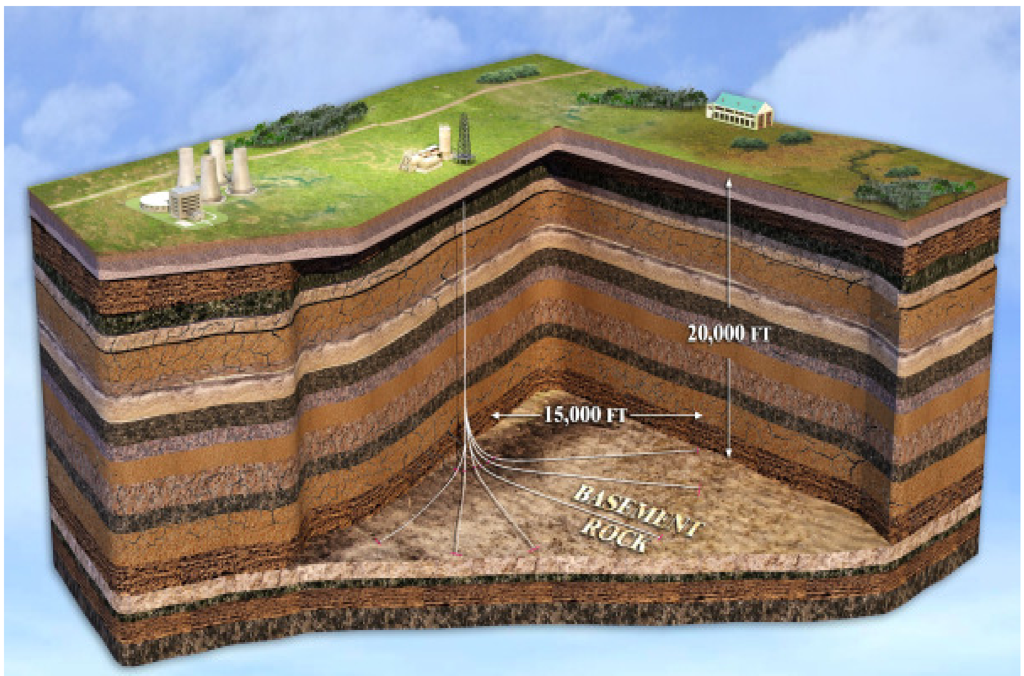
HIGH-LEVEL NUCLEAR WASTE DISPOSAL: THE OPTIMAL SOLUTION



October 2018

Solving the Nuclear Waste Disposal Crisis

The present R&D relates generally to disposing of nuclear waste and more particularly, to: (a) the operations of nuclear waste disposal; and (b) utilization of specialized capsules or containers for nuclear waste which may be sequestered in lateral wellbores drilled into deep geologic formations, such that, the nuclear waste is disposed of safely, efficiently, economically and in addition, if required, may be retrieved at a later date.

High-Level Nuclear Waste Disposal: The Optimal Solution

SOLVING THE NUCLEAR WASTE DISPOSAL CRISIS

IT CAN BE DONE

Here are two bold statements about nuclear waste. Safe nuclear waste disposal is not rocket science. It is not even new. According to French nuclear scientists, Nature had safely stored highly radioactive nuclear material underground at Oklo in Gabon West Africa for at least 2 Billion years.

Today, the final solution for safe nuclear waste storage fundamentally requires only a triad of components, working together:

a closed deep geologic basin,
a well-engineered nuclear waste capsule,
a means to place and retrieve the waste capsule in that closed geologic basin i.e. a cleverly designed wellbore.

All three components are currently available. Some processes have even been patented and published.The final solution is accomplished by harvesting and encapsulating the high-level waste, locating a suitable repository site, drilling a clever wellbore system and landing the encapsulated waste in these wellbores. That's all.

HISTORY

There is an overriding need for an ultimate solution to the waste problem. Spent Nuclear Fuel (SNF) and High Level Waste (HLW) are accumulating at more than 2,000 MT per year on the surface, in warehouses and concrete casks. In the US, a 74,000 MT stockpile already exists. In a single well-publicized example, hundreds of millions of dollars are being expensed today to store 43 concrete casks, filled with waste on a surface cement pad, behind a chain link fence, close to a NY power plant. A final solution is critically needed and timely for several reasons. In addition, today (2018), about $300,000,000 USD are contemplated to develop a storage system in the western US for nuclear waste to be stored in casks, indefinitely.

> ***Based upon studies by the nation's top scientists, the United States Congress has decided the best solution to the critical problem of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) disposal is to place it in solid rock deep underground.*" - USDoE, Sept 1992.**

YUCCA MOUNTAIN

First, in the US, there is the recurring Yucca Mt. problem. For decades the US has been trying to develop a multi-billion dollar final depository for nuclear waste in the desert near Las Vegas Nevada. Pushback has been overwhelming from many sides on this issue. Today, Yucca Mt. is a rotting carcass of an idea that may be resurrected by the US Congress. The ghost of Yucca Mt. continues to dominate the thinking of some politicians. If done, Yucca Mt. requires hundreds of millions of dollars to be expended in a futile effort; according to some technical experts to re-start this 1970s project. This project may never come to fruition because of massive ongoing litigation, a multitude of defined and demonstrated technical, political, economic and scientific deficiencies that Yucca Mt. faces from all sides. Two questions should be asked concerning the Yucca Mt situation:

(1) *What is right about the Yucca Mt. exercise? The short answer is, very little,*

(2) *What is wrong with this approach to the Yucca Mt. nuclear waste disposal? There is no short answer.*

Volumes have been and are still being written about the problems associated with Yucca Mt. The Yucca Mt. narrative must be changed. Some technical experts consider Yucca Mt to be a futile exercise. There is a significantly better option available today.

Second, the economic, legal, political and environmental cost of maintaining the Yucca Mt. status quo is becoming unsustainable now and shall escalate further soon. Power companies are beginning to sue the US government to "*take*" the waste as the Government promised in earlier agreements.

Third, there is a general belief that the nuclear power industry shall generate a resurgence by adopting small modular reactors (SMR) as the preferred means of power generation and distribution in the future. The SMRs shall be smaller, about 300 – 600 MW units which are factory-built modules, transportable to the final power site for assembly and more easily permitted by regulators. They are aimed at developing countries and shall be available on demand from the major power manufacturers in the US, Europe, China, and Korea. The SMR waste products must also be disposed of. Geologic waste repositories shall be in place and strategically deployed when these power plants come online.

THE OPTIMAL SOLUTION - TECHNOLOGICAL PROCESS

In addressing the development of the waste disposal technology, it is noteworthy that in July 1997, the first patent application on using horizontal laterals for nuclear waste disposal was filed with the United States Patent Office. The first patent (US,5,850,614) on the use of horizontal wellbores in deep geological HLW disposal systems was later issued. Twelve years later, in 2009, the U.S. government research laboratory at Sandia released a significant report supporting the efficacy of this published disposal technology. This report though expansive and detailed failed to adequately address or include the more critically important advanced oilwell drilling technologies which can now form the backbone of the waste sequestration process.

The final solution developed and implemented by scientists, engineers and technologists must focus on proven technologies and additionally on those processes that can be learned from the natural environment. From examining how fossils have survived. How artifacts have been able to withstand thousands of years of burial in certain environments. Which geologic environments provide closure, longevity and protective measures. How and why buried fluids exist, contained under pressure, for millions of years in specific geologic basins and formations with favorable petrophysical properties, and finally, to utilize and or adapt these processes to benefit the nuclear waste disposal development.

Thanks to a robust oil and gas exploration industry that has 150 years of successful experience in finding deep closed high-pressure, isolated, fluid bearing basins, these particular geologic basins can be adequately defined and explored in greater detail than ever before. Besides, 3-D and 4-D seismic exploration coupled with sophisticated clusters of high-speed computers allow the geoscientists to peel back the earth's surface, like an onion. They can produce subsurface maps with any required level of precision. In their “viewing salons,” they can project these subsurface images in 3D and literally “walk” around and through these structures examining them in minute detail with their special virtual-reality 3D glasses. This is the status of the subsurface exploration technology today. It is truly a 21st-century expertise available for waste disposal use to pinpoint the best nuclear waste repository site.

OTHER DISPOSAL OPTIONS

Today, some existing and proposed disposal methods try to bury the high-level waste (HLW) in shallow salt beds, excavated mined vaults, moderately deep shale formations, tectonic plates, seabed ooze, deep vertical wellbores and other variations of the geologic isolation alternative. They all have many deficiencies including; extreme cost, in the billions, long delivery times, measured in decades; radioactive safety issues due to surface leakage and contamination; technical and scientifically infeasibility, politically impossible to implement because of widespread public resistance and the environmentally sensitive misconceptions of the radioactive waste - real and imaginary.

By implementing the three innovative operational fundamentals discussed here, the SNF and HLW are finally removed from the biosphere.

THE ULTRA DEEP GEOLOGIC REPOSITORY - UDGR

The first leg of the triad is a deep underground closed geologic repository for the nuclear waste material. After drilling into it, the selected repository can be scientifically shown by conventional radioisotope dating techniques to have been closed for several million years. It can thus arguably be expected to remain closed for at least another 10,000 years. Further, waste generated radionuclides are held in place, deep in the repository by the combination of massive engineered barriers of the wellbores, waste capsule construction and the overburden of thousands of feet of basement rock, sedimentary rock and clays surrounding and above the horizontal wellbores.

Advanced nuclear waste capsules form the second leg of the triad. These contain the nuclear waste material and provide for long-term survivability, radionuclide protection and absorption within the deep underground wellbores.

Specially designed vertical and interconnected wellbores, which provide the delivery means whereby the capsules can be inserted and "landed" in the selected deep underground closed geologic repository. These form the third and final leg of the triad.

These wellbores are cylindrical in geometry and comprise multiple concentric high-grade steel pipes of varying sizes with specially cement-filled annular regions which together provide an impenetrable barrier to fluids and which are expected to resist degradation for tens of thousands of years of storage time.

The innovative element of this technology recommended to resolve this hitherto intractable problem comprises a series of specially engineered horizontal wellbores. Horizontal wells do not create any vertical loading problems as occurs in vertical wells. In a horizontal well, gravitational effects i.e. the weight of the very dense nuclear waste only occurs over less than one foot, i.e., the diameter of the wellbore, whereas in vertical wells the weight "*on-bottom*" is developed from 15,000 feet of heavy nuclear material above and in the capsules. This situation causes an extreme, catastrophic, compressive loading of the lower radioactive material within the vertical wellbore at the bottom of the wellbore.

These horizontal wellbore segments are implemented and "kicked off" from an initial deep vertical wellbore, utilizing well-known drilling operations and are then drilled laterally for several thousand feet into a suitably selected basement rock formation. Computer simulations show that a single well-engineered wellbore system can hold more than 1,000,000 lbs of HLW without compromising the current heal load limitations imposed by Governing Regulatory Agencies.

Today, lateral wellbores have been routinely drilled more than 40,000 feet of total measured length. This can be, a 10,000-foot vertical interval followed by a 30,000-foot lateral horizontal section. The current total measured record length for a lateral wellbore system is 41,667 ft or almost 8 miles [(5)]. The modern automatic drilling rig system, comprises several remote control computer-driven modules, it includes down-hole drilling motors, massive top-drive motors with up to 5,000 HP and several redundant safety systems.

The drilling rig has tremendous mechanical capabilities. This apparatus can lift up to 2,000,000 lbs of steel pipes effortlessly. Not only are these powerful systems effective, but they also produce significant drilling results <u>in days and weeks</u> <u>and not in years.</u> This means that the recommended mode of horizontal wellbores for nuclear waste disposal can be effectively implemented in months rather than decades as being envisioned for sites like Yucca Mt and other mined solutions in Europe and Canada.

Today, the speed of execution of the drilling process is a breakthrough in the mindset of HLW disposal technology. Contemporary groups, institutions, governmental bodies, Government laboratories and commercial companies <u>all think in decades</u> to effect a viable HLW solution in mines or similarly designed shallow buried nuclear waste warehouses. With the novel wellbore technology illustrated herein, this process is effectively implemented in less than one or two years from initial siting of the nuclear repository location to loading and landing the capsules in place at a depth more than 25,000 feet deep underground in the geologic repository horizontal systems.

Under certain pre-determined operational conditions, the encapsulated waste may be retrieved. A unique capsule design connector allows for retrieval of the capsule from the underground disposal location in the lateral wellbores.

In a break from the conventional, the technology involved in the deep lateral wellbore process is very mature and dependable. There are no learning curves involved in any aspect of this project. The bottom line is that the oil well drilling industry has demonstrated by successfully drilling over 2,000,000 wells and several hundred million feet in different types of rock material worldwide. The drilling technology is eminently capable of performing as required in this disposal process.

The deep geologic repository can be implemented anywhere at any time, because the current mature oil and gas well drilling industrial enterprise has probably the most sophisticated, supply-oriented, logistical command and control operations on the planet. These operations range worldwide, anywhere, from the Arctic, the Siberian theaters, deep offshore platforms in the North Sea and the Gulf of Mexico, the African Jungles, to the remote deserts of Continental Africa or China. This industry knows how to operate equipment that is sophisticated, complicated and expensive in areas which are usually considered inhospitable, dangerous, formidable and unreachable. Furthermore, the supporting technology, seismic, geological evaluation, petrophysical analysis, formation evaluation form the backbone of exploration in the energy industry. The technology is well developed.

In the popular vernacular, it is an understatement to say that the available types of downhole formation analysis tools are “mind-boggling." There are literally dozens of applications that provide the highest quality analytical data and the most precise definition of the in-situ properties of the rock formation into which the waste material will be disposed of. A few of the logging suites available today to define the geologic repository rock material. These are: micro-resistivity, acoustic, nuclear, gamma ray, pulsed neutron, carbon-oxygen, NMR, porosity, permeability, saturation, fluid contacts, lithology, fractures, mechanical properties, anisotropy, fluid types and the list goes on.

Contrary to public remarks by a political supporter of the “mining disposal approach” for HLW,

> “*With the mining disposal methods, you* ***can look at the rock face*** *and see the type of storage repository…*”.

The current downhole logging technologies debunk this thinking and provide a very detailed comprehensive formation and rock analysis, deep into the rock matrix, away from the actual wellbore, and this detailed data allows the prospective site for the final disposal of SNF and HLW to be certified as safe with a high degree of scientific certainty.

Existing wellbore technology can also provide a theft deterrent system which precludes the re-entry and misappropriation of this stored nuclear material for possible unlawful uses. Any non-state agent will need a massive drilling rig, easily visible by satellite observation to drill down to and re-enter the wellbores in the repository to take away the waste capsules. It will also require several months of tough drilling to enter the wellbores since a series of un-drillable “bridge plugs” installed inside the wellbores will thwart any effort to drill into the closed wellbores. These plugs shall shred the drill bits being used by the party trying to steal the waste capsules for nefarious intent.

THE WASTE CAPSULE SYSTEM

The waste capsule is another critical and integral part of the technology triad. Its form and function should allow the waste to be protected for more than the required 10,000 years of burial. The novel waste capsule process design includes a more direct approach to handling and packaging the SNF waste material. It differs from currently accepted processes. It is proposed, in the US, after cooling for a prescribed number of years in power plant cooling ponds or surface storage casks, the control rod fuel assemblies, either intact or minimally disassembled are then encapsulated in a single step in a supported cylindrical nuclear waste carrier system with an internal core.

In other countries, like Canada and Russia, no control fuel rod disassembly is required because of their specific circular or hexagonal design geometries are more amenable to a cylindrical core encapsulation system. The cylindrical nature is crucial and more compatible operationally to the types of equipment and machinery that are already well developed and established in the oil-well drilling industry for handling, loading, transporting, drilling and delivering devices and materials into deep underground wellbores which are always circular in cross-section.

This novel direct capsule forming approach departs significantly from the accepted capsulation methods. It does not utilize a series of unnecessary and expensive intermediate steps which hitherto have been used to take the fuel rod assembly through cooling pool operations, surface operations, including dismantling the assembly, reprocessing, post-treatment and repacking the highly radioactive pellets into a form suitable for encapsulation.

Continuing the preferred encapsulation operations used by this novel technology, the entire nuclear waste fuel core is fitted inside a metal carrier tube constructed of a metal or metallic alloy which is characterized by both its strength and its corrosion resistance. Between, the nuclear fuel core and the metal tube is a void space in which a specialized protective medium is employed. This innovative addition maximizes the longevity of the capsule before waste core degradation occurs. It also simultaneously minimizes radionuclide migration away from the core material. The metal carrier tube is a first concentric layer radially outward from the nuclear waste core. This carrier tube completely encloses and surrounds the waste fuel core.

Directly adjacent and juxtaposed externally to this carrier tube is an inner steel tube which provides both external support, protection and increased strength to the carrier tube carrying the nuclear fuel core. The wall thickness of this inner steel tube is at least ½ inch and constructed of steel with a yield strength in excess of 75,000 psi. The steel type should be at least N-80 grade and preferably P-110 grade or better. All of these steel products are readily available off-the-shelf in the existing oil and gas industry.

These steel tubes provide additional engineered barriers to protect the nuclear waste while buried. Surrounding this innermost steel tube are multiple concentric alternate layers of steel and annular cement filled layers which together form a composite engineering barrier which is designed to last for millennia. It is contemplated that the steel and cement outer layers shall eventually degrade after several millennia at which time the internal protective medium which could be a bentonite clay-like material or a long-term bitumen-like medium shall provide the long-term protection of the nuclear waste material in a shielding manner similar to that which occurs in the tar sands of Athabasca, Canada.

In the tar sand material in which the bitumen material which was deposited in the Cretaceous period surrounds the billions of sand grains and fills the interstitial pore space in the rock with the viscous highly immobile material.

This composite mixture has maintained a heterogeneous mass collectively called tar-sand which for more than 100 million years was stable, stagnant and impervious to flow. Today, it is made mobile by high pressure and high-temperature steam injection extraction methods. This type of encasement of SNF/HLW by the protective medium shall maintain a safe disposal cocoon preventing migration of radionuclides away from the SNF/HLW core.

ENGINEERED BARRIERS

The current improved engineered barrier system implemented in these novel capsules have designed the longest duration barrier, the protective medium to be the inner-most layer of protection. In a naturally occurring degradation process, the degradation begins at the outermost layer in contact with the geologic rock matrix and then continues inwards into the central core of the system. The outer protective layers, outer annular cement, outer steel pipes, inner annular cement, inner steel pipe, in this capsule design all will degrade over varying time horizons. The inner-most tar-like medium has been historically demonstrated in the geological record, to be an effective fluid and migration barrier for millions of years. In numerical terms the cement and steel may degrade in 4,000 to 10,000 years. However, the tar-like medium enclosing the central core shall be viable and be a protective medium for hundreds of thousands of years.

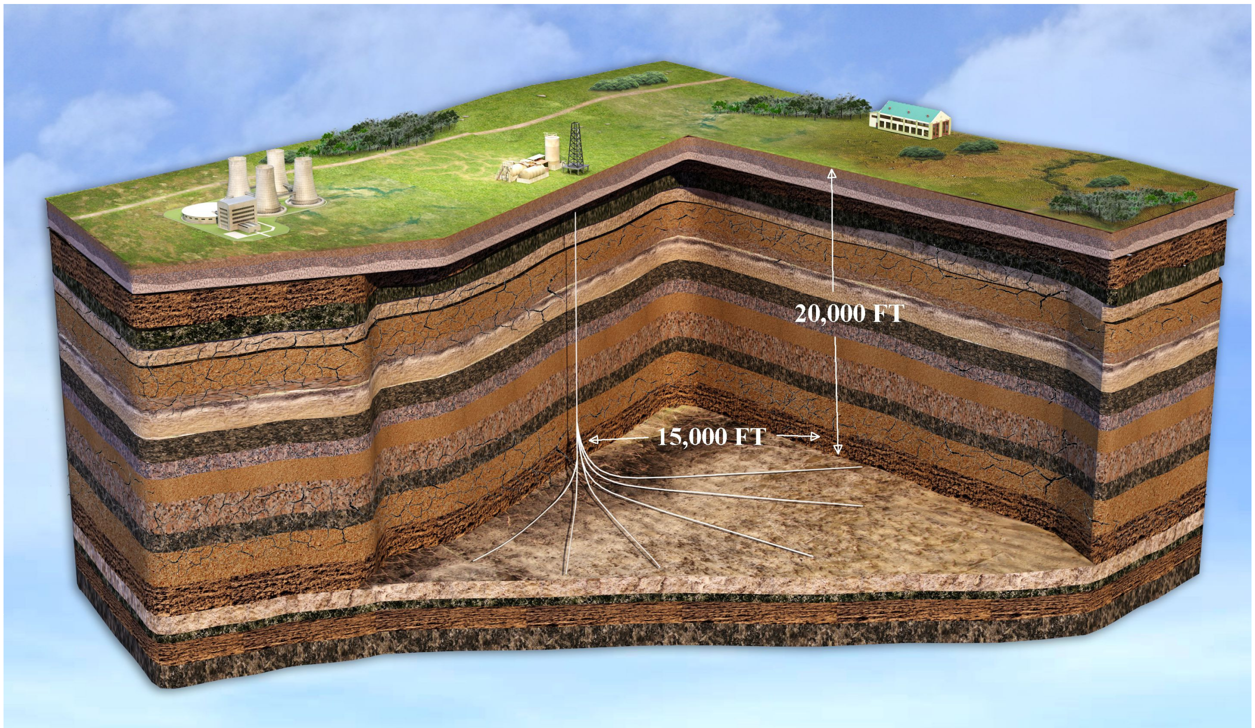
CONCLUSIONS

Finally, the deep geologic repository with its horizontal wellbores will function as intended since it is an entirely passive system that depends on a massive protective arrangement of overburden rock and the mechanical, physical and chemical defenses to maintain isolation from the biosphere. Also, ongoing O&M costs are minimal for a project of this size and complexity.

The technology is extremely versatile. The well-designed systems can dispose of various types of wastes which can be handled by modifications of the primary capsule module to handle fuel rods or derivatives of liquid waste products which have been chemically or physically modified.

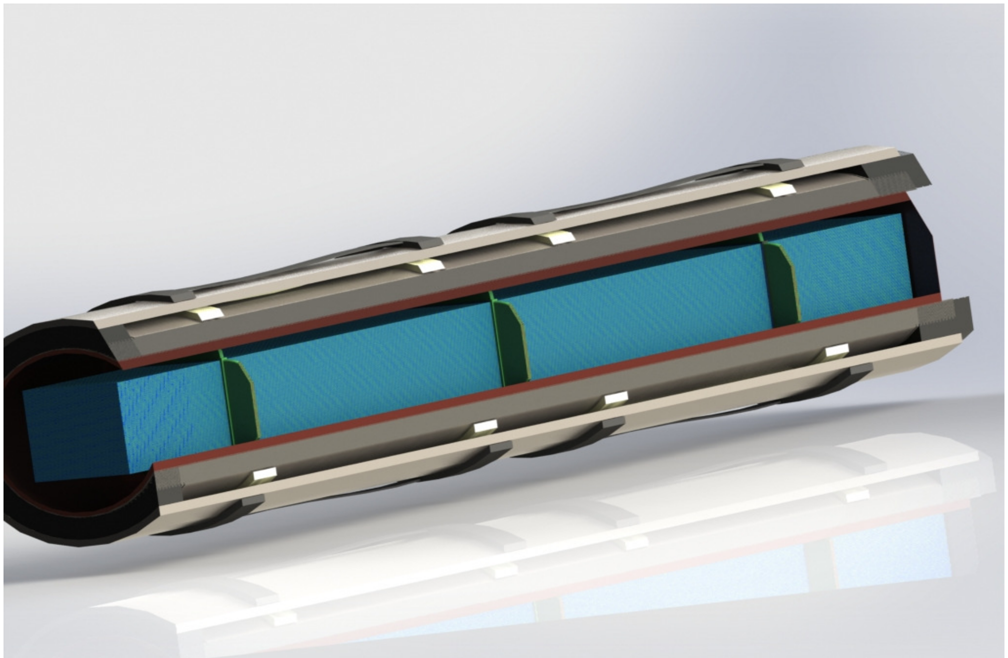
Finally, the public is keenly aware of the need for safe and reliable nuclear waste disposal and the deep geologic repository meets all the requirements by providing a straightforward and dependable technology which is demonstrably more effective at protecting their safety and welfare at a minimal comparative cost.

Today there is an urgency. The incumbent thinkers have been entrenched for decades. Well connected, they have had well-funded programs. It is imperative that new ideas see the light and provide the long-term economic solution that HLW needs.

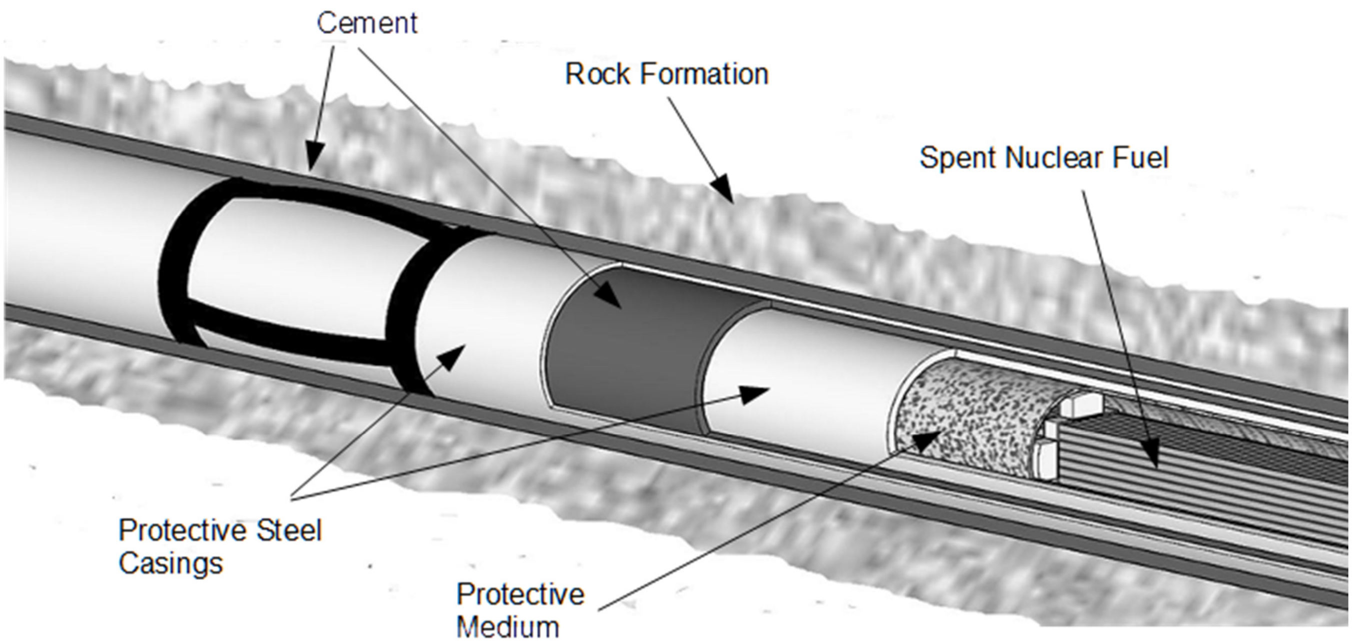


ULTRA DEEP GEOLOGIC REPOSITORY: DRILLED TO 20,000 FEET WITH MULTIPLE 15,000 FOOT LATERAL HORIZONTAL WELLBORES DRILLED IN BASEMENT ROCK FORMATIONS TO CONTAIN HUNDREDS OF NUCLEAR WASTE CAPSULES

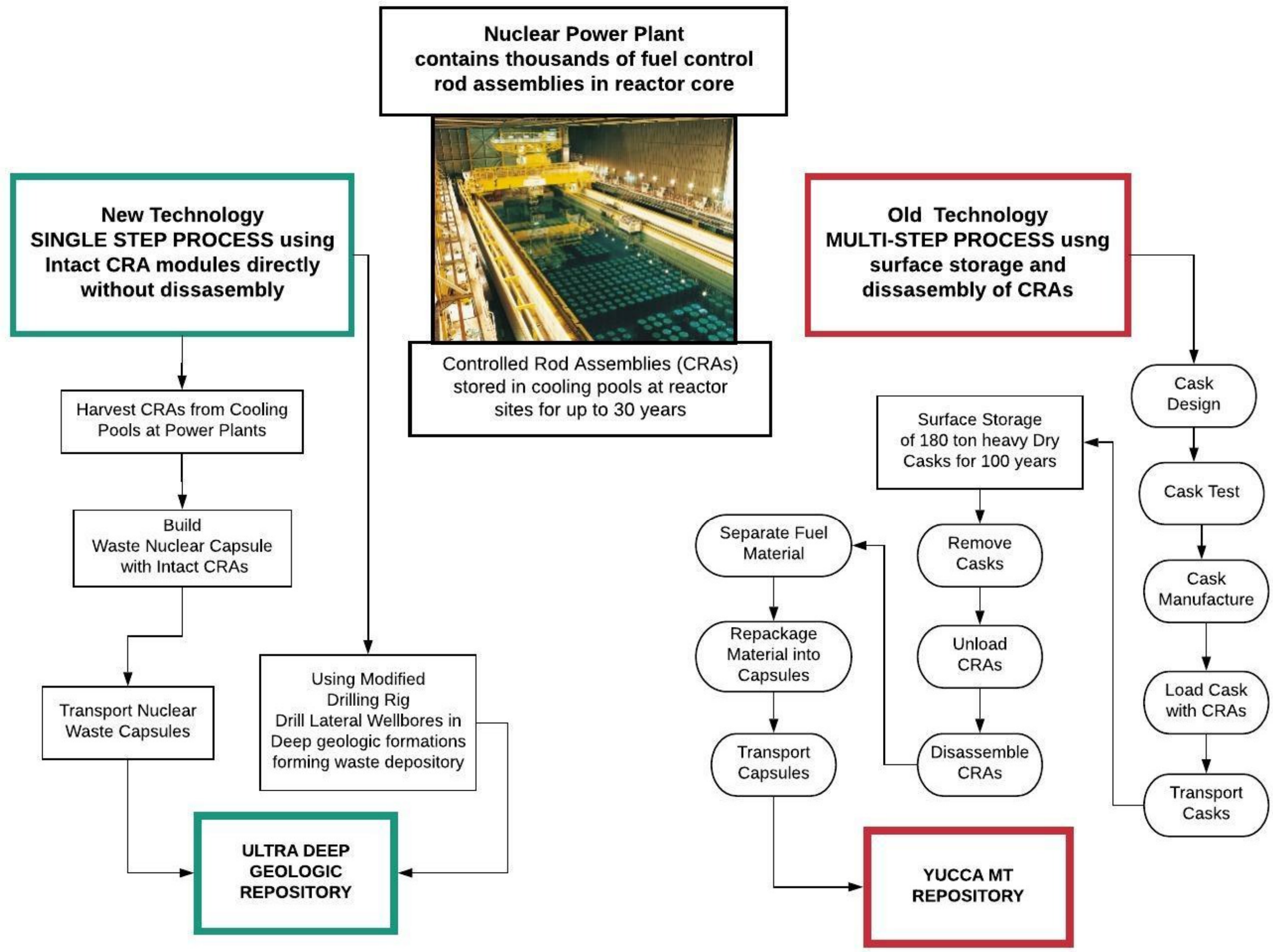
NUCLEAR WASTE CAPSULES INSERTED IN MULTIPLE 15,000 FOOT LATERAL HORIZONTAL WELLBORES DRILLED FROM THE SAME VERTICAL WELLBORE INTO IMPERMEABLE BASEMENT ROCK FORMATIONS 20,000 FEET DEEP IN THE EARTH



SECTION OF A NUCLEAR WASTE CAPSULE CARRYING AN INTACT 5-INCH CONTROL FUEL ROD ASSEMBLY SPENT NUCLEAR FUEL CORE INSERTED INTO THE NUCLEAR WASTE CARRIER TUBE



MULTIPLE ENGINEERED BARRIER SYSTEMS OF STEEL AND ANNULAR CEMENT LAYERS IMPLEMENTED BETWEEN THE GEOLOGIC REPOSITORY BASEMENT FORMATION ROCK AND THE NUCLEAR WASTE CAPSULE PROTECTIVE SYSTEMS



NEW SINGLE STEP vs OLD MULTI-STEP PROCESS FOR NUCLEAR WASTE DISPOSAL

2018 Patents Pending

NEW DIRECT DISPOSAL METHOD IN WHICH SNF RODS ARE COOLED FOR YEARS IN COOLING PONDS THEN ENCAPSULATED INTACT INTO SPECIALIZED CARRIER TUBES FOR STORAGE AND DISPOSAL IN LATERAL WELLBORES. COMPARED TO A YUCCA MT. TYPE DISPOSAL PROCESS OF DISASSEMBLED RODS AND PROCESSED SNF BEFORE DISPOSAL IN NEAR SURFACE TUNNELS.

REFERENCES

United States Patent US 5,850,614. Method of disposing of nuclear waste in underground rock formations. (Crichlow - 1998)

United States Patent US 6,238,138. Method for temporary or permanent disposal of nuclear waste using multilateral and horizontal boreholes in deep isolated geologic basins. (Crichlow – 2001)

Environmental Impact Statement for a geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive waste at Yucca Mountain, Nye County, Nevada. USDoE, DOE/EIS-0250 (2002), Las Vegas NV, 89036-0307

United States Patent 8,933,289. Method for temporary or permanent disposal of nuclear waste. (Crichlow – 2015)

"Performance Assessment for Radioactive Waste Management at Sandia: National Laboratories: A 30-year History", Bonano, E.J., Kessel, D., Marietta, M., Swift, P., and Dotson, L.a.   Sandia National Laboratories, Albuquerque, New Mexico, U.S.A. SANDAI-2010-0807C.

"Origin of the Lower Cretaceous Heavy Oils ("Tar Sands") of Alberta",. Michael S. Stanton, Search and Discovery Article #10067 (2004).

"GEOLOGY OF NATURAL BITUMEN AND HEAVY OIL RESOURCES". James G. Speight, C*onsultant, CD & W Inc.,2476 Overland Road, Laramie, Wyoming 82070-4808, USA.*

"Deep Borehole Disposal Research: Geological Data Evaluation, Alternative Waste Forms, and Borehole Seals". SANDIA LABORATORIES. (SAND2014-17430R)

"Well Design & Completion of World's longest offshore ERD well drilled (13,500m) in Sakhalin-1, Russia: A case study". Rohit Kumar Singh, AEE(P), N. A. Jamir, CE(D), Amrulkhan Mahorvani, AEE(P), Deep Shah, AEE(P), Ajay Kumar, SE(P), Y. C. Shukla, GGM(P), ONGC Videsh Ltd

"BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE", Report to the US Secretary of Energy (2012). USDoE.