Development of a Conditioning System for the Dual-Purpose Transport and Storage Cask for Spent Nuclear Fuel from Decomissioned Russian Submarines

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ABSTRACT

Russia, stores large quantities of spent nuclear fuel (SNF) from submarine and ice-breaker nuclear powered naval vessels. This high-level radioactive material presents a significant threat to the Arctic and marine environments. Much of the SNF from decommissioned Russian nuclear submarines is stored either onboard the submarines or in floating storage vessels in Northwest and Far East Russia. Some of the SNF is damaged, stored in an unstable condition, or of a type that cannot currently be reprocessed. In many cases, the existing Russian transport infrastructure and reprocessing facilities cannot meet the requirements for moving and reprocessing all of this fuel from remote locations. Additional transport and storage options are required. Some of the existing storage facilities being used in Russia do not meet health and safety and physical security requirements. The U.S. has assisted Russia in the development of a new dual-purpose metal -concrete transport and storage cask (Russian Registration# TUK-108/1) for their military SNF and assisted them in building several new facilities for off-loading submarine SNF and storing these TUK-108/1 casks. These efforts have reduced the technical, ecological, and security challenges for removal, handling, interim storage, and shipment of this submarine fuel. Currently, Russian licensing limits the storage period of the TUK-108/1 casks to no more than two years before the fuel must be shipped for reprocessing. In order to extend this licensed storage period, a system is required to condition the casks by removing residual water and creating an inert storage environment by backfilling the internal canisters with a noble gas such as argon. The U.S. has assisted Russia in the development of a mobile cask conditioning system for the TUK-108/1 cask. This new conditioning system allows the TUK 108/1 casks to be stored for up to five years after which the license may be considered for renewal for an additional five years or the fuel will be shipped to "Mayak" for reprocessing.

The U.S. Environmental Protection Agency (EPA), in cooperation with the U.S. Department of Defense (DOD) Office of Cooperative Threat Reduction (CTR), and the Department of Energy's (DOE) Oak Ridge National Laboratory, along with the Norwegian Defense Research Establishment, worked closely with the Ministry of Defense and the Ministry of Atomic Energy of the Russian Federation (RF) to develop an improved integrated management system for interim storage of military SNF in Russia. The initial Project activities included: (1) development of a prototype dual-purpose, metal-concrete 40-ton cask for both the transport and interim storage of RF SNF, and (2) development of the first

transshipment/interim storage facility for these casks in Murmansk. The U.S. has continued support to the project by assisting the RF with the development of the first mobile system that provides internal conditioning for the TUK-108/1 casks to allow them to be stored for longer than the current licensing period of two years.

Development of the prototype TUK-108/1 cask was completed in December 2000 under the Arctic Military Environmental Cooperation (AMEC) Program. This was the first metal-concrete cask developed, licensed, and produced in the RF for both the transportation and storage of SNF from decommissioned submarines. These casks are currently being serially produced in NW (Northwest) Russia and 108 casks have been produced to date. Russia is using these casks for the transport and interim storage of military SNF from decommissioned nuclear submarines at naval installations in the Arctic and Far East in conformance with the Strategic Arms Reduction Treaty (START II).

The design, construction, and commissioning of the first transshipment/interim storage facility in the RF was completed and ready for full operation in September 2003. Because of the RF government reorganization and changing regulations for spent fuel storage facilities, the storage facility at Murmansk was not fully licensed for operation until December 2005. The RF has reported that the facility is now fully operational.

The TUK-108/1 SNF transport and storage casks were designed to have a 50-year storage life. Current RF practice is not to condition the submarine SNF or cask during the cask loading. Current RF regulations allow up to 4 mm of residual water (up to 3.2 liters) to remain in the casks. It has been determined that allowing this amount of residual water to remain untreated for a period longer than two years can produce hydrogen gas through hydrolysis which will increase the risk of explosion and could cause some corrosion of internal components. A solution to this problem was to develop and utilize a cask conditioning system to remove the residual water and create an inert storage environment in the cask by back-filling the internal cask cavity with an inert gas, such as helium or argon. This system is compatible with the existing TUK-108/1 design and is mobile for use at multiple submarine dismantlement sites. The RF has required that this cask conditioning system be tested and commissioned at the “Zvezda” Shipyard in the Far East near Vladivostok, one of the major RF submarine fuel off-loading and storage facilities. Currently, the fuel cannot be transferred to “Mayak “ for reprocessing until the completion of the 20 km railroad connector between “Zvezda” and the main rail line to “Mayak”. The cask conditioning system will allow extension of the currently-stored casks for an additional three years, at which time the rail connector line should be completed. The current license to store these casks at “Zvezda” was scheduled to expire on 31 December 2006. Without the cask-conditioning system, the license could not be extended, no more fuel could be off-loaded from the decommissioned submarines, and the START objectives could not be met at “Zvezda”.

Completion of this cask conditioning system has removed a significant bottleneck for the completion of the Russian submarine decommissioning program under the START II Agreement.

INTRODUCTION

In 1997 a nine-year program was initiated to develop an integrated waste-management system for SNF from decommissioned nuclear submarines. This program has consisted of three projects:

1. Design, construction, certification and commissioning of a prototype 40-ton metal-concrete container (TUK-108/1) for storage and transportation of SNF from decommissioned nuclear submarines of the Russian Navy;
2. Design, construction, certification and commissioning of the prototype storage/transshipment facility for this SNF;

3. Design, construction, licensing and commissioning of the prototype cask conditioning system to ensure safe long-term storage of this spent nuclear fuel.

This program was implemented under the framework of the Arctic Military Environmental Cooperation (AMEC) Program, which focuses on solutions to environmental problems in Northwest Russia. However, the SNF management system developed under these three projects is equally applicable to the Far East. The AMEC Program, an agreement between the Defense Ministries of Norway, Russia, and the United States, was initiated in 1996 to create a forum for increased dialogue and development of joint activities addressing Arctic military environmental issues, particularly in Russia. The United Kingdom joined AMEC in 2003, but has not been active in these projects.

These three projects address specific environmental issues associated with the removal, transportation, and storage of SNF from nuclear submarines being decommissioned in Northwest Russia under the START Agreement. Design of the prototype dual-purpose cask began in 1997 and construction was completed on schedule in September 1999. The cask was tested and certified for production in December 2000 [1,2,3]. The construction of the SNF transshipment and interim storage facility was initiated in mid-2000 and completed in September 2003. Facility hot-testing was conducted in June and August 2003 and the Facility was fully commissioned for operation in January 2004 [4-10]. The design and development of the cask conditioning system was initiated in 2002 and was completed in early 2007. Fig. 1 shows the transportation routes from the major Naval removal/storage sites to the "Mayak" reprocessing facility. These routes are limited and extremely long. Considering this and the limited rail transporters for the cask them was bottleneck in moving the Naval SNF. The completion of these projects has helped remove this bottleneck.

Fig. 1. Russian Naval rail routes and distances for spent fuel shipments to "Mayak"

DEVELOPMENT OF A SNF TRANSPORT AND STORAGE CASK

The specific objective of the first AMEC Project was to design, construct and certify a dual-purpose, metal-concrete, transport and storage cask for SNF from RF nuclear submarines. The Norwegian Defense Research Establishment, the RF Ministry of Atomic Energy (now the RF Federal Atomic Energy Agency), and the U.S. Environmental Protection Agency participated in this project.

The TUK-108/1 cask is a metal-concrete cask designed to contain up to 49 undamaged RF submarine fuel assemblies. It is approximately 4.5-m high and 1.6-m in diameter and weighs approximately 40 metric tons loaded. The cask is designed for a minimum 50-year life and meets all applicable Russian Federation and International Atomic Energy Agency (IAEA) norms and standards for storage and transport of SNF. The cask design has been certified for both transport and storage of RF military SNF by the RF Ministry of Defense, the Ministry of Atomic Energy (now the RF Federal Atomic Energy Agency), and the Ministry of Health.

Serial production of the TUK-108/1 cask started in 2000. The RF reports more than one hundred casks, of the TUK-108/1 type, have been fabricated. The RF further reports that these casks are being used at the FGUP "Atomflot"(Murmansk), Zvezdochka (Severodvinsk), Zvezda (Vladivostok-Bolshoi Kamen), and "Mayak"(Chelyabinsk) facilities for the storage and transport of military submarine SNF. It has also been reported that this same cask design has been tested and certified for the storage and transportation of civilian RF icebreaker SNF. Fig. 2 shows the TUK-108 prototype cask with one of the existing naval fuel canisters inserted in the center. The remaining six canisters for the cask are shown in the right part of the figure. Each cask accommodates seven canisters with each canister accommodating up to seven naval fuel assembles.

Fig. 2. TUK 108/1 Spent Fuel Cask and canisters for naval submarine fuel assemblies from decommissioned nuclear submarines

SNF TRANSSHIPMENT/INTERIM STORAGE FACILITY

The objective of this project was to design, construct, and license a facility at FGUP "Atomflot" in Murmansk suitable for interim storage of up to nineteen of the TUK-108/1 40-ton casks containing SNF. The transshipment/interim storage facility design includes a reinforced concrete foundation for storing the 40-ton casks in a vertical position. Vertical concrete shield walls are constructed around the outer periphery of the foundation plate to minimize radiation dose to site workers who must pass the storage facility. These shield walls extend upward to about three meters, which is about two-thirds of the cask's height.

The storage facility at FGUP "Atomflot" meets all Russian codes and IAEA standards and guidelines for the design, construction, and licensing of a transshipment storage pad for SNF. The storage facility is designed for at least a 50-year service life. It is also designed to withstand a worst-case accident scenario of a plane crash. Current plans are for loaded casks to be temporarily stored in the pad for 30-60 days, but no longer than 1 year. The storage facility is also designed to withstand the extreme temperatures (-50^{o}C to +32^{o}C) of the Arctic, and maximum seismic activity of 6 points on the MSK/Richter scale. The facility is located and designed to facilitate the use of existing equipment, railways, and transfer and handling facilities. The storage facility is designed to accommodate both TK-18 transport casks and the new TUK-108/1 transport and storage casks while utilizing the existing fuel loading facilities (the floating service ships) and rail transport cars for the casks. The project also supported Russia in designing and installing appropriate physical protection, and material accounting and control systems for the SNF being stored at the facility. The facility is also equipped with a dedicated dress-out area and sanitary passage to the facility.

The facility has all environmental/radiation monitoring required by RF standards and norms for operation of the SNF storage facility. A separate AMEC Project (has designed and installed the "PICASSO" system, that provides additional environmental/radiation monitoring for a larger area of the FGUP "Atomflot" Facility. Figure 3 shows the TUK-108 prototype cask in the Facility during the initial cold-testing in June 2003.

Fig. 3. Completed Transshipment/Interim Storage Facility with the TUK-108 Prototype Cask in one of the 19 storage positions

SNF CASK DEWATERING AND FUEL DRYING SYSTEM

To increase the operational safety and performance of the 40-ton casks, a new project was initiated to review and improve on existing cask dewatering and drying systems and procedures. To date sixty-five TUK-108/1 casks had already been loaded with fuel and placed in storage at the RF "Zvezda" Naval Shipyard. Current Russian SNF management procedures allow up to 3.2 liters of water to remain within the cask and fuel canisters after the cask is sealed. This residual water significantly increases the chances for corrosion and hydrolytic gas production within the cask if stored for longer periods of time (more than 2 years). The Rostechnadzor license for storage of 15 of these casks expired on 31 December 2006. Therefore, the development of a conditioning system to remove residual water was necessary to allow continuation of safe SNF storage in the casks. This system would permit storage for an additional 3 years and would support the extension of the existing two-year license to allow for up to 5 years storage. This three-year extension would allow necessary time for construction and repair of a key railroad junction which interrupts the rail path to Mayak. The FGUP "Zvezdochka" site in Severodvinsk may face a similar problem. The interim SNF storage facility is located on the island of Yagry which is separated from the main railhead by a bridge which shortly will require repair or new construction.

This project provided a detailed review of existing fuel management methods, including both physical systems and procedures. This review also identified required modifications to assure that the cask could be safely and effectively used over its lifetime to transport and store SNF without any problems of corrosion and gas production. A Conceptual Plan for the project was completed and approved in August 2002. After completion of the Conceptual Plan, the project was put on a two year hold since Russia announced plans to develop a large stationary cask conditioning system at "Mayak". However, this plan was not implemented. Russia then requested the AMEC Program to proceed with the original plan for a mobile cask conditioning system. The project was reactivated in June 2005. The Project's Technical and Economic Feasibility Study was completed, the new design was approved, and construction of the system for drying the fuel and internal cavity of the cask was completed in December 2006.

The presence of water inside the TUK-108/1 is possible due to the following situations:

- water may be condensed from moist air on the warmer external surface of canisters during the canister-by-canister loading of the SNF inside the TUK-108/1;
- water is introduced as precipitation while the cask is open
- water is introduced into the cask during decontamination and preparation for shipment of the empty cask to the fuel loading facility (e.g. "Zvezda", "Zvezdochka" and FGUP "Atomflot".)

The presence of water inside the TUK-108/1 can cause the following physical processes:

- corrosion of the components of the TUK-108/1 (surface corrosion, crevice corrosion, pitting corrosion, intercrystalline corrosion, corrosion cracking);
- generation of hydrogen and hydrogen peroxide in the process of radiolysis of residual water under influence of gamma radiation from the SNF;
- generation of nitric acid in wet air atmosphere under influence of gamma radiation of the SNF;
- generation of aggressive sulfur dioxide gases (H_2S, SO_2) due to gamma radiation of rubber seals on the inner and outer canister lids.

OAO "KBSM" developed a mathematical model "Track" for calculation of the drying procedure of the cask. Thermal condition of cask is constantly changing during the drying process which
Theoretical calculations of hydrogen concentrations in the canisters with SNF from second generation nuclear submarines, after 5 year storage inside the TUK-108/1, will be 0.17 % of the total volume and inside the internal cavity of the TUK-108/1 is ~0.02 %. These calculations suggest that there should be a

large safety margin for the possible breach due to an explosion, assuring the safety and integrity of the canisters and the internal cavity of the TUK-108/1. However, taking into account the generation of significant amounts of aggressive acidic products (H_2O_2, HNO_3, NO_2, H_2S, SO_2), it is necessary to condition and dry the internal cavity of the TUK-108/1 and to back fill it with inert gas in order to provide additional assurances for the safe long-term storage of the SNF inside the TUK-108/1.
Radioactivity from fission product gases that might be expected during the drying of one TUK-108/1 are:

- krypton-85 (gas) $3.2 \cdot 10^7$ Bq;
- cesium-134 (gas) $0.43 \cdot 10^5$ Bq;
- cesium-137 (gas) $2.0 \cdot 10^5$ Bq;
- cobalt-60 (gas) $2.0 \cdot 10^5$ Bq.

Preliminary calculations to determine the characteristics of the radioactive gases that might be expected during the evacuation of the canister show no need to introduce filtration of the gas that will be removed as part of the drying system since no particulates are expected. However, taking into account the requirements to minimize any impact to the interim storage infrastructure, it will be recommended to include filtration of the effluent stream to remove any possible particulates.

Fig. 4 presents a pictorial of the cask conditioning system being developed and fabricated for testing at the FGUP "Zvezda" Facility. Fig. 5 shows the major components of the cask vacuum drying system.

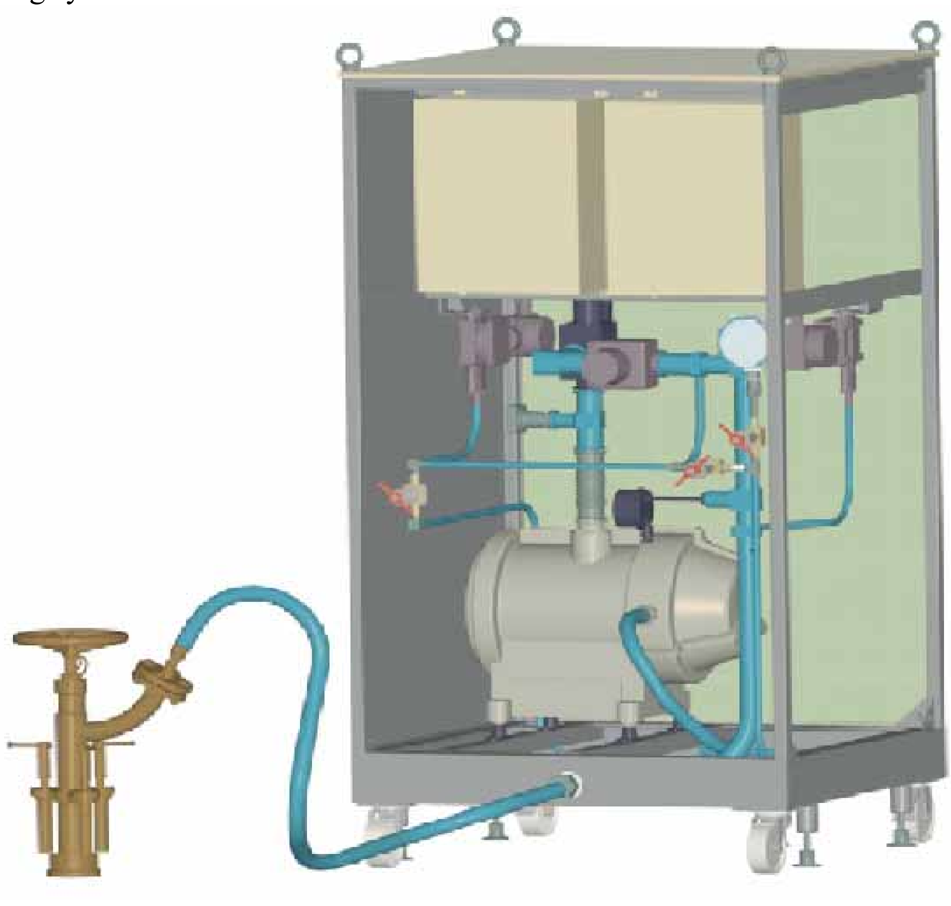

Fig. 4. Pictorial representation of the mobile cask conditioning system for the TUK-108/1 casks at FGUP "Zvezda"

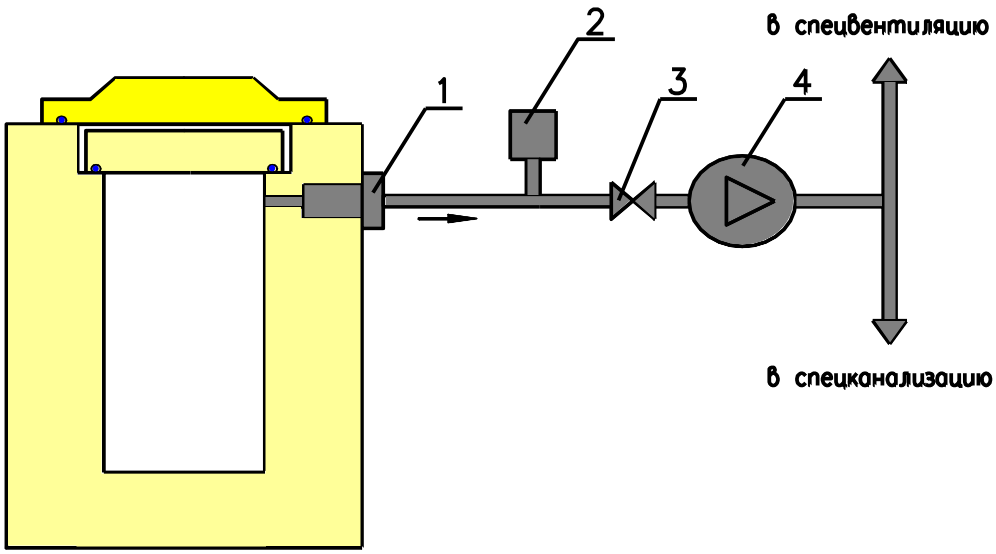

Fig. 5. Block diagram of cask conditioning system with key components identified by number: (1) connecting sleeve with seal; (2) instrumentation; (3) shut down valve; (4) vacuum pump

The following characteristics were considered during the design of the TUK-108/1 cask internal cavity drying process:

- high probability of low temperatures both outside and within the interim storage building
- low probability of cladding failure and out-gassing of fission products from the spent nuclear fuel during loading;
- short time (less than 5 years) that water is irradiated and radioactive hydrolysis takes place;
- high thermal resistance of the cask wall, unique to metal and concrete casks, isolates the internal cavity and prevents water vapor from leaving the cask during the process of drying by heating; relatively small quantity of water and the absence of direct contact in the cask cavity between spent fuel assemblies and water and water vapor
- the application of rigid specifications for the canisters containing spent fuel assemblies reduces the amount of radioactive gases in the vapor removed from the cask, eliminates the need for a condenser in the drying scheme as a mechanism to concentrate the activity, and avoids problems related to pressure control in the system.

Conditions for cask drying are highly dependent on the temperature of the storage faciity. For example, results show that when a cask with a normal radioactive field and thermal profile was stored for 10 days or more at a storage site under an average temperature of minus 16 °C, it was necessary to place the cask inside a room with an ambient temperature of 15 °C for approximately 7 days to reach an equilibrium temperature in the cask. During this time, the minimum temperature at the bottom reaches the level of 12 to15 °C and the drying of the internal cavity by the residual heat becomes possible. Preliminary estimates show that difficulties in carrying-out the drying of the TUK-108/1 may arise when the temperature at which the process is performed is closer to the lower limit (10 °C) of the range of permissible temperatures identified in the design specifications. In the range of 10-15 °C, additional heating is required to perform the cask drying. –At the final design stage an additional calculations were made to determine the optimal conditions of temperature and pressure that guaranteed successful implementation of the drying process.

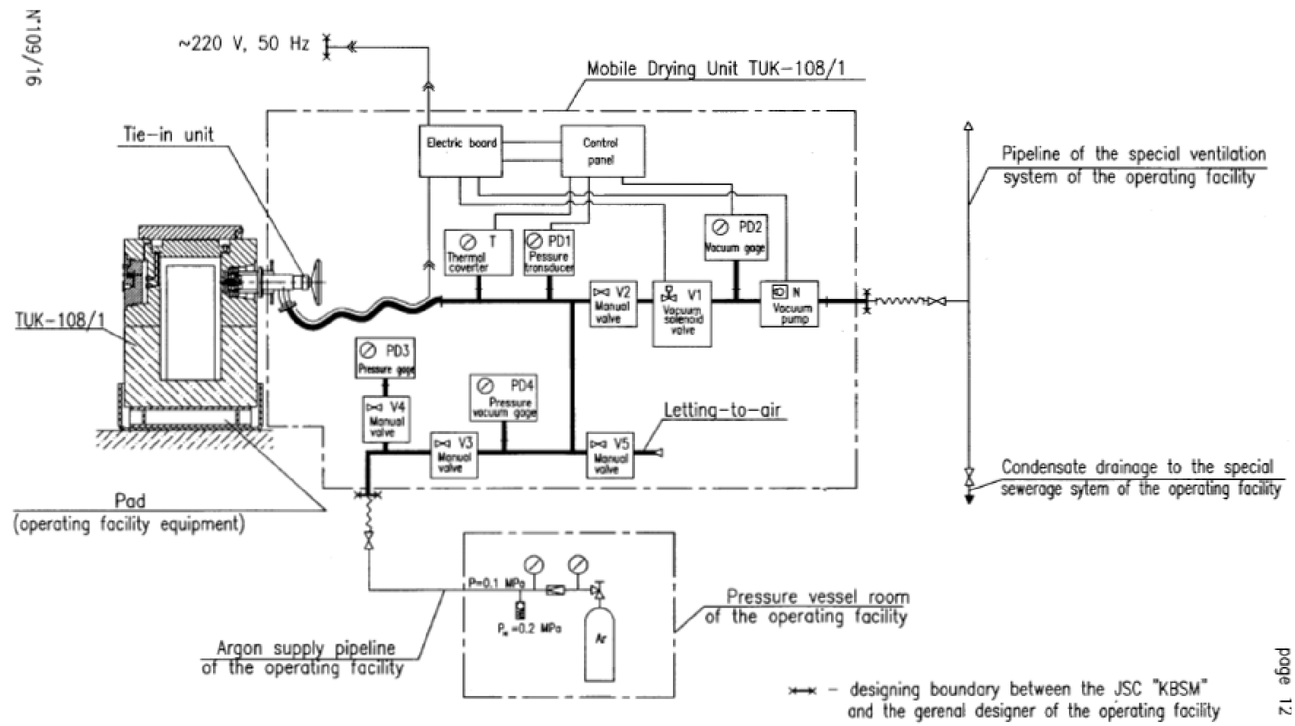

Fig. 6. Schematic drawing of the TUK 108/1 Vacuum Drying and Gas Charging System

The design shown in Fig. 6 is a mobile cask conditioning system containing a vacuum system connected to a special ventilation system, a special filtration and waste disposal system, gas supply for back filling and connection to the electric power supply of the interim storage facility to provide power during the drying process. The evacuation system includes: a vacuum pump, isolation valves, instrumentation, electric power supply, piping, a tie-in device to the cask venting valve and a system of seals to assure that vacuum is maintained and complete removal of all gases, liquids and water vapor is attained. All required parts of the vacuum system are off-the-shelf equipment and readily available.
The drying of the cask is performed in the servicing area on the site of the specific operating facility. At all operating facilities, including, FGUP "Zvezdochka", FGUP " "Zvezda", and FGUP "DalRAO", the cask conditioning system will be located at a support and service platform that allows access to the external venting valve for the internal cavity of the TUK -108/1.

The mobile system is connected to the cask by an air-tight metal sleeve with a tie-in or lock-down device intended for opening and closing the valve to the internal cavity. The metallic sleeve is protected by thermal insulation and has a heating unit to prevent condensation of the vapor being pumped out. The metallic sleeve with the tie-in device is part of the unit, but it is transported separately from the mobile unit in its own packing and connected to the system and the cask at the servicing platform of the operating facility.

The system is also connected with locking, air-tight connectors to facility systems for special ventilation, special waste collection and disposal, and gas supply cylinders from the operating facility. The pipes that connect the mobile unit to the operating facility systems are a fixed part of the cask servicing platform. The liquid/gas mix being pumped out by the vacuum pump from the cask is discharged through filters that are part of the special ventilation system for the operating facility. The condensate generated in the pipelines, downstream from the pump, collects at low points in the piping and through an isolation valve is drained to the special liquid waste disposal system.

After the drying is completed, the cask is backfilled with inert argon gas which is supplied from . outside the operating premises in compliance with Russian Federal Nuclear Safety Regulations NP-044-2003.

CONCLUSION

The design and fabrication of the mobile cask conditioning system has provided the additional performance assurances to modify the TUK 108/1 cask license to extend the temporary storage duration from 2 years to 5 years. This gives operational flexibility to each site to continue loading spent fuel in casks while providing a contingency for any delays in shipping the casks to “Mayak” for fuel reprocessing. This additional flexibility has removed a key process bottleneck to the safe and timely removal of spent fuel from nuclear submarines in Northwest and Far East Russia. This cask conditioning system is the final step in the development of an integrated system for management of spent nuclear fuel from decommissioned submarines.

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