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ABSTRACT

There has been increased public interest in the potential effects of nuclear powerplant accidents since the Soviet reactor accident at Chernobyl. People have begun to look for more information about the amount of radioactivity that might be released into the environment as a result of such an accident. When this issue is discussed by people working in the field of nuclear energy, they often talk about the source term. This technical concept was used exclusively by scientists and members of the nuclear power industry. People have become interested in what it represents rather than the concept. The purpose of this pamphlet is to make this complex idea, the source term, meaningful in understanding nuclear powerplant safety. Topics include: (1) "Nuclear Power Plant Safety: Source Terms"; (2) "Why It's Called 'Source Term'"; (3) "Source Term Research"; (4) "Understanding Source Term Behavior"; (5) "Potential Hazards"; (6) "Design Characteristics"; (7) "Use of Source Terms"; (8) "Source Term Reassessment"; and (9) "Toward a Better Understanding." Also described are two factors indicating that in the event of an accident, less radioactivity would be released than had been estimated in previous licensing documents. (RT)

Since the Soviet reactor accident at Chernobyl, there has been increased public interest in the potential effects of nuclear powerplant accidents. People have begun to look for more information about the amount of radioactivity that might be released into the environment during such an accident.

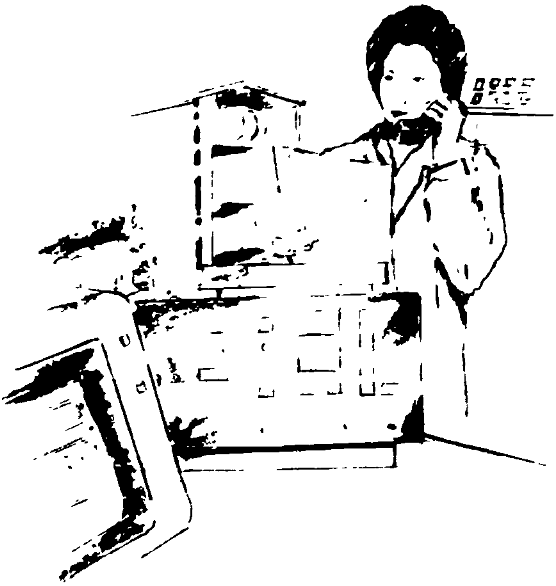
When people working in the field of nuclear energy discuss this issue, they often talk about the source term. Far from being a household word, this technical concept was used almost exclusively by scientists and members of the nuclear power industry until Chernobyl. Even now, most people are less interested in the concept of the "source term" than in what it represents.

Because the source term is very important in helping to understand and prevent the possible consequences of a nuclear powerplant accident, U.S. scientists have studied it for almost 30 years. The purpose of this pamphlet is to take a complex idea, the source term, and make it meaningful in understanding nuclear powerplant safety.

Nuclear Powerplant Safety: Source Terms

When scientists and engineers in the United States design nuclear powerplants, safety has the highest priority. The design objective is to prevent accidents that might release radioactive materials into the environment. In planning, design engineers try to anticipate each problem that might cause such an accident. They collect and analyze data from research programs; they also study reactor performance data from operating powerplants; and they use computers to simulate accidents and "model" the behavior of radioactive materials within the reactor, the coolant system, and the containment building. By anticipating problems, engineers are able to design systems to prevent radioactivity from being released into the environment.

One very important part of reactor safety planning is to understand just what might be released if an accident were to occur. *The source term, in the context of nuclear powerplant safety, is the amount and type of radioactive material that could be released into the environment as a result of a reactor accident.* Making predictions of the source term helps engineers to design safe and efficient nuclear powerplants.



Why it's called "Source Term"

During the early years of nuclear power, scientists conducted research to improve their understanding of how the radioactivity released from a radioactive source might be dispersed into the environment. Sophisticated mathematical models were developed to aid in these calculations. One of the considerations, for example, was how weather might affect the movement of radioactivity. Mathematical equations were developed to model and estimate the concentration of radioactivity in an area downwind from a source. In these equations, called Gaussian Plume Dispersion models, the term "Q" is used to express the amount of radiation released from the source. Thus, Q became known as the "source term."

Source Term Research

Source term research has been conducted for over 25 years in the United States and other countries. As a result, U.S. researchers have estimated the effects of accidents that could conceivably occur at a commercial nuclear powerplant licensed to operate in the United States.

In 1962, the former Atomic Energy Commission (AEC) provided guidance to the U.S. nuclear industry for calculating source terms. The AEC's guidance was deliberately conservative because the Commission wanted to ensure a high margin of safety based on the best technology available at the time. In the years that followed, advances in reactor research, computer technology, mathematical modeling, and the study of chemical reactions and heat transfer improved our understanding of source terms.

As a result of these advances, the AEC published a report in 1975 called the *Reactor Safety Study* (also known as WASH-1400). This study assessed the probabilities of various reactor accidents, their associated source terms, and the potential effects on public health. The report became the basis for some of the regulations used to certify the safety of current commercial nuclear powerplants. It intentionally made conservative estimates of the source terms.

Since the *Reactor Safety Study*, there have been major advances in the technology for calculating source terms. The advances grew out of extensive data collected from international research programs, from large- and small-scale experiments, and from Three Mile Island (TMI) and other accidents. This improved technology has provided a new perspective on source terms, leading to a recognition that we need to re-evaluate existing regulations governing nuclear powerplant design, siting, licensing, and emergency response planning. Scientists now believe that, in general, the source terms that have been considered for these purposes were overly conservative.

Containment Building: 3′ Reinforced Concrete

Containment Lining: ¾″ Thick Steel

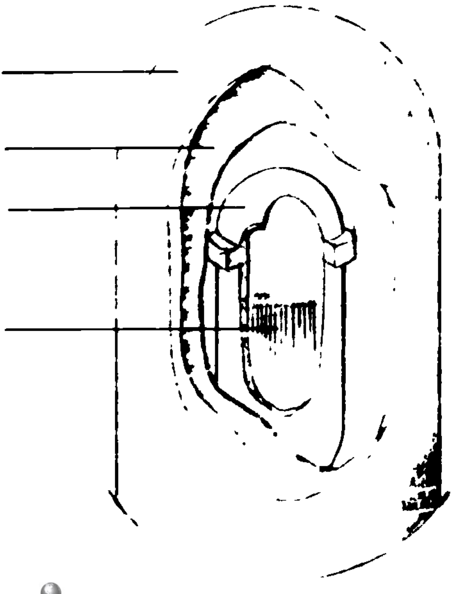
Reactor Vessel: 8″-10″ Thick Steel

Fuel Rod: Length 12′, Diameter ¾″, Containing a Stack of Ceramic Uranium Pellets Sealed in a Zircaloy Tube

Understanding Source Term Behavior

The source term is the amount and type of radioactive material that could conceivably escape into the environment as a result of a reactor accident. Radioactive material forms in the fuel of a nuclear reactor as it operates. Uranium is used as fuel in a nuclear powerplant to generate heat. The heat is used to generate steam, which powers large turbine-generators that produce electricity. When the uranium fuel is used, other radioactive materials — called *fission products* — are produced in the fuel. These products include iodine, cesium, tellurium, and many others. During normal nuclear powerplant operation, these materials remain contained within the fuel.

However, if a severe accident were to occur that resulted in the melting of the fuel, then radioactive materials could be released into the reactor vessel, the thick steel container that



holds the reactor fuel. Scientists must, therefore, ask themselves certain questions: How will the radioactive materials behave? Will they stay in the reactor vessel? Could they escape through a break in the piping system or an open valve? Will they be released into the environment if such engineered safety systems as the containment structure around the reactor should fail?

While these are basic questions to ask, they are not questions that can be answered with a simple "yes" or 'no." The safety design objective is to make these answers "no" to the extent possible. But it is recognized that some very unlikely accident sequences can be suggested in which releases could occur. To evaluate the risks from events that have such low probability of occurring, a technique called *probabalistic risk assessment* is used. For each calculated risk, there is both a probability and a source term.

Many countries that use nuclear power conduct substantial source-term research. The goal is to confirm our current understanding of source terms and to provide new information that will ... scientists to more accurately predict the

Worldwide Source Term Research

behavior of radioactive material during various types of accidents. From this international research, scientists nave concluded that even though a severe reactor accident could conceivably occur, it does not necessarily mean that the radioactive material will be released into the environment. If safety barriers do their jobs, there would be no harm to the people who live [illegible] work around a nuclear powerplant.

Potential Hazards

Research indicates that although there are over fifty different types of radioactive fission products in the nuclear fuel, only four have significant potential for causing harm to humans and the environment. These four materials are iodine, tellurium, cesium, and strontium, and they are important for these reasons:

Iodine
Iodine is readily absorbed into the food chain and tends to concentrate in the thyroid gland. This, in turn, has the potential for causing cancer. However, radioactive iodine decays away in a few days and only contributes to risk soon after an accident.

Tellurium
Tellurium becomes iodine as it undergoes radioactive decay. There is less tellurium, but it takes longer to decay. Otherwise, the health impacts are similar to iodine.

Cesium and Strontium
Cesium and strontium are radioactive for a long period of time. The materials can contaminate property and, therefore, would require extensive cleanup. Cesium and strontium can be absorbed into the food chain and are potential cancer-causing agents.

Design Characteristics

More than just an understanding of radioactive material behavior is needed to estimate the source term for a particular nuclear powerplant. The size of the source term is also dependent on the design of the nuclear powerplant and the manner in which it is operated. Each nuclear powerplant design and accident sequence has its own source term. Safety features used in nuclear powerplant design, such as massive containment buildings and specially engineered safety systems, can lower the source term and increase the safety margin plant.

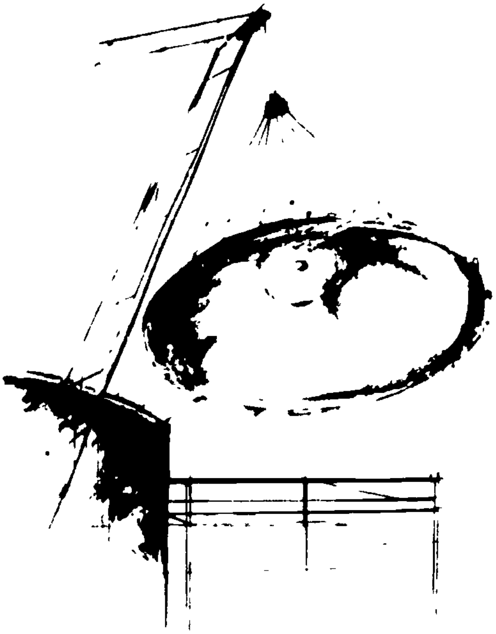
Such design differences were a major topic among scientists attending the 1986 International Atomic Energy Agency Conference held in Vienna on the Soviet reactor accident at Chernobyl. These scientists were unanimous in their opinion that the Chernobyl accident does not change previous estimates of the source terms for reactors similar to those used in U.S. commercial powerplants. The Chernobyl accident released large amounts of radioactivity into the environment. However, the design of the Chernobyl nuclear powerplant is unique to the Soviet Union and is not used in any commercial nuclear powerplant elsewhere in the world. The Chernobyl-type plant is unstable under certain operating conditions — conditions that cannot physically exist with U.S. commercial nuclear powerplants. Furthermore, the Chernobyl-type plant has only a partial containment structure that is much different from the containment structures used for U.S. commercial nuclear powerplants.

Uses of Source Terms

Source terms are used to predict the health and environmental consequences that could result from a reactor accident. Small source terms indicate little or no consequences; large source terms indicate larger consequences. Source terms also serve as a basis for licensing and regulating nuclear powerplants in the

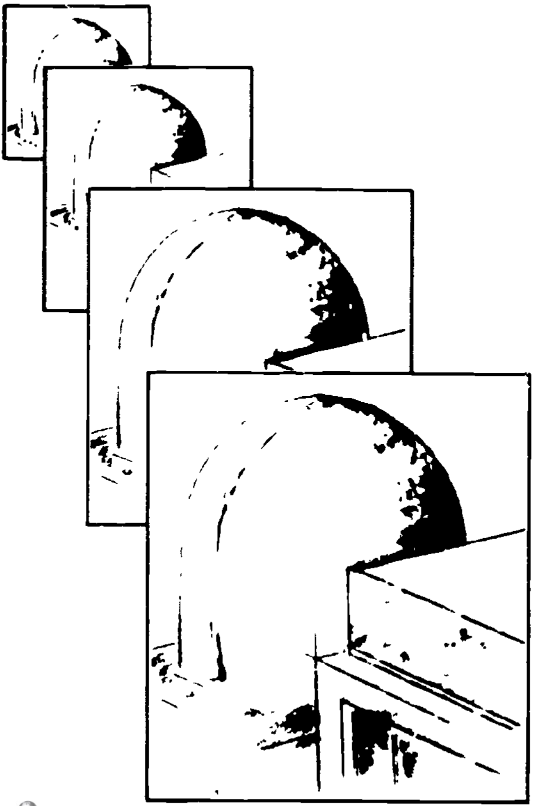
United States. Source-term technology is used to evaluate sites for nuclear powerplants to ensure that, among other considerations, the controlled area around the powerplant is large enough that potential public exposures will be within strictly regulated limits. These data are also important for utilities when they prepare environmental impact statements and emergency response procedures.

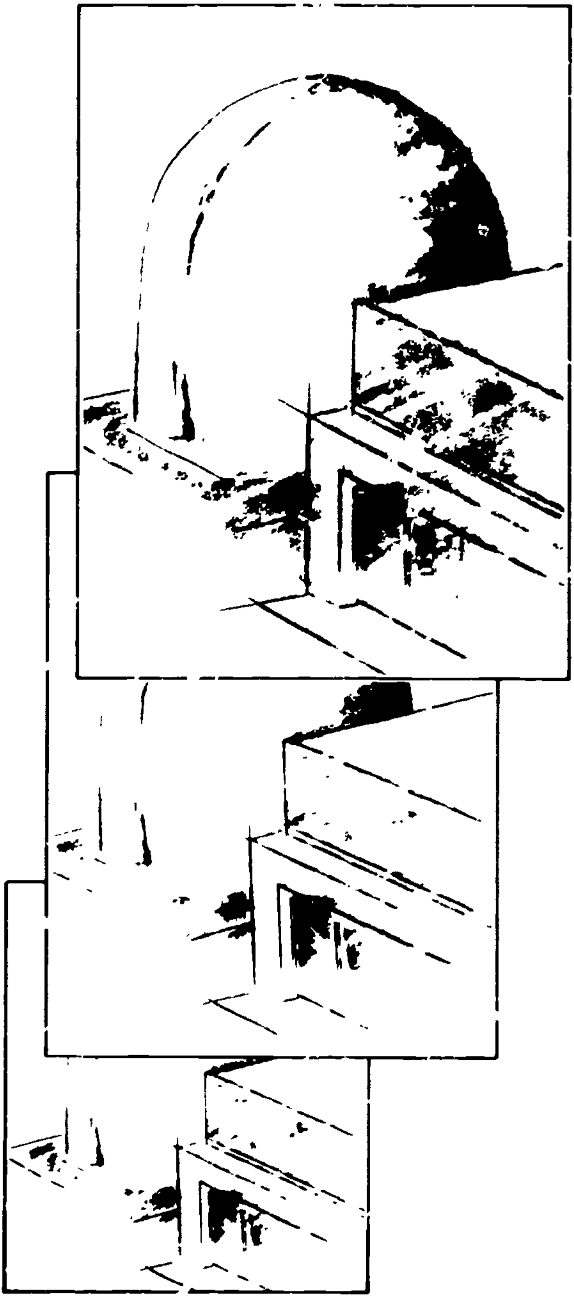
Finally, the design and evaluation of engineered safety systems at nuclear powerplants are, in part, based on our understanding of what happens to radioactive materials during an accident. The analysis of safety systems even includes any effects of radiation on instruments, electronics, or other materials within the powerplant.



Source Term Reassessment

The Nuclear Regulatory Commission is in the process of reassessing the technical basis for estimating source terms. The reassessment results partly from the fact that releases from the TMI accident were extremely low compared with the estimates that were made for that type of accident in the 1975 *Reactor Safety Study* (WASH-1400). In addition, reviews of source-term data by scientific groups such as the American Physical Society, American Nuclear Society, and others suggest that previous estimates of potential releases from reactor accidents in the United States were, in general, too high and that there is a greater margin of safety than previously thought.





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Two factors indicate that in the event of an accident, less radioactivity would be released than had been estimated in previous licensing documents.

Factor 1:

Factor 2:

Before the accident at TMI, scientists predicted that during a severe reactor accident, radioactive iodine and cesium would escape as gases into the environment. The accident at TMI and recent studies, however, indicate that radioactive iodine and cesium will combine with each other and be deposited in the reactor system and the inner wall of the containment building rather than being released into the environment.

Studies and tests have shown that the containment structure surrounding the reactor can withstand and contain the interior pressure that could result from an accident better than previously assumed. These studies also indicate that if a leak actually did develop, it would probably occur several hours after the accident. The delay would result in a significant decrease in the source term and, therefore, in the amount of radioactivity that would be released.

Toward a Better Understanding

Nuclear powerplants have been a commercial source of electricity in the United States for almost 30 years. During this time, the emphasis on safety has resulted in a reliable energy source that now provides over 16 percent of our electrical power. Today, scientists and engineers all over the world have a new perspective of the potential consequences of reactor accidents. Studies have shown that some physical and chemical conditions during an accident actually help prevent the release of radioactive materials into the environment. There has also been significant progress in the techniques used to predict the consequences of possible reactor accidents. With this progress in the understanding of source terms, the Government and the nuclear industry are working to improve the systems and the planning that help ensure nuclear powerplant safety, now and in the future.

The U.S. Department of Energy produces publications to fulfill a statutory mandate to disseminate information to the public on all energy sources and energy conservation technologies. These materials are for public use and do not purport to present an exhaustive treatment of the subject matter.

This is one in a series of publications on nuclear energy. For additional information on a specific subject, please write to ENERGY, P.O. Box 62, Oak Ridge, TN 37831.

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