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Russian Risk Assessment Methods and Approaches[1]

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Abstract

One of the benefits resulting from the collapse of the Soviet Union is the increased dialogue currently taking place between American and Russian nuclear weapons scientists in various technical arenas. One of these arenas currently being investigated involves collaborative studies which illustrate how risk assessment is perceived and utilized in the Former Soviet Union (FSU). The collaborative studies indicate that, while similarities exist with respect to some methodologies, the assumptions and approaches in performing risk assessments were, and still are, somewhat different in the FSU as opposed to that in the United States.

The purpose of this paper is to highlight our present knowledge of risk assessment methodologies and philosophies within the two largest nuclear weapons laboratories of the Former Soviet Union, Arzamas-16 and Chelyabinsk-70. Furthermore, this paper will address the relative progress of new risk assessment methodologies, such as Fuzzy Logic, within the framework of current risk assessment methods at these two institutes.

Introduction

The nuclear weapons complex of the United States is necessarily concerned with the continuous development and improvement of risk assessment methods which can be of use in performing studies of various nuclear systems. While such systems are designed to have very low failure probabilities, such failures are, nonetheless, feasible and the resulting consequences can be unacceptable. Hence, it is of interest to learn how low probability, high consequence systems are analyzed by the nuclear weapons complex of the Former Soviet Union (FSU), particularly at Arzamas-16 and Chelyabinsk-70, the two largest nuclear weapons institutes of the FSU. Furthermore, collaboration which is currently underway regarding risk assessment methodologies between these two institutes and Sandia National Laboratories (SNL) may provide new and interesting insights which may be used to enhance the analyses currently in use at these three facilities.

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Goals and Limitations

The material presented in this paper was primarily taken from several contracts that Sandia National Laboratories has had and, in some cases, currently has with the two Russian institutes, as well as from discussions with the technical people involved in these contracts. Since this work is ongoing, this paper should be considered a "snapshot"; hence, the views presented are our own and are, at best, incomplete. It is hoped that one of the benefits of this paper is to further the dialogue and understanding between the U.S. and Russian institutes in this important field.

The primary projects used to draw the current impressions and conclusions were those between Sandia National Laboratories and the two Russian institutes which described Russian methods of probabilistic risk assessment (recently completed) and on the evaluation of qualitative risk assessment methodologies (currently in progress) (Refs. 1-3). Task reports addressing human factors, which were written by Arzamas-16 and Chelyabinsk-70, in fulfillment of contracts with Sandia, were also referenced for this paper (Refs. 4-5). Supplementing these references were technical dialogues that were held between the principal investigators from Sandia, Arzamas-16, and Chelyabinsk-70 (Refs. 6-7). These technical dialogues were relatively recent and provided the opportunity for the principal investigators to know each other and to begin to understand the capabilities available at each facility.

It must be emphasized that the purpose of this paper is not to describe the technical details of the reports received from Arzamas-16 and Chelyabinsk-70, but rather to report the observations that have been made to date regarding risk assessment capabilities at these two institutes.

Background information on Arzamas-16 and Chelyabinsk-70

A. Arzamas-16

Arzamas-16, also known as the All-Russian Institute of Experimental Physics, or Всероссийский научно-исследовательский институт эксперименталной физики (ВНИИЭФ, or VNIIEF in English) was established in 1946, near Sarov, Russia. The first of the Russian Federal Nuclear Centers (RFNC), it is located in an isolated forest area approximately 400 km southeast of Moscow and about 150 km south of Nizhny Novgorod. It was initially established as a research, design, and development facility with two experimental facilities and internal test sites in the surrounding forests. Manufacture of the first Soviet nuclear weapon components and associated laboratory testing was performed here (Ref. 8). Today, VNIIEF is a complete nuclear weapon design organization involving the design of nuclear weapon charges and warheads, as well as various research and testing programs. Currently, VNIIEF is involved in such activities as nuclear weapon work, nuclear power safety, disarmament and nonproliferation activities, industrial technologies applications, and fundamental research (Ref. 9).

B. Chelyabinsk-70

The Russian Federal Nuclear Center (RFNC) at Chelyabinsk-70 was established in 1954 (Ref. 8). This establishment became known as the All-Russian Institute of Technical Physics, or Всероссийский научно-исследовательский институт технической физики (ВНИИТФ, or VNIITF in English). Chelyabinsk-70 is located about 200 km south of Yekaterinberg (formerly known as Sverdlovsk). Chelyabinsk-70 is also heavily involved in nuclear weapon development work, but is also involved in activities such as experimentation connected with studying and modelling nuclear explosions, development of nuclear and non-nuclear technologies, fundamental research in experimental and theoretical physics, and technology transfer (Ref. 10).

Terminology

When groups of people from different cultural, ethnic, or even scientific, backgrounds engage in technical discussions, it is important to recognize two issues: (1) differences in terminology and (2) use of technical jargon.

As an example of the differences in terminology, one only needs to consider the definition of risk. Risk, as defined by the VNIITF scientists interacting with Sandia, for example, is actually that which is used by reliability engineers rather than risk assessment analysts. This use of the term *risk* is discussed later on in this paper.

In addition to the way in which the terminology is defined, the technical jargon used within a particular community must also be addressed when discussing technical issues. This particular issue surfaced, for example, when Sandia placed a contract with VNIITF in order to learn more about their risk assessment techniques. When Sandia began receiving reports from VNIITF, some of the terms used in the English language version of these reports were confusing to the readers and it was initially assumed to be due to translation difficulties from Russian to English. Since the reports that were sent to Sandia were written in both Russian and English, it was easy to refer to the orginal Russian descriptions in order to determine if there were any translation difficulties. However, this investigation indicated that this was not the case at all. The issue was ultimately resolved with a meeting between the Sandia and Chelyabinsk scientists during which the terms that were unfamiliar to Sandia were identified as "internal jargon" used by the Chelyabinsk scientists (Ref. 11).

By way of illustration, a sampling of the technical jargon used at VNIITF with regard to risk or safety assessments is presented below (Refs. 11,12):

Jargon	Meaning
Method of Branching Hypotheses	Event tree construction

Cutting Algorithm	Solving the event tree using a graphical technique in order to find the total probability of an event
"Slow" Fire	Fire which is next to the object in question
"Quick" Fire	Fire in which the object in question is inside the fire
Sufficent Safety Level	Acceptable Risk Level

For example, someone not familiar with the VNIITF terminology may associate the term "quick fire" with a rapidly spreading fuel fire rather than that whereby an object in question is contained inside a fire. Hence, as apparent from the samples illustrated above, in order to avoid any confusion and misunderstanding when engaged in technical discussions, it is important that any perceived jargon or differences in terminology are identified and defined as soon as possible.

The Concept of Risk

Before any understanding is developed regarding the role of risk assessment in the FSU, it is necessary to initially compare the definition of the term *risk* as used in both the United States and the FSU.

In the United States, there are several definitions of risk. One definition which is obtained from a dictionary refers to risk as "the possibility of suffering harm or loss (Ref. 13)." Reliability engineers, on the other hand, may modify this definition to read as the "probability" of suffering harm or loss (Ref. 14). Individuals in the risk assessment business in the United States, however, generally use the mathematical definition shown in equation 1 (Ref. 14):

$$\text{risk}\left[\frac{consequence}{time}\right] = \text{frequency}\left[\frac{events}{time}\right] \times \text{magnitude}\left[\frac{consequence}{event}\right] \quad . \qquad \text{(eq 1)}$$

Just as there is more than one way to define risk in the United States, the same situation occurs in Russia as well. The following sections will illustrate how the term *risk* is used at VNIITF and VNIIEF.

A. VNIITF

At Chelyabinsk-70, one way to define *risk* is that of a conditional probability which is described as the probability of a hazard, given the accident (Ref. 11):

$$\text{risk} = P\langle hazard | accident \rangle \quad . \qquad \text{(eq 2)}$$

The differences between this definition of risk and the one expressed by equation 1 are worth noting. First of all, the definition described by equation 1 is in terms of both consequence and time, which is not the case for the definition described by equation 2. Furthermore, equation 2 is only concerned with whether or not a hazard exists, not with any consequences due to the hazard. Finally, it has already been stated that reliability engineers define risk as a probability, and equation 2 certainly satisfies that particular definition. Hence, based on equation 2, it appears that risk is viewed from a reliability standpoint at by certain groups at VNIITF, rather than from a risk assessment basis.

Another definition of risk which is used at Chelyabinsk is one first used by W. D. Rowe in which risk is referred to as a "probabilistic loss" (Ref. 15):

$$\text{risk} = \text{"probabilistic loss"} = (negative\_event\_probability) \times (value\_of\_possible\_damage) \qquad \text{(eq. 3)}$$

where the "negative event" refers to an instance such as death, injury, and ecological damage, and the "value of possible damage" is transformed into a conditional average damage per unit time. This equation essentially reduces to equation 1 in which the event frequency is replaced by a dimensionless probability and the magnitude is replaced by a conditional damage (or consequence) per unit time. Furthermore, a report from VNIITF (Ref. 16) states that the "quantitative assessment" of risk "is the relation of one or other unfavourable consequences to their possible number per the definite period of time." This particular statement indicates that risk is perceived as a consequence per period of time, and that quantitative risk assessment is performed by determining and comparing the magnitudes of various consequences per time for different accident situations.

Descriptions of risk from VNIITF also emphasize the difference between individual risk and social risk, stating, for example, that the significance of the social risk is greater than that of the individual risk (Ref. 16). In addition, the dependence between the frequency of hazardous events and the number of victims should be taken into account for determining social risk. Furthermore, the admissible risk for the population should always be less than that for working persons (Ref. 16). This perspective isn't so different from that found in the U.S., except that, in the U.S., the emphasis is on voluntary versus involuntary exposure to risk. Voluntary exposure is perceived to have a greater level of (acceptable) risk than that of involuntary exposure. Also, Western society views single, large consequence events less favorably than the total of smaller events having the same risk (Ref. 17).

Based on the above statements, the key question becomes: *What is acceptable risk?* This acceptable risk is perceived to combine the technical, economic, social, and political aspects of risk (risk being consequence per time). This acceptable risk represents the *relation* between expenditures for attaining a certain level of safety and those expenditures for compensation in the case when the achieved level of safety turns out to be insufficient to prevent the damage (Ref. 16). In other words, if the compensation costs are considered to be adequate in the opinion of those considered to be potential victims, then the risk is considered to be acceptable (Ref. 16). Another way of looking at it may be that expressed in a report by VNIITF, whereby acceptable risk is defined as a "sufficient safety level," (Ref. 12), although "sufficient" was not explained. In the U.S., on the other hand, acceptable risk is usually viewed in terms of a permissible probability in which the greater the hazard severity, the smaller the probability (or frequency) of occurrence should be (Ref. 18). Furthermore, a cost-benefit analysis similar to that described above for VNIITF is often used in risk evaluations in order to determine the monetary benefit of either life-saving measures or the loss of human life (Ref. 17).

B. VNIIEF

Now consider how the term *risk* is defined at VNIIEF. In a task report written for Sandia concerning the evaluation of various qualitative risk assessment methodologies, risk was defined in the following manner:

$$\text{risk} = \frac{Losses}{time} \,, \qquad \text{(eq. 4)}$$

where the term "losses" referred to such concepts as human injuries and material losses (Ref. 19). This equation is similar to the "probabilistic loss" concept of equation 3. The rest of the discussion provided by VNIIEF, however, was almost identical to that found in Reference 14. Hence, it appears that the definition of risk, as exemplified by equation 1, is that which is used at this particular institute, and it may further be assumed that the reliability engineering definition of risk is also used there.

C. Summary

Not suprisingly, at both VNIITF and VNIIEF , as in the U.S., *risk* takes on more than one meaning, ranging from a conditional probability as that used in reliability analysis, to that which considers consequences per time. Futhermore, *acceptable risk* is defined in terms of a relation between those costs required to achieve a certain level of safety and compensation costs to victims. Finally, it appears that there is greater emphasis on the difference between societal risk versus individual risk. At both VNIITF and VNIIEF, like that in the U.S., it is felt that workers should always have greater risk than that of the general population.

Risk Assessment Methods

A. Discussion

If discussions with VNIITF scientists are any indication of how risk assessments are performed at that institute as a whole, then it can be safely said that risk assessments at VNIITF are actually assessments dominated by reliability methodology, with consequence analyses being handled by other specialists not directly involved in the assessments (Ref. 20). Furthermore, VNIITF doesn't distinguish between reliability, safety, and risk assessments, as is done in the U.S. In fact, VNIITF never used the term "risk assessment" until the scientists there started working with those from Sandia (Ref. 20).

When an assessment is performed at VNIITF, major risk contributors are identified by performing tests under severe abnormal environments. Probabilities for these contributors are then calculated using mathematical models that range from simple to very elegant. The risk contributors are then divided into two groups: those having high probabilities and those having low probabilities. Those contributors having high probabilities are the most important risk contributors, while those having low probabilities are identified as "soft spots," which can then be prioritized if so desired (Ref. 20).

The task reports cited in Reference 1 contain a detailed description of the methodology, mathematical models, computational formulas and algorithms used in performing risk assessments at VNIITF. Sample problems are contained in the reports for the purpose of illustrating the methodology. It is apparent from these task reports that some of the mathematical modeling used at VNIITF is quite elegant. In addition, while event trees are discussed in the reports, fault tree analysis does not appear to be addressed. Emphasis is also made on the quality of the calculational nature and experimental tests that are implemented in the course of the assessment. Finally, it appears, from the these task reports, that the risk assessment methodology at VNIITF is dominated by reliability analysis methods (Ref. 1).

In addition to the observations cited above, the task reports that were written by VNIITF for the Sandia/VNIITF contract on Russian methods on probabilistic risk assessment do not mention sensitivity studies for the purpose of ranking the importance of the parameters that influence risk assessment, although VNIITF has indicated that such studies are also performed (Refs.1, 20) (Note: there was no similar contract between Sandia and VNIIEF). These reports also imply that the validity of the risk assessment is defined by the quality of the calculational and experimental research. For example, thermal and strength calculations, as well as the test configuration simulating the accident, are key parameters in the assessment (Ref. 1).

New risk assessment methods, such as the application of fuzzy logic, do not appear in the available reports and literature references from VNIITF and VNIIEF. Such new methodologies are now being introduced to these institutes through technical dialogue and presentations (Ref. 21). Textbooks on fuzzy logic, as well as on other, more mature approaches such the Analytic Hierarchy Process (Ref. 22), are also being introduced to VNIITF and VNIIEF for their review and consideration. Furthermore, a written comparison of relative merits and shortcomings of these methods with other, known methods in Russia is currently being compiled (Refs. 2,3). This comparison has not resulted, to date, in the identification of any novel or different risk assessment methods currently in use in Russia.

B. Conclusions

Based upon the currently available information, the following conclusions can be made regarding risk assessments at VNIITF and VNIIEF:

- Risk assessment appears to be dominated by reliability assessment methodology.
- Some of the mathematical modeling used in the risk assessment methodology at VNIITF appears to be quite elegant.
- No known significant new research has been presented to Sandia to date by VNIITF and VNIIEF in the area of risk assessment.
- Validity of the assessments conducted at VNIITF and VNIIEF are determined by the quality of the calculational and experimental research performed.

The Role of Human Factors in Russian Risk Assessment Methods

A. Discussion

To date, we have seen almost no Human factors and human reliability articles in the available Russian literature on risk assessment. The reason for this lack of information in the available literature, as brought out during technical dialogues with VNIITF scientists, is that human factors simply weren't considered in the Former Soviet Union. Rules and procedures that were in place were considered to be sufficient for addressing human operations during those days. Hence, according to VNIITF scientists, this is why Russia is lagging the U.S. in this important arena (Ref. 23). This last observation was confirmed when reviewing a series of Russian volumes on reliability (Ref. 24). Furthermore, libraries are scattered in Russia, with limited electronic information exchange. Therefore, it is difficult to obtain information regarding human factors and reliability (Ref. 25). In addition, while the post-restrictive society now has limited access to data bases like accident statistics, some of these data bases were (and in some cases still are) classified, making access very difficult. An example of this problem was identified by a rail transportation safety study which ultimately had to be cancelled due to restrictions on the accessibility of Russian data (Ref. 26).

The approach to human factors at both VNIITF and VNIIEF is to place a large emphasis on selection and training of personnel (in that order) (Ref. 27). Furthermore, when including human failure in risk assessment, quantification is avoided. Qualification of the human failure is performed instead, taking into account organizational measures (procedures, etc.) (Ref. 28).

There is no specific special methodology for accounting for human factors and its influence on safety in the performance of work at VNIITF. VNIITF feels that difficulties in defining formalized human activities make data gathering and hence, assessment, in this area practically impossible. Hence, the quantitative assessment of human factors/reliability is not carried out at VNIITF (Ref. 28). The argument is made by VNIITF that human factors is essentially accounted for by performing a "defect" analysis during the operation of complex engineered systems whereby the "negative" influence of human factors is identified, such as design drawbacks, production defects, and the "violation of requirements of technical documents." VNIITF also applies additional "special mechanical and organizational measures" while performing complex and hazardous activities (Ref. 29).

VNIITF identifies several areas for minimizing human error (Ref. 30):

- Make the system resistant to erroneous actions by implementing positive measures in the design (safety devices)
- Selection and professional training of specialists engaged in the design of complex engineered systems
- Strict observance of the technical and regulatory requirements
- Independent expert examination of design and testing results
- Testing of the system in order to simulate possible erroneous actions and the study of the system response to these actions
- Defect minimization in the production of complex engineered systems

A search of Russian literature performed by VNIIEF essentially confirms what is stated above. This review of the Russian literature by VNIIEF indicates a heavy emphasis on established procedures and protective measures. For example, one reference in the literature indicates that the origins of the Chernobyl accident was a combination of the "violations of the order and mode of operation" by the staff (Ref. 5). Based upon the Chernobyl experience, two human factors activities are now emphasized in Russia (Ref. 5):

- Personnel training, including the emphasis of the effects of deviations from the safety rules
- Auditing to ensure compliance to procedures

B. Conclusions

Based upon the above discussion, the following conclusions can be made regarding the role of human factors in risk assessment methods at VNIITF and VNIIEF:

- Russia is lagging in human factors and human reliability risk assessment methodology as developed in the West.
- Human factors is largely governed by training and adherence to procedures.

Overall Conclusions regarding Risk Assessment Methods and Approaches at VNIITF and VNIIEF

Work is still ongoing between Sandia, VNIIEF, and VNIITF in developing a common understanding of how risk assessments are performed in all three institutes. Nonetheless, some observations can be drawn, based upon both the available literature and technical dialogue that has occurred to date:

- The Russian approach to risk assessment (dominated by reliability modeling) and human factors/engineering (dominated by training and procedures) appears to be somewhat different than that used in the U.S.
- The Russian reliability methodology for safety appears to be mathematically sophisticated.
- There are no known new risk assessment approaches being developed at VNIIEF and VNIITF, such as the application of fuzzy logic and fuzzy algebra. However, this particular area is being pursued by the two Russian institutes in cooperation with Sandia National Laboratories.
- Russia is lagging the U.S. in the area of Western human factors methodology.

Again, it must be emphasized that this paper only highlighted salient points which have been learned to date regarding risk assessment methods conducted at VNIIEF and VNIITF. Technical dialogue is still ongoing and future papers will explore some of the issues mentioned here in greater detail, as well as advances made by VNIITF, VNIIEF, and Sandia in applying new methodologies.

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