl in the USSR has had an extraordinary effect both on technology and on politics. The accident was a catstrophe which had an impact on the health of many people, and its consequences have been felt worldwide. But people can learn from mistakes, and there is much evidence both that people have already learnt a lot from Chernobyl, and that there is still a lot more to be learned.

The shock of the accident may have convinced the hard-line Soviet military elite that nuclear war is unthinkable, and thus contributed to the end of the Cold War. For if a device that is designed not to explode blew up because of human error, how much more probable is it that one of the thousands of devices that have been designed to explode could do so? If Chernobyl could make such a mess, how much worse a mess would be caused by a nuclear war?

Less than a year after Chernobyl, in February 1987, a historic conference was held in Moscow under the title 'Forum for a Nuclear-Free World'. The conference was attended by 1200 leading figures from all walks of life. We believe that this meeting changed the views of the Soviet leadership and helped Mikhail Gorbachev to begin to change the hard-line Soviet policies soon thereafter.

That Chernobyl had indeed triggered a change in policy was unexpectedly confessed recently by Soviet Defence Minister Marshal Dmitrii Yazov. One of us (RW) visited Marshal Yazov with the delegation from the Sakharov Congress on Peace, Progress and Human Rights on 31 May 1991 to describe our human rights mission which had visited the border between Armenia and Azerbaijan. Marshal Yazov did not want to hear our description of the actions of the Soviet Fourth Army, which had violated international law. He changed the subject, and noted that the Sakharov Congress had also discussed the effects of Chernobyl. He stated that the accident demonstrated, to those previously unconvinced, that nuclear war is unthinkable and would destroy the planet.

The accident also forced Soviet leaders to recognize the failure of their society to manage modern technology. This failure is, we believe, largely due to the secrecy that

0963-6625/92/030251 + 09 $04.50

was endemic in the Soviet Union. Bureaucrats in all countries like to hide their incompetence and lack of understanding in secrecy. The justification 'the people will not understand' often means that the bureaucrat does not understand. In this article we argue this by discussing a number of synergistic causes of the accident and its consequences.

Causes of the accident

The Chernobyl accident revealed that the RBMK (high capacity, boiling water) reactors suffered from an extraordinary mixture of bad design, bad regulation and bad operation, all of which seem endemic in the Soviet system. Below we list the most obvious design faults, gleaned partly from our own experience and partly from a number of other sources.[1–3]

A positive void coefficient: If the power is accidentally increased the temperature in the core rises, and so does the steam fraction in the cooling water. This decreases the water density and the absorption of neutrons by the water and therefore leaves more neutrons available for chain reactions, which further increases the power. Under normal conditions, with many control and safety rods in the core, this instability is more than compensated by the fuel temperature coefficient, which is always negative. However, with almost all the rods pulled out, the value of the positive void coefficient was greatly enhanced; it overcame the fuel coefficient and the prompt power coefficient was positive.

Control rod design: Instead of causing an immediate decrease in reactivity on insertion, this design adds reactivity for a few seconds before it is fully compensated inside the reactor core. Under normal conditions this is compensated by maintaining a required minimum number (25 before 1986; now 80) of the control rods partially inserted to the point where the very first part of any additional insertion causes a strong negative impact on the total reactivity.

Operation beyond safe conditions: The reactor can operate beyond safe conditions merely by unimpeded decision of the operator. For example, the operator could override the above requirement and remove almost all of the control rods from the core without adequate thought and verification. In Western plants, the operating staff are not allowed to take such independent steps.

The emergency cooling system: This system only protects against the break of one coolant pipe at a time. The reactor is unprotected if several pipes break at once.

Obvious shortcomings of the management system include:

- failure to study 'precursors' of the accident (partial meltdown at the Leningrad nuclear power plant in October 1975; Chernobyl Unit I accident in September 1982);
- failure to communicate the existence of these precursor accidents to all engineers and operators;
- failure to inform engineers and operators about the design weaknesses. The positive addition of reactivity from rod insertion was found at Ignalina in 1983 but operating procedures were not modified;

- 'cover-up' and refusal to listen to criticism.

Other obvious regulatory problems include:

- failure to demand a clear set of operating rules;
- failure to ensure that unusual procedures (such as the safety system test that ultimately caused the accident) be discussed and checked in advance;
- failure to perform a full safety analysis (including a probabilistic risk analysis).

Operating problems particular to the Chernobyl accident include:

- operating with only seven control rods in the core;
- carrying out a test when the reactor was not well controlled (it was supposed to run at 30% nominal power, but actually it was at about 5% and very unstable);
- switching off six separate safety systems (although this probably was not the cause of the accident).

On 25–29 August 1986 the Soviet Union took the extraordinary step of sending experts to the International Atomic Energy Agency in Vienna to describe to the world's experts their understanding of the accident and its consequences. Dr Valerii Legasov, head of the Soviet team, said that it was clear that the Soviet Union had paid too little attention to the man–machine interface, 'and this was a major error on our part'. This, and other statements, led many observers to believe that the (sole) cause of the accident was human error. But given the long list of problems noted above, it is not possible to assign a specific single cause to the accident. Moreover, human beings are responsible for each of the contributing causes in the list. We are reminded of a cartoon which appeared in the *New Yorker* magazine shortly after the accident. Two dogs are conversing. One dog says: 'They attributed it to human error', and the other replies: 'But everything in the world is due to human error'.

Safety analysts in the West have realized for a long time that there is rarely a single cause for an accident; this means that an accident can be prevented, or more precisely that accident probabilities can be reduced, by more than one action. This is called 'Defence in Depth', and has always been a key ingredient of reactor safety.

No-one is sure of the exact sequence of events that led to the accident. When the reactor blew up, the top 2000 ton cover-plate lifted, turned on its side and slid down beside the reactor. All control rods not already out of the core then came up with the cover-plate, and all water coolant pipes were broken. If the reactor was not already 'prompt critical', it became so at once. As Valerii Legasov laconically stated in Vienna: 'the only way of stopping the nuclear reaction was for the reactor to rearrange itself: which it did.' But what caused the reactor plate to lift? Presumably it was steam pressure in the small cavity above the reactor and just below the plate. This steam might have come from breaks in several of the 1700 fuel coolant pipes. Did these fuel coolant tubes break simultaneously because of pressure and temperature shock (as many US experts believed in May 1986), or was this a result of a prompt critical excursion, as suggested by Dr Armen Abagyan at the Vienna meeting in 1986? No-one knows for sure.

Chernobyl was not the only large radiation accident in the Soviet Union. Only recently some data were released on previous radiation accidents and incidents in the USSR, specifically concerning the effects of high occupational doses at Chelyabinsk military installation in 1947–1960,[4] and of the Kyshtym accident in 1957.[5]

The one common thread through all of these accidents is the complete failure of the Soviet system to manage modern technology in a safe manner. This failure is due in large part to the secrecy that was endemic in Soviet society and to a lesser extent in tsarist Russian society before it. Society existed in compartments, with little communication between them. Secrecy was often justified by the desire to avoid panic. The rest of the world has always accused Russians of secrecy. In 1950, a letter from a British Embassy official was circulated in London which complained both about secrecy, and about the restraints upon his movements throughout the countryside. To the scientists and others visiting the Soviet Union for the first time, this seemed to describe their own experiences. But a close examination showed the date to be the late seventeeth century!

It has been said that experience is learning from mistakes; and bitter experience is learning from one's own mistakes. Secrecy then, is inimical to safety, for with secrecy about accidents, one can only learn from one's own mistakes and not from the mistakes of others. The testimony of Mr Anatoly Dyatlov, deputy chief engineer at Chernobyl, that he did not know of the previous accidents at reactors of the same type seems horrifying to someone from the West, but is no surprise to a resident of the former USSR.[6]

Secrecy about the consequences of an accident also has an extraordinary effect on public trust. Two weeks after the Chernobyl accident Mikhail Gorbachev in his first television address to the Soviet people promised that all the details of the accident would be made available to the world. But abandoning a 300-year old habit of secrecy is hard.

The report of the Soviet Union to the IAEA experts at the Vienna meeting in 1986 was impressive, both because of the amount of detailed work that went into it and because of the release of the information, which was unprecedented for a Soviet or Russian government. But for the first two days of that meeting, the Soviet representatives did not talk freely. Dr Kalugin, writing in the Soviet popular science magazine *Priroda* in November 1990, informed us that 'the members of the Soviet delegation were strictly instructed not to meet with foreigners, not to answer any questions on their part, and to follow the published report in every respect. Only because of the resolute stand taken by [Dr Valerii] Legasov was it possible to go away from this policy.'[7] Nonetheless, even Legasov was not completely open. In October 1986 he reported to the Soviet Academy of Sciences, and (according to Andrei Dmitrievich Sakharov who was present) stated: 'I did not lie in Vienna; but I did not tell the whole truth.'

Mr Edward Warman, an engineer working for Stone & Webster Engineering Corporation, and one of us (RW) are persistent people. There was no room for us in the US delegation, but we wormed our way in anyway. The morning of Wednesday 27 August was free, and while most of the delegation went sightseeing, we went to the IAEA building to 'talk to the Russians'. We walked into the room where Dr Legasov and his team were meeting, and stated that we had measurements and reports of radioactivity in Europe and wanted to compare and match them with measurements taken in the USSR. Perhaps our persistence in a spirit of trying to understand the truth without recrimination helped Legasov and his colleagues to abandon the policy of secrecy. Two Soviet expert delegates, Professor Oleg Pavlowsky and Dr Vladimir Demin, came out of the meeting to discuss their measurements and calculations.

At this meeting in 1986 we were told to expect a detailed report about radiation exposures within six months. But instead the flow of information slowed right down. A report, less detailed than that at the meeting, appeared a year later, but not much more came out until March 1989. The old habit of secrecy had restored itself, even though secrecy and trust are so hard to reconcile.

In December 1987, one of us (RW) asked Dr Legasov why the fact of the accident had been kept secret from the population of Kiev for several days. In an impassioned 15 minute answer, he explained that it is important not to confuse the public by telling them about something that you do not yet understand yourself. It became clear that this was a widespread view among honourable people in the USSR, because they feared panic more than anything else. Alas, they caused more trouble in the long run. We now know of the following restrictions on the flow of information:

- Just before the August 1986 IAEA meeting Dr Demin removed from the official report about six pages describing the radioactive contamination 100 km north-east of Chernobyl in Belorussia and in Russia. This important fact was not discussed. Demin says that he was told to remove those pages by Legasov, who in turn claimed that he was acting on orders from higher up. Dr Demin has apologized to Western scientists. Perhaps he should also apologize to the Belorussian people.
- The report of the Soviet experts to the 1986 Vienna meeting was declared secret in the USSR. This had the bizarre result that Americans knew more than the Soviet people!
- Geiger counters were not available to the public, and those in the hands of physicians and others were often locked up by the KGB.
- Publication of the 'unauthorized' measurements of radioactivity by, for example, the nuclear physics department of Belorussia university, was forbidden until 1990.[8]
- One of us (AS) who lectured on radioactivity to the public in Leningrad (now St Petersburg) was explicitly forbidden to use foreign sources of information about radioactive contamination; this was a usual precondition before a lecture could be arranged.
- Physicians in the Ukraine and Belorussia were forbidden to mention radiation in their diagnoses.[8]
- Appeals by private individuals in south-eastern Belorussia to children not to drink milk in the first weeks of May 1986 were stopped on the grounds that the appeals might cause panic.[8]

These and other restrictions on information flow were more than enough for the citizens of Belorussia and the Ukraine to mistrust their political leaders. They also mistrusted those scientists from Moscow who followed the politicians by accepting the constraints.

Once trust is lost, it is difficult to regain. It is particularly hard when the people are asked to believe that the effects of radiation that they do not understand are limited. The poor quality of medical help in the former USSR, combined with the lack of agreement between the official experts (who had access to information) and other scientists (whose ability to receive information and therefore their ability to understand was restricted) all make it harder to rebuild trust.

A report by a committee of the USSR Academy of Sciences, chaired by Academician Nazarov, shows the massive nature of the problem caused by this lack of trust.[9] It describes a relatively consistent 'Chernobyl syndrome', which includes such concerns as life and health; medical services; resettlement; benefits and payments; place in the social structure; lack of trust in the authorities; and absence of information. Feelings of depression are widespread: 'this grief breaks our hearts . . . We can think about nothing else . . . It all keeps piling up, people are on the verge of psychosis . . . We are just walking corpses . . . We will all die by 1993.' Many respondents viewed themselves as guinea pigs; this is promoted both by poor medical services and bonuses causing suspicion that people are paid to keep others in the contaminated areas.

The radiation doses and the objective effects

The previous section describes the perception among the population of extraordinarily large medical consequences of the Chernobyl accident. It is important, however, to try to understand whether or not these perceptions correspond to reality. Many of these fears are of illnesses that can occur from other causes by chance; and the anecdotal nature of the information does not allow reliable attribution. Other fears are of 'non-objective' medical end points that are hard to attribute to any specific cause. Fortunately, in many cases scientists can overcome the secrecy because radioactivity leaves its own fingerprint. In order to estimate the average health effects to the general public, it is sufficient to discuss the average radiation doses with some accuracy.

Immediately after the explosions there was extraordinary confusion. Some of the puzzled operators ran into the reactor room to see what had happened, thereby getting a large radiation dose of which they died a few days later. Others braved radiation hazards to secure chemicals, including hydrogen gas in the generators. When the firemen put out the fires on the roof they were walking among chunks of the radioactive reactor core. About 200–300 firemen received large radiation doses and soon developed acute radiation sickness; previous experience tells us that this corresponds to doses of about 100–500 rem accumulated in a short time.

The general public received much smaller doses. Moreover, the lifetime dose can be estimated fairly accurately for a member of the public who has not changed his residence. This is because we know the amount and type of radioactive elements that were present in the core after three years of nuclear fission. We calculate that the dose to an individual, added up over all subsequent times, comes mainly from the long-lived radioactive isotope caesium 137; most of the caesium 137 is still on the ground and the concentration can be measured and checked by others. Checks of the accuracy of the maps of deposited caesium circulated by Moscow have been made by the International Chernobyl Project of the IAEA for Bragin, Belorussia, and show general agreement with the official figures.[10] These radioactivity maps are therefore almost universally accepted. The dose from ingested radionuclides is expected to be less than half the doses noted from direct exposure, so that although the internal dose depends upon the particular food that was eaten, the error in estimating the average is not too large.

There remains the question of how much radioactive iodine was ingested in the first days after the accident. Although it is likely that iodine was deposited in similar ways to the caesium, the iodine has decayed by now and so there is no way of verifying its concentration. Official estimates from Moscow suggest that for a few thousand people the dose to the thyroid was over 1000 rem. This, however, is not as bad as it sounds: it is not a dose to the whole body, and it is considerably less than a therapeutic dose to the thyroid of radioactive iodine, which does not lead to attributable cancers. Therefore it will be particularly interesting if some thyroid cancers can eventually be attributed to radiation.

Official Soviet estimates suggest that the total dose added for all members of the former USSR is less than 50 million man-rems. These estimates are plausible. According to the 1986 report to the Vienna meeting, the section of the public which received the largest dose is a group of persons within 20 km of Chernobyl; presumably these people were downwind of Chernobyl and were evacuated late. For these 25 000 people the official dose estimate was 1 050 000 man-rems or 43 rem per person.[2]

This figure is similar to the average radiation exposure of the Hiroshima and Nagasaki survivors. These survivors have 2–5% increase in their probability of cancer during their lifetimes.[11] It is therefore reasonable to assume that a similar number—perhaps 500—will get cancer as a direct result of Chernobyl. Since 5000 are expected to die of cancer anyway, and 2000 from smoking cigarettes, careful studies will have to be made to separate out the effects of Chernobyl. For other members of the public, the identifiable cancers will be even fewer.

There have been anecdotal accounts of increases in leukaemias, thyroid nodules and thyroid cancers.[12] Epidemiologists should eventually be able to study the incidence of these diseases. But in the only study of which we are aware, the increase in cancers occurred before the anticipated latency period, and can probably be attributed to improved reporting.[13]

The situation is different for the 600 000 'liquidators'—the Soviet citizens involved with the clean-up after the accident. There is no way that the dose to these people can be checked, and we are dependent on whatever official figures are made available. Some figures were given informally by Dr Leonid Ilyin at a meeting in Paris in April 1991.[14]

The 100 000 civilians in this group had a dose of 21 rem (average); the 200 000 civilians in the second year got 11 rem. There were probably large peaks above these numbers, and the reliability of individual numbers is highly questionable. Anecdotes suggest that supervisors, in the case of army officer liquidators, would demand that a man work a double shift when another worker failed to turn up as assigned. In such cases, the dose might not have been properly assigned to the man who actually did the work. For a small group there is a bigger potential error. It is widely, although informally, reported that several scientists who worked or are working inside the sarcophagus of Unit IV studying the core behaviour have deliberately faked the records so that they will be allowed to work longer in the radioactive environment. In principle, this large group of liquidators should be ideal for an epidemiological study, if reliable records can be obtained. But the contribution to the integrated dose, that is the total dose added over all people, is still less than 10 million man-rems.

Public policy conclusions

It is almost certain that the doses to the public are low enough that any increase in cancer rates due to Chernobyl will be less than the typical increase from a lifetime of cigarette smoking. Unfortunately this is not the general perception, either in the USA or in Minsk, Belorussia. There are interesting public policy questions associated with this simple statement of fact.

- Why has this statement of perspective not been widely circulated and understood?
- Should we improve education about radiation matters, particularly among physicians, in order to emphasize such points? In this connection it is noteworthy that an International Sakharov College of Radioecology was formally

established on 20 January 1992 by vote of the Council of Ministers of Belorussia, following discussions in the Supreme Soviet of Belorussia.

- Keeping unpleasant news, or indeed any news, from the public may give a temporary respite for harassed and overworked officials. But in our view it leads to a disastrous loss of trust in the long run.

A more general conclusion is that widespread secrecy in a technological society eventually leads to accidents; keeping even the engineers, not to mention the public, in the dark about past accidents may help in the short term, but ultimately it backfires. Free information exchange is necessary to avoid both social and technological catastrophes. Excessive secrecy is characteristic of all totalitarian regimes and is one of their principal weaknesses.

The accident at Chernobyl had a smaller effect on public health than the accident at Bhopal; yet we still have a fertilizer industry, and Union Carbide is not yet bankrupt. The accident at Chernobyl had far fewer effects on the ecosystem than the shrinking of the Aral Sea (a catastrophe caused by using feed rivers for irrigation); yet we still use water for irrigation. In our view, therefore, it would be erroneous and in the long term possibly even disastrous to conclude that the world should not have nuclear power. This would badly reduce the world's options in coping with human poverty and other needs, and with reducing the global environmental changes that may arise from the excessive burning of fossil fuels.

Acknowledgment

We appreciate the comments of Dr Herbert Kouts on the draft of this paper.

References

1 First international Andrei Sakharov Memorial Congress on Peace, Progress and Human Rights, Moscow, 21–25 May 1991: recommendations and proposals of experts on the theme 'Global Implications of the Chernobyl disaster and the future of Nuclear power'.
2 USSR State Committee on the Utilization of Atomic Energy, 1986, The accident at the Chernobyl nuclear power plant and its consequences. Information compiled for the IAEA Experts' meeting, 25–29 August 1986, Vienna.
3 Borovoi, A. A., 1990, Inside and outside the sarcophagus. *Priroda*, November, 83–90.
4 Shlyakhter, A., and Wilson R., 1991, Radiation doses and cancer. *Nature*, **350**, 25.
5 Tomanov, G. N., Buldakov, L. A., and Shvedov, V. L., 1990, Irradiation of the population and medical consequences of the accident. *Priroda*, May, 63–67.
6 Letter from A. Dyatlov to H. Blix, Director, International Atomic Energy Agency, Vienna, 1991.
7 Kalugin, A. K., 1990, Today's understanding of the accident. *Priroda*, November, 70–77.
8 Private communications from Dr Alexander Lyoutsko, Rector, Sakharov College of Radioecology in Minsk; and from Dr Stanislaw Shuskevich, Chairman of the Supreme Soviet of Belorussia.
9 Nazarov, A., 1991, The sociological, socio-psychological and medico-psychological aspects of expert assessment of the general situation in the region affected by the Chernobyl accident. *Environmental Management in the USSR*, Issue 9, compiled by A. N. Gratsiansky (Moscow: All-Union Institute of Scientific and Technical Information), pp.80–105.
10 Ilyin, L. A., Balonov, M. I., Buldakov, L. A., *et al.*, 1990, Radiocontamination patterns and possible health consequences of the accident at the Chernobyl nuclear power station. *Journal of Radiological*

Protection, **10**(1), 3–29; IAEA, 1991, *The International Chernobyl Project: an Overview. Assessment of Radiological Consequences and Evaluation of Protective Measures* (IAEA: Vienna).
11 BEIR, 1990, Health effects of exposure to low levels of ionizing radiation. Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, Board on Radiation Effects Research, Commission on Life Sciences, National Research Council, National Academy of Sciences.
12 Boyarskaya, O. Ya., 1991, Tumours of the thyroid gland among children after the Chernobyl accident. Note presented at the Sakharov Congress on Peace, Progress and Human Rights, Moscow, 21–25 May.
13 Shibab-Eldin, A., Shylakhter, A., and Wilson, R., 1992, Is there a large risk of radiation? A critical review of pessimistic claims. Argonne National Laboratory Report (in the press).
14 Ilyin, L. A., 1991, Public dose burdens and health effects due to the Chernobyl accident. Talk at the international meeting organized by Soviet and French nuclear societies, Paris, 15–17 April.

Authors

Alexander Shlyakhter is a former staff scientist with the reactor physics group at the theory division of Leningrad (now Petersburg) Nuclear Physics Institute in Russia and is currently a Research Associate at the Jefferson Physical Laboratory, Harvard University, Cambridge, Massachusetts 02138, USA. His research includes nuclear physics, radiation safety, and environmental risk analysis.

Richard Wilson is Mallinckrodt Professor of Physics at the Jefferson Physical Laboratory, Harvard University, Cambridge, Massachusetts 02138, USA. His principal research has been in high energy physics, and in analyzing environmental risks. He has visited Chernobyl three times, with his Geiger counter, and has made an extensive study of the accident. He is Chairman of the International Advisory Committee of the Sakharov College of Radioecology.