TRITIUM, MAN-MADE HYDROGEN

3/10/2016

INTRODUCTION

Tritium ($_1T^3$), an isotope of hydrogen, occurs only in trace amounts in nature since it has a half-life of 12.33 years. It has wide use in the biological, biochemical and life science and drug metabolism studies, ensuring the safety of new drugs. It is used in self-luminous aircraft and commercial exit signs, in luminous dials, gages, Liquid Crystal Displays (LCDs) such as used in wrist watches and laptop computers, and in the production of luminous paint. It is also used in thermonuclear weapons, or hydrogen devices, and is conceived as an important fuel for future fusion reactors.

Tritium is relatively short-lived and penetrates the body weakly through the air compared to other radioactive contaminants. A tritium leakage situation has materialized from piping corrosion in aging nuclear power plants.

PRODUCTION

Tritium must be produced in nuclear reactors through the interaction of thermal neutrons with the $_3Li^6$ isotope of lithium through the reaction:

$$_0n^1 + {}_3Li^6 \rightarrow {}_2He^4 + {}_1T^3 \qquad (1)$$

It can also be produced through the interaction of fast neutrons with the $_3Li^7$ isotope through the reaction:

$$_0n^1 + {}_3Li^7 \rightarrow {}_0n^1 + {}_2He^4 + {}_1T^3 \qquad (2)$$

The first reaction is an exothermic reaction, whereas the second reaction is endothermic.

Because of its use in thermonuclear weaponry, it has been routinely produced from Lithium Aluminate ($Li_2Al_2O_4$) in Graphite-moderated, water-cooled reactors at the Hanford Reservation along the Columbia River in the State of Washington in the USA. These aged reactors have since been shut down because they resemble the RBMK-1000 reactor design in the Ukraine involved in the Chernobyl accident. It has also been produced from the LiAl alloy used at the, also now shut down, Heavy Water (D_2O) cooled and moderated reactors at the Savannah River Laboratory in South Carolina.

Tritium, once produced, transforms over time into the $_2He^3$ isotope of helium. About 5 percent of any available tritium transforms into helium per year through the nuclear transformation releasing an electron and an antineutrino:

$$_1T^3 \rightarrow {}_2He^3 + {}_{-1}e^0 + \nu^* \qquad (3)$$

TRITIUM AS TERTIARY FISSION PRODUCT

Tertiary fission occurs where a fissile elements splits into three rather than two fission products and leads to the production of tritium in power reactors. It is produced at a rate of 8.7 x 10^{-5} tritons / fission event in U^{235} fuelled reactors.

The energy of the tertiary fission tritons has a most probable energy of 7.5 MeV. In the zirconium cladding, the range of 7.5 MeV tritons is 5 mils and for 15 MeV tritons it is 14.5 mils. A similar range occurs in UO_2 and a smaller range occurs in stainless steel cladding. The cladding thickness is 16.5-33 mils, suggesting that the tertiary tritons would not penetrate the cladding, and is contained within the fuel element. A minute amount could diffuse through cracks in the cladding to the coolant both from the reactor during operation and from the spent fuel storage pools.

When the spent fuel is reprocessed, the tritium is carried by the liquid stream and can be released after dilution with water. Alternatively, the water is vaporized and is discharged as steam through a tall chimney.

TRITIUM FROM BORON CHEMICAL SHIM

Boric acid is added to the water coolant in pressurized water reactors where boron acts as a neutron poison. As it burns out, it offsets the reduction in reactivity due to fuel burnup. Accordingly, both thermal and fast neutron reactions lead to the formation of significant amounts of tritium in the coolant.

After 350 days of reactor operation, the tritium production from the reaction:

$$ {}_0n^1 + {}_5B^{10} \rightarrow 2\,{}_2He^4 + {}_1T^3 \qquad (4) $$

reduces to 400 ppm after an initial value of 1,500 ppm. This reaction has a threshold of 1 MeV with a cross section of 15 mb at 1 Mev that increases to 75 mb at 5 MeV and remains constant from 5-10 MeV. For the fast neutron flux above 1 MeV, a cross section value of 50 mb can be considered.

Another duplex reaction leads the production of tritium from the boron shim:

$$ \begin{aligned} &\textit{Thermal}: \quad {}_0n^1 + {}_5B^{10} \rightarrow {}_2He^4 + {}_3Li^7 \\ &\textit{Fast}: \qquad {}_0n^1 + {}_3Li^7 \rightarrow {}_0n^1 + {}_2He^4 + {}_1T^3 \end{aligned} \qquad (5) $$

The second reaction has 3 MeV threshold with a cross section of 15 mb at 1 MeV, increasing in a linear fashion from 0 at 3 MeV to 400 mb at 6 MeV, then remaining constant over the 6-10 MeV interval. For the fast neutron flux above 1 MeV, a cross section value of 50 mb can also be considered.

The accumulated tritium activity should be considered as a contributing to the hazard of accidental leakage from the primary loop and in a Loss of Coolant Accident (LOCA) analysis.

TRITIUM DECAY

The transformation of tritium into the He isotope is governed by its radioactive decay equation with N(t) being the number of nuclei present after a certain time t:

$$N(t) = N_0 \, e^{-\lambda t} \qquad (6)$$

where: N_0 is the initial number of nuclei present at time t = 0
λ is the decay constant = (ln 2)/$T_{½}$
$T_{½}$ is the half life for Tritium = 12.33 years

A Fortran-90 procedure that can display the decay features of the tritium isotopes is listed here:

```
!       Decay Curve generation for Tritium
!       N(t)=No*exp(-lambda*t)
!       lambda=decay constant= - ln 2 / T
!       T=half-life
!       Program written in ANSI Fortran-90
!       Visual Fortran Compiler
!       Procedure saves output to file:output1
!       This output file can be exported to a plotting routine
!       M. Ragheb, University of Illinois
        program decay
        real x, lambda
!       This half life is for the tritium 1T3 nucleus
        real :: T = 12.33
        integer :: steps=100
        real ratio(101), xtime(101)
!       Calculate decay constant
        x = log(2.0)
        lambda = x/T
        write(*,*) x, lambda
!       Open output file
        open(10,file='output1')
!       Calculate ratio N(t)/No
        steps = steps + 1
        do i =  1, steps
                xtime(i) = i - 1
                ratio(i) = exp (- lambda*xtime(i))
!       Write results on output file
                write(10,*) xtime(i), ratio(i)
!       Display results on screen
                write(*,*) xtime(i), ratio(i)
!               pause
        end do
        end
```

The output file was plotted in Fig. 1 using the Excel Package where the ratio N(t)/N0 is shown as a function of time, and shows the rapid decay of tritium as a function of time.

Tritium can be made to interact with another isotope of hydrogen, deuterium ($_1D^2$) through the DT fusion transformation:

$$_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + {}_2He^4 + 17.6 \text{ MeV} \qquad (7)$$

The energy release in this fusion reaction is only about one tenth the amount released through the fission of a fissile isotope such as $_{92}U^{235}$ or $_{94}Pu^{239}$ which amounts to about 200 MeV. This characterizes fusion as an "energy poor" nuclear process as compared with fission.

This energy release partitions itself in inverse proportion to the masses of the neutron and the helium product nuclei. The heavier helium nucleus carries about twenty percent of the energy: 3.54 MeV. The lighter neutron carries about eighty percent of the energy release: 14.06 MeV. This is seven times the average energy carried by a neutron resulting from a fission reaction at about 2 MeV. This characterizes the fusion process represented by the DT reaction as a "neutron rich" nuclear process as compared with fission.

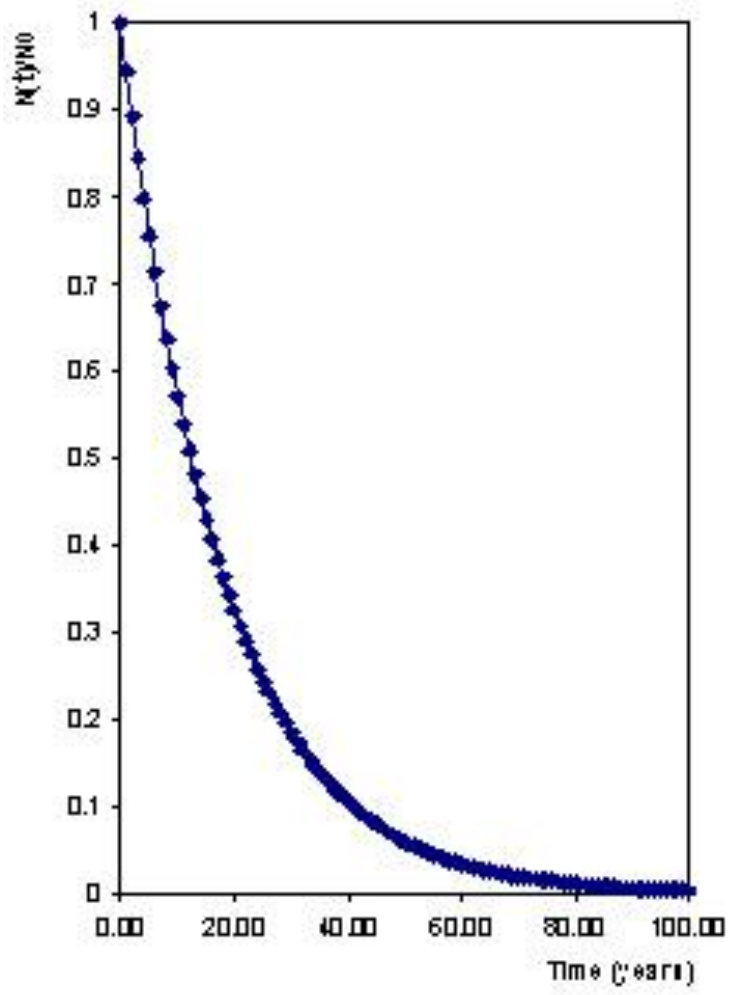

Figure 1. Decay curve for tritium.

TRITIUM USAGE

The DT fusion reaction is conceived to be the easiest fusion reaction to achieve on earth towards the human goal of reproducing a version of what occurs in the stars as a first generation fusion reactor. This is so, since this reaction requires a relatively lower plasma temperature, and proceeds at a much faster rate than the fusion reactions occurring in the stars.

It is also a reaction used in different ways in different forms of weapon devices:

BOOSTED FISSION DEVICES

In this case, the fission energy release is amplified by a significant factor through adding an amount of deuterium and tritium to the fissile material. The energetic 14 MeV neutrons produced by the DT reaction amplify the fission energy release by fissioning a tamper of (fissionable) $_{92}U^{238}$ surrounding the original (fissile) $_{92}U^{235}$ or $_{94}Pu^{239}$ fission material. The term "fissile" here identifies isotopes that can fission with a low energy neutron, even a zero energy neutron. These isotopes have an even atomic number and an odd mass number. On the other hand, the term "fissionable" identifies that would not fission with low energy neutrons, but could fission if the neutron carry a substantially high energy above a known threshold. This category of nuclei include some nuclei with an even atomic number, as well as an even mass number. Since the fission of the common fissionable uranium isotope $_{92}U^{238}$ has a threshold neutron energy around 6 MeV, it would not substantially fission under the effect of fission neutrons with an average energy of 2 MeV. However, in the presence of the more energetic 14 MeV neutrons from the DT reaction, the tamper material can be made to fission, adding to the energy release from the original fissile material in the device's core. A field commander will find in this process an added versatility. He can decide to release the initial energy of his fission device at 20 kilotons (kt) of TNT equivalent. Alternatively, by adding a small vial of tritium to his device, he may decide to boost the energy release of the device to for instance the 100 kt TNT level.

THERMONUCLEAR FUSION DEVICES

The energy release from a fission device is used to initially ignite a DT reaction in a small amount of deuterium and tritium. The soft x-rays produced by the fission process are focused to heat and compress a powder core of Li^6 deuteride (Li^6D). The neutrons produced from the fission process locally breed tritium from the lithium isotope in the lithium deuteride. At high temperature and pressure, the bred tritium fuses with deuterium in an expanding ignited fusion process. If we consider a cylindrical geometry, an ignited fusion reaction at one end can propagate to the other end of an arbitrarily long cylinder with substantial energy release that is unattainable in fission devices limited in their energy output by mass criticality considerations. The 14 MeV neutrons from the ensuing DT reaction can further be amplified through fissioning a surrounding tamper of the fissionable, but not fissile, $_{92}U^{238}$ isotope, leading to a fission-fusion-fission process capable of producing Megaton (Mt) TNT equivalent, a three orders of magnitude amplification above the yield of typical fission devices. The BRAVO test in 1954 produced an unexpected 15 Mt TNT yield equivalent.

ENHANCED NEUTRON RELEASE DEVICES

The fission component in the core is minimized, and the outer tamper fission amplifier is eliminated resulting in a primarily DT fusion device. The 14 MeV neutrons from the DT fusion reaction are thus prevented from interacting with the device's materials and are released to use their highly penetrating power, and their ability to generate intense penetrating gamma rays, to affect tank crews and penetrate command centers and other industrial and military targets. In this enhanced radiation mode, the blast and the fire generated by the x-rays released from a

conventional device are minimized. This suggests the possibility of leaving such targets intact for the invading force once the human operators in the defending force are turned inactive under the biological effects of large acute doses or neutron and gamma radiation. These devices have been designated as neutron bombs.

DIRECTED ENERGY DEVICES

A strong magnetic field could be used to divert the 20 percent of the energy carried out by the charged particles in the DT reaction to specified targets. This would avoid the inverse square law reduction of the energy flux from nuclear devices as a function of the distance away from their explosion centers. Suggestions along this line of directed energy to use x-ray or gamma ray lasers pumped into cylindrical rods surrounding nuclear devices, or to use the DHe^3 fusion reaction:

$$_1D^2 + {}_2He^3 \rightarrow {}_1H^1 + {}_2He^4 \qquad (8)$$

which produces only charged particles which can be directed by magnetic fields, have been advanced.

PURE FUSION DEVICE

The fusion chain reaction is initiated without the fission trigger. Magnetized Target Fusion implosion has been suggested in this regard and is pursued experimentally at The Los Alamos National Laboratory. This involves the creation of a magnetic field through a cylindrical chamber using a current pulse of 2 MA. Another pulse of 6-8 MA creates a plasma that is propelled by the Lorentz force and collides with another plasma in an adjacent region.

A warm 100-300eV magnetized DD or DT plasma with a volume of about 1 liter is thus created. It is imploded to an intermediate density at 10^{20} [ions/cm^3] over several microseconds by a metal liner driven inward by an explosive charge. Metallic liners driven by chemical explosives create the strong currents. The liners compress enclosed magnetic fields to the mega-gauss level, creating large currents. In such a device, 3-30 mg of DT fuel could release 1-10 GJ of energy equivalent to a small device yield of 0.2 to tons of TNT equivalent.

As shown in Fig. 2 a possible experimental setup using a chemical explosive driving a conical liner and igniting 1/10 of a microgram of deuterium gas at 1.2 atmosphere, is shown. Nine percent argon gas is added to the deuterium gas and they are implanted in a conical depression in a large anvil, and covered with metallic foil. A double conical shell covers the fuel. The inside of the cone is a heavy metallic tamper that is compressed by the explosive surrounding it. Upon initiation of the explosive, a mach stem shock wave is formed, driving down the axis of the cone. The deuterium or DT fuel, is compressed by a factor 0f 10^3, heating it to about 500 eV for a billionth of a second. The tip of the inverted cone reaches higher densities possibly igniting the tip of the cone. The produced electrons would in principle further compress the already compressed fuel by generating soft x-ray in the material of the foil and the anvil, leading to a propagation of the ignited tip.

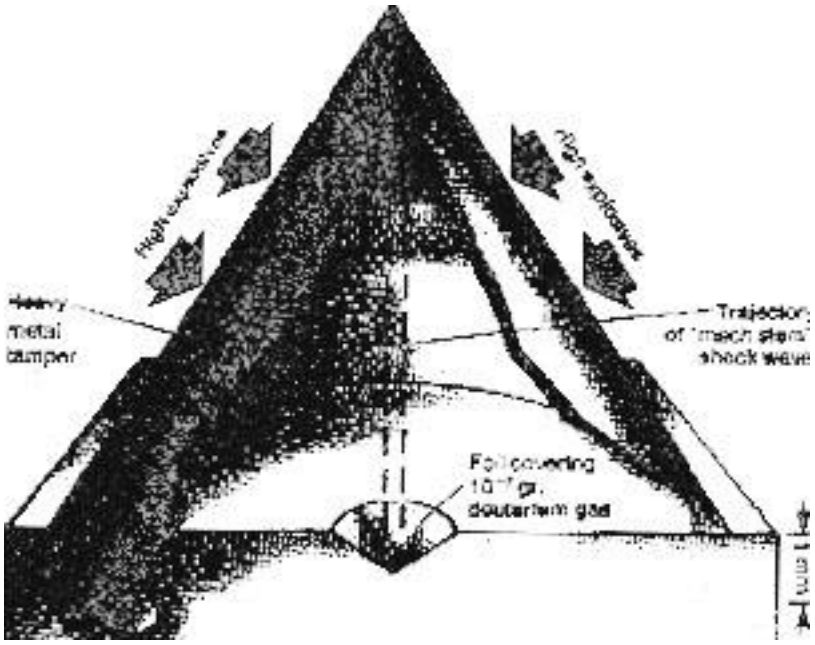

Figure 2. Explosive metallic liner Mach stem shock wave compressing deuterium gas.

Other ingenious configurations are being pursued such as the Z-pinch at Sandia National Laboratory. A dense high temperature plasma is created to provide an intense source of x-rays. It is formed by a rapid discharge of current from a bank of capacitors, through a cylindrical array of thin parallel wires. The plasma is imploded on the axis by the pressure of the external magnetic field created by the current. Two coaxial symmetrically located such sources should be able to compress a DT pellet positioned between them within a common x-ray enclosure.

In Russia, the cumulation process of shock waves from chemical explosives is being studied in spherical systems of alternating ligh Z and low Z materials. The reported results are such that the temperatures achieved are a factor of ten below the ignition threshold, and neutron generation is less than 10^{14} neutrons.

TRITIUM STOCKPILES

To maintain the thermonuclear capability in the USA, the traditional barrier that was maintained between military production of strategic elements in military reactors and their production in civilian nuclear power plants had to be breached. Since the aged Hanford and Savannah River reactors are not producing Tritium any more, a civilian source had to sought.

The Watts Bar Nuclear Power plant near Spring City, 55 miles southwest of Knoxville, Tennessee, will start producing tritium by the year 2003, while continuing to produce civilian electricity for the Tennessee Valley Authority (TVA). This is conceived as a set back for the arms control efforts aiming at reducing the megatonnage of thermonuclear weapons components. This is so since it can be shown that controlling the production of tritium can lead to effective control of nuclear weaponry within a generational time. This can be shown in the following analysis.

The number of tritium nuclei disappearing after a time t can be written, using Eqn. 4, as:

$$N_0 - N(t) = N_0 \ (1 - e^{-\lambda t}) \qquad (9)$$

Introducing the variable P representing the percentage of tritium nuclei that have disappeared after a time t:

$$P = \frac{N_0 - N(t)}{N_0} \times 100 = (1 - e^{-\lambda t}) \times 100 \qquad (10)$$

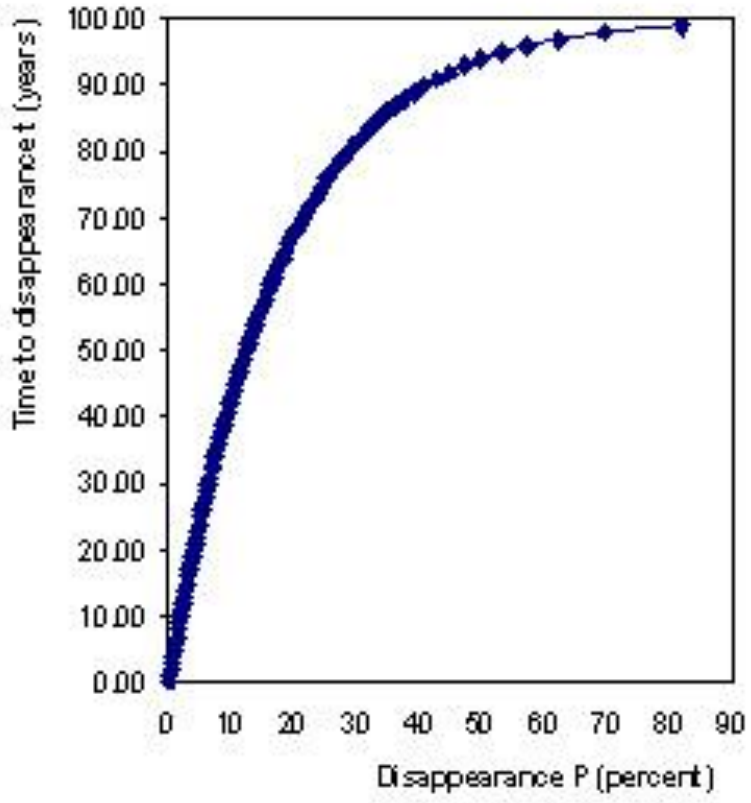

Figure 3. Time to disappearance of a tritium percentage P.

A Fortran-90 procedure to calculate this time to a percentage disappearance is here listed:

```
!       Procedure to calculate the time to disappearance t of a certain percentage P of Tritium
!       t= - (1/lambda) * ln [ 1 - (P/100) ]
!       lambda=decay constant= - ln 2 / T
!       T=half-life
!       Program written in ANSI Fortran-90
!       Visual Fortran Compiler
!       Procedure saves output to file:output1
!       This output file can be exported to a plotting routine
!       M. Ragheb, University of Illinois  12/16/1999
        program time_to_disappearance
        real x, lambda
```

```
!       This half life is for the tritium 1T3 nucleus
        real :: T = 12.33
        integer :: steps=99
        real xtime(100), percent(100)
!       Calculate decay constant
        x = log(2.0)
        lambda = x/T
        write(*,*) x, lambda
!       Open output file
        open(10,file='output1')
!       Calculate time to disappearance for a percentage P
        steps = steps + 1
        do i =  1, steps
                percent(i) = i-1
                xtime(i) = -(1.0/lambda)* log (1.0 - (percent(i)/100.))
!       Write results on output file
                write(10,*) xtime(i),percent(i)
!       Display results on screen
                write(*,*)  xtime(i),percent(i)
!               pause
        end do
        end
```

The output file was plotted using the Excel Package where the time t in years is shown as a function of the percentage disappearance P in Fig. 3. This graph shows that within a year, a significant 5 percent of the available tritium will disappear. It further shows that most of the tritium available for thermonuclear and boosted weaponry would become unavailable with a generation's time.

By taking the natural logarithm of both sides of the previous equation, one can express the time t in terms of the percentage disappearance P by the following equation:

$$t = -\frac{1}{\lambda} \ln\left(1 - \frac{P}{100}\right) \qquad (11)$$

TRITIUM LEAKAGE FROM NUCLEAR FACILITIES

Tritium has leaked from three-quarters of USA commercial nuclear power sites, often into groundwater from corroded, buried piping that is embedded in concrete. It has leaked from at least 48 of 65 sites, according to the USA Nuclear Regulatory. Leaks from at least 37 of those facilities contained concentrations exceeding the federal drinking water standard. The leaks have been found within plant boundaries. None is known to have reached public water supplies.

At three sites, two in Illinois and one in Minnesota, leaks contaminated drinking wells of nearby homes, but not at levels violating the drinking water standard. In New Jersey, tritium has leaked into an aquifer and a discharge canal feeding Barnegat Bay off the Atlantic Ocean.

Tritium moves through soil quickly, and when it is detected it often indicates the presence of other isotopes that are often leaked at the same time. Cesium^{137} turned up with tritium at the Fort Calhoun nuclear unit near Omaha, Nebraska, in 2007. Strontium^{90} was discovered with tritium two years earlier at the Indian Point nuclear power complex, where two reactors operated 25 miles north of New York City.

The tritium leaks generate concerns among engineers about the reliability of emergency safety systems at the 104 nuclear reactors situated on the 65 sites. Some of the leaky

underground pipes carry water meant to cool a reactor in an emergency shutdown. More than a mile of piping, much of it encased in concrete, can lie beneath a nuclear power plant.

Tritium is relatively short-lived and penetrates the body weakly through the air compared to other radioactive contaminants. Each of the known releases has been less radioactive than a single X-ray. The main health risk from tritium would be in drinking water. The USA Environmental Protection Agency says tritium should measure no more than 20,000 picocuries per liter in drinking water. The agency estimates seven of 200,000 people who drink such water for decades would develop cancer. The NRC and industry consider the leaks a public relations problem, not a public health or accident threat.

POWER PLANTS COMPONENTS AGING

Corrosion has propagated for decades along the hard-to-reach, wet underbellies of the reactors, generally built in a burst of construction during the 1960s and 1970s. There were 38 leaks from underground piping between 2000 and 2009, according to an industry document presented at a tritium conference

At the three-unit Browns Ferry complex in Alabama, a valve was mistakenly left open in a storage tank during modifications over the years. When the tank was filled in April 2010 about 1,000 gallons of tritium-laden water poured onto the ground at a concentration of 2 million picocuries per liter. In drinking water, that would be 100 times higher than the EPA health standard.

At the LaSalle site west of Chicago, tritium-laden water was accidentally released from a storage tank in July 2010 at a concentration of 715,000 picocuries per liter; 36 times the EPA standard.

In 2009, 123,000 picocuries per liter were detected in a well near the turbine building at Peach Bottom west of Philadelphia; six times the drinking water standard.

In 2008, 7.5 million picocuries per liter leaked from underground piping at Quad Cities in western Illinois; 375 times the EPA limit.

Subsurface water not only rusts underground pipes, it attacks other buried components, including electrical cables that carry signals to control operations. A 2008 NRC staff memo reported industry data showing 83 failed cables between 21 and 30 years of service, but only 40 within their first 10 years of service. Underground cabling set in concrete can be difficult to replace.

Under NRC rules, tiny concentrations of tritium and other contaminants are routinely released in monitored increments from nuclear plants; leaks from corroded pipes are not permitted. The leaks sometimes go undiscovered for years. Many of the pipes or tanks have been patched, and contaminated soil and water have been removed in some places. But leaks are often discovered later from other nearby piping, tanks or vaults. Mistakes and defective material have contributed to some leaks. Corrosion, from decades of use and deterioration, is the main cause.

Over the history of the USA industry, more than 400 known radioactive leaks of all kinds of substances have occurred. Several notable leaks above the EPA drinking-water limit for tritium happened years ago, and from underground piping: 397,000 picocuries per liter at Tennessee's Watts Bar unit in 2005; 20 times the EPA standard; four million at the two-reactor Hatch plant in Georgia in 2003; 200 times the limit; 750,000 at Seabrook in New Hampshire in

1999; nearly 38 times the standard; and 4.2 million at the three-unit Palo Verde facility in Arizona, in 1993; 210 times the drinking-water limit.

It is hard to pinpoint partial cracks or damage in skinny pipes or bends. The industry tends to inspect piping when it must be dug up for some other reason. Even when leaks are detected, repairs may be postponed for up to two years with the NRC's blessing. Since much of the piping is inaccessible and carries cooling water, the worry is if the pipes leak, there could be a meltdown.

A tritium leak reading occurred in 2002 at the Salem PWR nuclear plant in Lower Alloways Creek Township, New Jersey. Tritium leaks from the spent fuel pool contaminated groundwater under the facility, located on an island in Delaware Bay, at a concentration of 15 million picocuries per liter. That is 750 times the EPA drinking water limit. Tritium found separately in an onsite storm drain system measured 1 million picocuries per liter in April 2010.

In 2015, the operator, PSE&G Nuclear, discovered 680 feet of corroded, buried pipe that is supposed to carry cooling water to the Salem Unit 1 PWR in an accident, according to an NRC report. Some had worn down to a quarter of its minimum required thickness, though no leaks were found. The piping was dug-up and replaced. The operator had not visually inspected the piping, the surest way to find corrosion, since the reactor went on line in 1977, according to the NRC. PSE&G Nuclear was found to be in violation of NRC rules because it had not even tested the piping since 1988.

In 2015, the Vermont Senate was so troubled by tritium leaks as high as 2.5 million picocuries per liter at the Vermont Yankee reactor in southern Vermont, 125 times the EPA drinking-water standard) that it voted to block relicensing; a power that the Legislature holds in that state. In March 2015, the NRC granted the plant a 20-year license extension, despite the state opposition. The operator Entergy sued Vermont in federal court, challenging its authority to force the plant to close.

At the 41-year-old Oyster Creek in southern New Jersey, the country's oldest operating reactor, in April 2009, a week after it was relicensed for 20 more years, plant workers discovered tritium by chance in about 3,000 gallons of water that had leaked into a concrete vault housing electrical lines. Workers have found leaking tritium three more times at concentrations up to 10.8 million picocuries per liter; 540 times the EPA's drinking water limit, according to the New Jersey Department of Environmental Protection. None has been directly measured in drinking water, but it has been found in an aquifer and in a canal discharging into nearby Barnegat Bay, a popular spot for swimming, boating and fishing. An earlier leak came from a network of pipes where rust was first discovered in 1991. Multiple holes were found, "indicating the potential for extensive corrosion," according to an analysis released to an environmental group by the NRC.

PIPING PROBLEMS AT AGING POWER PLANTS

At Exelon, the country's largest nuclear operator, with 17 units, piping problems are common. At a meeting with regulators in 2009, representatives of Exelon acknowledged that "100 percent verification of piping integrity is not practical, as excavations have significant impact on plant operations.

At the company's two-reactor Dresden site west of Chicago, tritium has leaked into the ground at up to 9 million picocuries per liter, 450 times the federal limit for drinking water. At least four separate problems have been discovered at the 40-year-old site since 2004, when its

two reactors were awarded licenses for 20 more years of operation. A leaking section of piping was fixed that year, but another leak sprang nearby within two years. The Dresden leaks developed in systems that help cool the reactor core in an emergency. Leaks also have contaminated offsite drinking water wells, but below the EPA drinking water limit.

There has been contamination of offsite drinking water wells near the two-unit Prairie Island plant southeast of Minneapolis, then operated by Nuclear Management Co. and now by Xcel Energy, and at Exelon's two-unit Braidwood nuclear facility, 10 miles from Dresden. The offsite tritium concentrations from both facilities also were below the EPA level. The Prairie Island leak was found in the well of a nearby home in 1989. It was traced to a canal where radioactive waste was discharged. Braidwood has leaked more than six million gallons of tritium-laden water in repeated leaks dating back to the 1990s -- but not publicly reported until 2005. The leaks were traced to pipes that carried limited, monitored discharges of tritium into the river.

In 2015, Exelon, which has acknowledged violating Illinois state groundwater standards, agreed to pay $1.2 million to settle state and county complaints over the tritium leaks at Braidwood and nearby Dresden and Byron sites. The NRC also sanctioned Exelon.

Tritium measuring 1,500 picocuries per liter turned up in an offsite drinking well at a home near Braidwood. Though company and industry officials did not view any of the Braidwood concentrations as dangerous, unnerved residents took to bottled water and sued over feared loss of property value. A consolidated lawsuit was dismissed, but Exelon ultimately bought some homes so residents could leave. Exelon refused to say how much it paid, but a search of county real estate records shows it bought at least nine properties in the contaminated area near Braidwood since 2006 for a total of $6.1 million. Exelon says it has almost finished cleaning up the contamination.

An NRC task force on tritium leaks in 2015 dismissed the danger to public health. Its report called the leaks: "a challenging issue from the perspective of communications around environmental protection."

Exelon has been performing $14 million worth of work at Oyster Creek to give easier access to 2,000 feet of tritium-carrying piping. The USA reactors fleet keeps getting older; 66 have been approved for 20-year extensions to their original 40-year licenses, with 16 more extensions pending.

TURKEY POINT TRITIUM LEAK

Miami-Dade County, Florida in March 2016 reported that the waters of Biscayne Bay measured 215 times the level of radioactive tritium as is found in normal ocean water. The leak appeared to be emanating from the aging canals in the Turkey Point Nuclear Generating Station located nearby operated by Florida Power & Light. The plant is located between two national parks and is subject to hurricanes and storm surges.

Biscayne Bay harbors one of the largest coral reefs on the planet and is situated near the Everglades. Hot, salty water from the canals appears to be flowing back into both national parks, which has caused concern among environmentalists and others from the time Turkey Point planned to expand its reactors in 2013.

The tritium levels far fall below levels experts consider dangerous, but as a telltale tracer it provided the critical link that high levels of ammonia and phosphorus in sections of bay bottom; pollution that is more damaging to marine life.

CONCLUSION

The fact that tritium needs continuous replenishment for the viability of the different types of nuclear devices, suggests that there is a need to monitor the production of tritium around the world as part of the international agreements and treaties concerning nuclear nonproliferation and arms control. Currently only fissile materials are being subjected to such safeguards agreements.

Tritium leakage from operating power plants points to a corrosion situation in the aging power plants fleet.

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