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Preliminary Results for a Russian Designed Explosive Resistant Container

Kevin E. Carbiener; Sandia National Laboratories; Livermore, CA

Abstract

The Russian Federal Nuclear Center Institute of Experimental Physics has completed a contract with Sandia National Laboratories to explore conceptual development of a family of containers capable of withstanding an internal explosion. The goal was containment of both the explosive force and hazardous by-products of a generic conventional explosive device. The Institute studied two designs, one for 2 kg and one for 50 kg of explosive. The designs were based on numerical calculations to extrapolate prior Russian design and experimental work to encompass these two cases. The Institute's analyses indicate that they achieved excellent results for both a spherical and a cylindrical container made from a stainless steel/fiberglass composite construction. Both designs incorporate unique design features for door closures, internal shrapnel resistance, and shock attenuation. The project identified testing requirements, potential design feature improvements, as well as a sensitivity to the mass of packaging material around the explosive. We are pursuing these issues in a follow-on contract that is being negotiated.

Introduction

The majority of work on explosive containers at Sandia National Laboratories has been focused on accident resistant containers for weapons. We designed these containers to be capable of sufficiently mitigating the destructive energy of an accident environment to prevent detonation of the explosive contents. At the Russian Institute of Experimental Physics, however, the focus has been on containers capable of withstanding the explosive force when the contents *are* detonated. We recognized this difference in perspective on container design as an opportunity for both countries to benefit. A contract was placed under the Department of Energy's Industrial Partnering Program whose general purpose is to further U.S. nonproliferation objectives by redirecting the expertise of scientists and engineers in the former Soviet Union from weapons-related activities to nonmilitary applications of commercial value and of mutual benefit to the United States and to the countries of the former Soviet Union.

Project Background

This project builds on the explosive container experience and expertise of the scientists and engineers at the Russian Federal Nuclear Center Institute of Experimental Physics (VNIIEF) located at Sarov (formerly known as Arzamas-16). The principal investigator is Professor Anatoli G. Ivanov, head of their Dynamic Strength Department. He had presented the results of their explosive container work in a paper to the Albuquerque Symposium of the Cooperative Program in Surety Technologies in October/November 1993. In discussions during the symposium we identified a mutual interest in developing designs based on the Russian work that could be used for safe handling and transportation of generic conventional explosives. The resulting contract between Sandia National Laboratories (SNL) and VNIIEF was signed in October 1994.

The designs were to be developed from the results of past VNIIEF experiments and design prototypes. We based the specifications for the container designs on the concept of an explosive device of unknown origin, condition, or sensitivity. Examples of devices include terrorist bombs and explosives involved in transportation accidents. Scenarios for use of these containers include safe handling (e.g., transportation and storage) and render safe procedures (e.g., detonation, x-ray examination, and remote dismantlement). We decided to explore two container designs, one that is easily transportable for a relatively small explosive and one that could be moved on a large truck for a larger explosive. The design goals that we agreed on for both containers are given in Table 1. Note that the difference between the explosive weight and the payload weight represents the weight of packaging material around the explosive.

Table 1 – Container Design Goals

Design	Maximum Payload Explosive Energy (kg TNT)	Maximum Payload Length (m)	Maximum Payload Diameter (m)	Maximum Payload Weight (kg)	Maximum Empty Container Length (m)	Maximum Empty Container Diameter (m)	Maximum Empty Container Weight (kg)
A	50	1.5	0.8 - 1.0	500	3.0 - 5.0	2.0	5,000 - 10,000
B	2	0.3	0.2	10	0.8	0.7	80 - 130

The objective of these designs was complete containment of the explosive force and its by-products (because they may be hazardous). The capabilities and safety factors of the containers had to be well understood to facilitate their use. Since it may be necessary to make an on-the-scene conservative estimate of the explosive power of the device to be contained, a clear understanding of their capabilities will make it easier to determine if use of one of these containers is appropriate.

Project Description

The contract stated that Container A is to be cylindrical in shape and Container B is to be either cylindrical or spherical. Easy access to the contents of the containers will be required, provided that the contents have not exploded. Otherwise, it is permissible for access to be more difficult. The designers should provide attachments to permit handling and securing of the containers during normal loading/unloading and transportation. Photographs of the earlier VNIIEF design prototypes that provided the basis from which this project's results were extrapolated are reproduced in Figures 1 and 2.

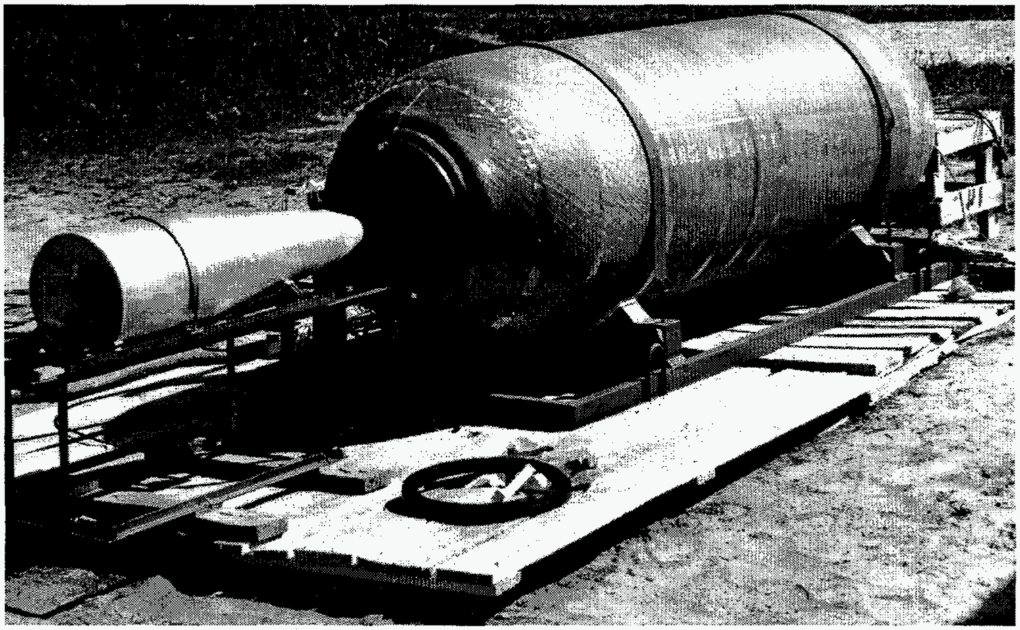

Figure 1 – Prototype VNIIEF Cylindrical Container

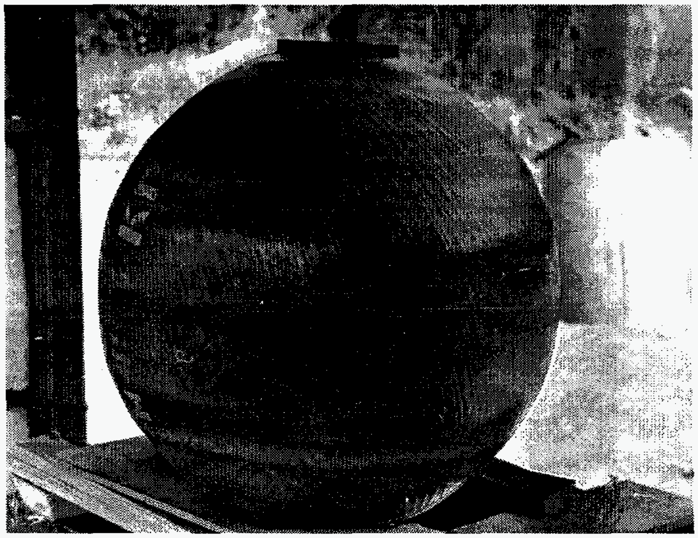

Figure 2 – Prototype VNIIEF Spherical Container

Only the explosive weight and the packaging material weight were specified in the contract. These materials were to be placed in the geometric center of the container cavity and the payload supporting structure was neglected for analysis purposes. The packaging material was to be composed of steel, aluminum, plastic, and wood in a ratio of approximately 2:1:1:1 respectively. The exact types and configurations of these materials were at the discretion of the analyst, but they were to be distributed approximately symmetrically around the outside of the explosive.

Since this initial project was focused on design development, it did not produce any hardware or independent experimental results. The product from this project is in the form of reports and presentations, the most important of which is a set of three design reports. These include a conceptual design report that describes the previous Russian work on which these designs are to be based and the concept for the new designs. The others are a preliminary and a final design report that describe the mature designs in more detail and the iterations that were required to arrive at those designs. The final report also includes any recommendations for design improvements that come to light in the final design stage. In addition to the design reports, a feasibility study and a test plan were presented. The feasibility study describes the new analysis that was performed to extend the results of past work to demonstrate that the new designs meet the requirements. The test plan describes the scale model and full scale testing that VNIIEF would perform to fully qualify the designs to the requirements.

Design Approach

Prior design work on explosive containers was used to establish the baseline container designs, and prior experimental work on containers and container elements under explosive loading was used to validate the numerical methods used. The payload was modeled as a spherical explosive charge surrounded by either a cylindrical or spherical package according to the design specifications. A gas dynamic code (B-71) was used to determine the pressure load resulting from the explosion of the payload as a function of time and location. These calculations were done both one-dimensionally (for a spherical payload) and two-dimensionally (for a cylindrical payload). For this part of the calculations, VNIIEF assumed the container to be rigid. This calculation also determined the dynamics of the shrapnel fragments resulting from destruction of the packaging materials as they are accelerated by the expanding explosion products. State equations and finite element grids were developed to model the different physical elements of the container. A two-dimensional, stress-strain structural code (DRAKON) was used to calculate the stress state and displacement of the container as a function of time and location. This calculation used the pressure and fragment contact results of the previous calculation as boundary conditions.

This technique was used on earlier projects by VNIIEF and validated with prior experimental results. However, these containers were the most complex application, in terms of the number of layers, of this dynamic strength code to date. One advantage of this approach is that a single run of the gas dynamic code could be used as input to several structural code runs as the design developed through several iterations.

Both containers used a composite case composed of a stainless steel structural shell surrounded by oriented tape-wound fiberglass. Both containers also employed a layered steel wire mesh between the payload and the container as shrapnel protection. The containers use two access doors made of steel and secured with bolts. The doors use additional cover plates to prevent the escape of explosion product gases that leak past the doors due to the high dynamic loads at the moment of explosion. VNIIEF intentionally designed the doors to be more difficult to remove after the explosion. Both containers have an external support structure for transportation and handling.

Container A Results

This container employs a cylindrical main body with spherical ends. Earlier concepts considered flat ends that would deform under the dynamic load like the cylindrical body and thus absorb dynamic energy. However, the designers rejected these in favor of the spherical ends because the stress concentration at the corners created the potential for failure. Under shock loading, the pressure is concentrated in the spherical end elements. To protect the ends they are filled with heat-resistant, rigid polyurethane foam dampers. The pressure loads on these dampers are evenly distributed by steel diaphragms located between the dampers and the payload. These diaphragms also serve as shrapnel protection for the foam dampers. Connection of the container body to the transportation support is provided in regions of the structural shell that are most static, or least stressed, to minimize the effects on the container. The details of this design are shown in Figure 3.

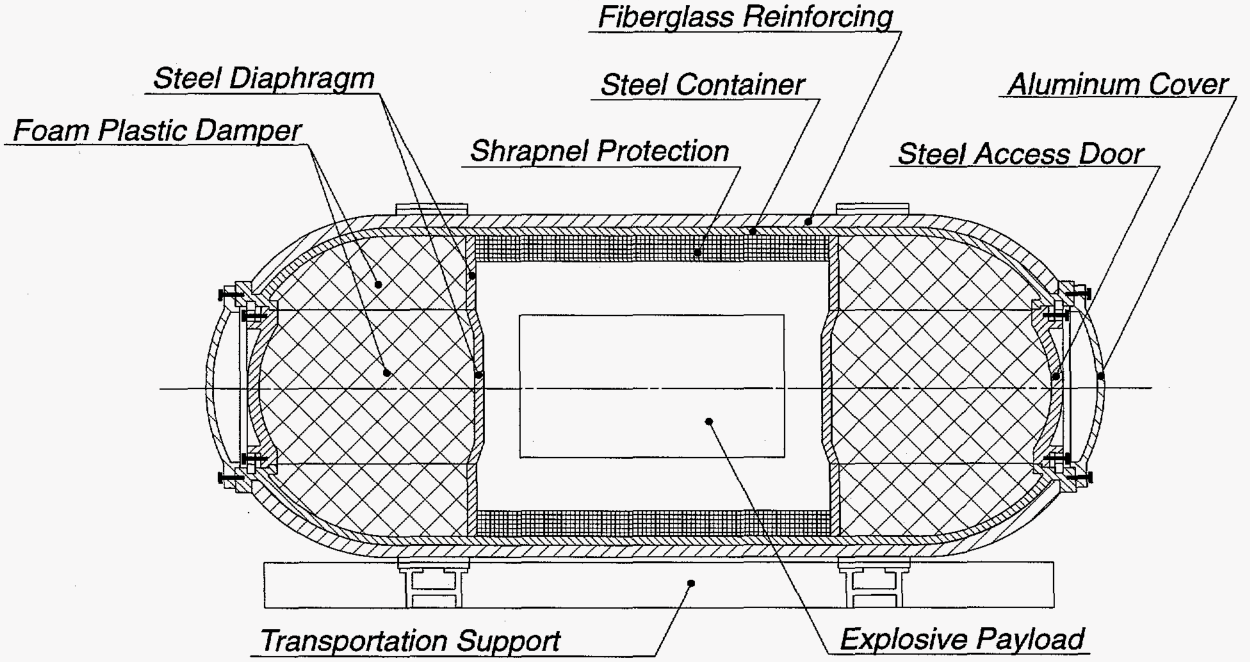

Figure 3 – Container A

The numerical analyses performed on this container design are consistent with experimental results and calculations from the existing containers of similar design. In addition, the numerical methods have been validated against prior experimental work. These results demonstrate the feasibility of this design to successfully meet the explosive requirements. However, the final results were arrived at through several design iterations and the final design exceeds the weight limit set in the original contract. The design changes that were made include: increasing the thickness of the fiberglass reinforcing layer, increasing the thickness of the steel diaphragm, and increasing the density of the foam damper material. The final specifications for Container A are given in Table 2. Considering both the tentative nature of the original design goals and the high quality of the design development study results, we feel that these specifications are perfectly acceptable.

Table 2 – Container A Specifications

Maximum Payload Explosive Energy (kg TNT)	Maximum Payload Length (m)	Maximum Payload Diameter (m)	Maximum Payload Weight (kg)	Maximum Empty Container Length (m)	Maximum Empty Container Diameter (m)	Maximum Empty Container Weight (kg)
50	1.5	0.9	500	4.8 without doors	1.94 without support	13,000

Container B Results

This container employs a spherical main body that provides a very efficient structure. However, it is also more sensitive to discontinuities like the door openings and supports. Because of its symmetry, this design does not employ the foam dampers or the steel diaphragms to protect the door ends of the container, but the designers had to pay particular attention to the design of the doors and the door openings. The doors and the door openings are of a heavier cross-section and the doors are designed with an inner contour that is convex inward toward the explosive payload. This design aids sealing by using the pressure of the explosion products to force the door joint to close tighter. In addition, the door design includes a stronger titanium cover cap to provide a more reliable secondary seal. Details of the transportation support structure were not provided by the final design report, but clearly the intent here is to rest the container inside the support with minimum perturbation of the structural shell of the container. The details of this design are shown in Figure 4.

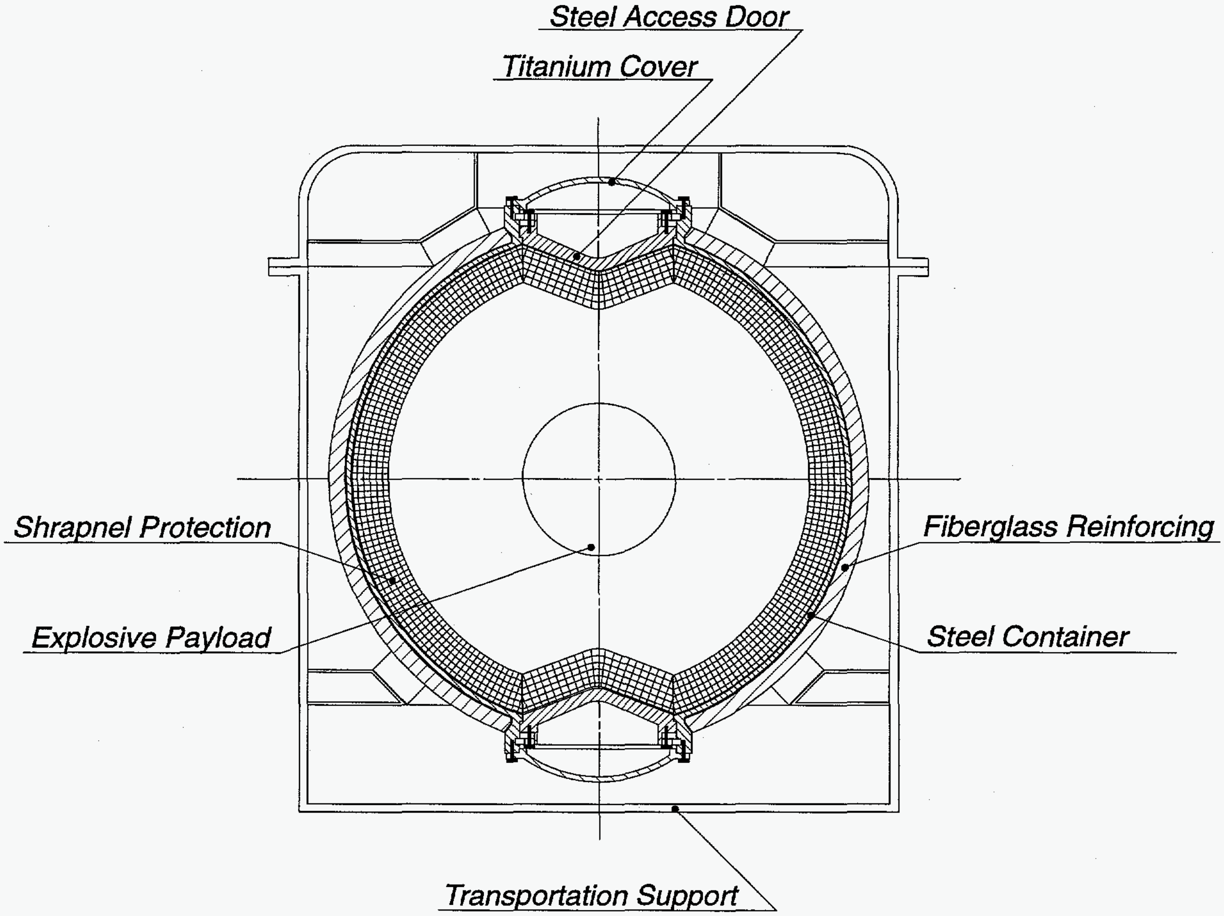

Figure 4 – Container B

The numerical analyses performed on this container design are also consistent with experimental results and calculations from the existing containers of similar design and the numerical methods have also been validated against prior experimental work. These results demonstrate the feasibility of the Container B design to successfully meet its explosive requirements. This design was also arrived at through several design iterations and the final design also exceeds the weight limit set in the original contract. The design changes that were made during the development of Container B include: increasing the thickness of the steel door, increasing the thickness of the steel door opening cross-section, and increasing the thickness of the fiberglass reinforcing layer. The final specifications for Container B are given in Table 3. VNIIEF believes that there is more risk associated with this design because there were fewer experimental verifications of prior containers and container elements than were available for Container A. However, for the same considerations as for the first design, we feel that these specifications are also acceptable.

Table 3 – Container B Specifications

Maximum Payload Explosive Energy (kg TNT)	Maximum Payload Length (m)	Maximum Payload Diameter (m)	Maximum Payload Weight (kg)	Maximum Empty Container Length (m)	Maximum Empty Container Diameter (m)	Maximum Empty Container Weight (kg)
2	0.3	0.2	10	0.8 with doors	0.7 without support	180

Recommended Testing

Since we included no new hardware or testing in the contract, part of the project was to develop a test plan for completing the designs and qualifying them. VNIIEF recommended a systematic approach with three phases of testing. The first phase is experiments on components or elements of the full container design. The goals of these tests are verification, optimization, and improvement of parts of the design. Examples include testing the fragment resistance of the shrapnel protection layer and studying the dynamic mechanical performance of the foam damper material under high rate loads. The second phase is scale model (proposed half scale) testing of the complete container design. The goals of these tests are verification of design parameters, checking for detrimental interactions among the design elements, and determining the ultimate load capability and actual safety factor of the containers. The final phase is full scale explosive testing to verify models and scale factors, and as proof of the final design.

Conclusion

I believe we have demonstrated the feasibility of explosion resistant containers based on the design principles originally developed by VNIIEF in support of their nuclear weapons program. These preliminary designs incorporate several unique features, and the analysis results and past experimental work indicate that they would be successful. This project has also met the goals of the sponsoring Industrial Partnering Program. It has built a nonmilitary application on the weapons-related experience of the Institute, the designs have potential commercial value, and the project was of mutual benefit to Russia and the U.S.

At the conclusion of the design work, VNIIEF had identified several areas that they believed presented valuable opportunities for improvement of the design. The final report provides a detailed listing of these, and they are summarized below:

> The fiberglass layer is the main load-bearing structure for internal pressure. They recommend investigating the use of quartz fiber or carbon fiber to improve the performance and decrease the weight of this layer.

They recommend eliminating the damper as protection for the doors and end elements and replacing it with an orifice or passage system that would take advantage of the Joule-Thomson effect when high pressure gases are throttled. This design would save significant weight and has been studied by VNIIEF but not developed.

There are significant opportunities for additional optimization of the shrapnel protection layer to achieve better performance and weight savings.

Due to the nonuniformity of the cylindrical design, there would be an opportunity to optimize the performance of both the structural shell and the shrapnel protection layer by tailoring their thickness as a function of position to match the applied loads and evenly distribute the stresses.

The same optimization described above for the cylindrical shell could be applied to the spherical end elements but the benefits are not expected to be as great.

The designs exhibited a strong sensitivity to the amount of packaging material used around the explosive. Significant weight savings could be achieved by reductions in the packaging weight for the same explosive weight. Since the packaging material specified in the contract was somewhat arbitrarily chosen to represent a "generic" explosive device, further study of this relationship and refinement of representative packaging configurations could yield substantial design benefits.

The opportunities for follow-on work to this contract have already begun to be realized and are providing additional evidence of the quality of this preliminary work. Sandia is currently pursuing contract negotiations with VNIIEF to incorporate some of the suggested improvements and take the Container A design to the next level in support of some of Sandia's accident response requirements. In addition, development of the Container B design has been approved and funded by the International Science and Technology Center (ISTC) in preparation for potential commercial applications. Sandia and Transnucleaire of France are both participating in the ISTC project as collaborators.

References

1. A. G. Ivanov, A. I. Abakumov, I. V. Devijatkin, et al., "Substantiation of Explosive-Resistant Containers Design Schemes," Science Research Report on Task 5 of VNIIEF-SNL Contract LC-4746, 1995.

2. A. G. Ivanov, A. I. Abakumov, I. V. Devijatkin, et al., "Test Plan of Explosion-Resistant Containers," Science Research Report on Task 4 of VNIIEF-SNL Contract LC-4746, 1995.

3. A. G. Ivanov, A. I. Abakumov, I. V. Devijatkin, et al., "Investigation Results Feasibility Assessment of A and B Type Container Design of Required Explosion Resistance," Science Research Report on Task 3 of VNIIEF-SNL Contract LC-4746, 1995.

4. A. G. Ivanov, V. N. Rusak, S. N. Zaikin, et al., "Choice of Design Versions for Explosion-Resistance Container," Science Research Report on Task 2 of VNIIEF-SNL Contract LC-4746, 1995.

5. A. G. Ivanov, S. N. Zaikin, V. A. Ryzhanskii, et al., "Explosion-Resistant Container Design Concepts," Science Research Report on Task 1 of VNIIEF-SNL Contract LC-4746, 1994.

6. A. G. Ivanov, et al., "Transportable Localizing Container for Explosive Cargoes," Symposium on Accident Resistant Containers and Transportation Surety, Albuquerque, New Mexico, USA, October 26 - November 3, 1993.

Biography

Kevin E. Carbiener
Sandia National Laboratories
Post Office Box 969, MS-9015
Livermore, California 94551-0969 USA

Kevin has worked as a technical staff member at Sandia National Laboratories in Livermore, California, since 1981. He is currently working on Sandia's technical integration team in support of the U.S. Department of Energy's Fissile Materials Disposition Program. His past Sandia experience includes: the design, certification, and production of accident resistant containers for nuclear weapons; weapon systems engineering; and artillery flight and ground test programs. His prior work experience was in petroleum, petrochemical, and light manufacturing industries.

Kevin received his master's degree in Mechanical Engineering from Stanford University in 1983 and his bachelor's degree in Mechanical Engineering from Oklahoma State University in 1981.