= 42) . For technetium @-@ 98 and heavier isotopes , the primary mode is beta emission (the emission of an electron or positron) , producing ruthenium (Z = 44) , with the exception that technetium @-@ 100 can decay both by beta emission and electron capture .

Technetium also has numerous nuclear isomers , which are isotopes with one or more excited nucleons . Technetium @-@ 97m (97mTc ; ' m ' stands for metastability) is the most stable , with a half @-@ life of 91 days (0 @.@ 0965 MeV) . This is followed by technetium @-@ 95m (half @-@ life : 61 days , 0 @.@ 03 MeV) , and technetium @-@ 99m (half @-@ life : 6 @.@ 01 hours , 0 @.@ 142 MeV) . Technetium @-@ 99m emits only gamma rays and decays to technetium @-@ 99 .

Technetium @-@ 99 (99Tc) is a major product of the fission of uranium @-@ 235 (235U) , making it the most common and most readily available isotope of technetium . One gram of technetium @-@ 99 produces 6 @.@ 2 × 108 disintegrations a second (that is , 0 @.@ 62 GBq / g) .

= = Occurrence and production = =

Only minute traces of technetium occur naturally in the Earth 's crust . This is because technetium @-@ 98 's half @-@ life is only 4 @.@ 2 million years . More a thousand of such periods have passed since the formation of the Earth , so the probability for the survival of even one atom of primordial technetium is effectively zero . However , small amounts exist as spontaneous fission products in uranium ores . A kilogram of uranium contains an estimated 1 nanogram (10 ? 9 g) of technetium . Some red giant stars with the spectral types S- , M- , and N contain a spectral absorption line indicating the presence of technetium . These red @-@ giants are known informally as technetium stars .

= = = Fission waste product = = =

In contrast to the rare natural occurrence , bulk quantities of technetium @-@ 99 are produced each year from spent nuclear fuel rods , which contain various fission products . The fission of a gram of uranium @-@ 235 in nuclear reactors yields 27 mg of technetium @-@ 99 , giving technetium a fission product yield of 6 @.@ 1 % . Other fissile isotopes produce similar yields of technetium , such as 4 @.@ 9 % from uranium @-@ 233 and 6 @.@ 21 % from plutonium @-@ 239 . An estimated 49 @,@ 000 TBq (78 metric tons) of technetium was produced in nuclear reactors between 1983 and 1994 , by far the dominant source of terrestrial technetium . Only a fraction of the production is used commercially .

Technetium @-@ 99 is produced by the nuclear fission of both uranium @-@ 235 and plutonium @-@ 239 . It is therefore present in radioactive waste and in the nuclear fallout of fission bomb explosions . Its decay , measured in becquerels per amount of spent fuel , is dominant after about 104 to 106 years after the creation of the nuclear waste . From 1945 to 1994 , an estimated 160 TBq (about 250 kg) of technetium @-@ 99 was released into the environment during atmospheric nuclear tests . The amount of technetium @-@ 99 from nuclear reactors released into the environment up to 1986 is on the order of 1000 TBq (about 1600 kg) , primarily by nuclear fuel reprocessing ; most of this was discharged into the sea . Reprocessing methods have reduced emissions since then , but as of 2005 the primary release of technetium @-@ 99 into the environment is by the Sellafield plant , which released an estimated 550 TBq (about 900 kg) from 1995 ? 1999 into the Irish Sea . From 2000 onwards the amount has been limited by regulation to 90 TBq (about 140 kg) per year . Discharge of technetium into the sea resulted in contamination of some seafood with minuscule quantities of this element . For example , European lobster and fish from west Cumbria contain about 1 Bq / kg of technetium .

= = = Fission product for commercial use = = =

The metastable isotope technetium @-@ 99m is continuously produced as a fission product from the fission of uranium or plutonium in nuclear reactors . Because used fuel is allowed to stand for several years before reprocessing , all molybdenum @-@ 99 and technetium @-@ 99m is decayed by the time that the fission products are separated from the major actinides in conventional nuclear reprocessing . The liquid left after plutonium ? uranium extraction (PUREX) contains a high concentration of technetium as TcO ?
4 but almost all of this is technetium @-@ 99 , not technetium @-@ 99m .
The vast majority of the technetium @-@ 99m used in medical work is produced by irradiating dedicated highly enriched uranium targets in a reactor , extracting molybdenum @-@ 99 from the targets in reprocessing facilities , and recovering at the diagnostic center the technetium @-@ 99m produced upon decay of molybdenum @-@ 99 . Molybdenum @-@ 99 in the form of molybdate MoO2 ?
4 is adsorbed onto acid alumina (Al
2O
3) in a shielded column chromatograph inside a technetium @-@ 99m generator (" technetium cow " , also occasionally called a " molybdenum cow ") . Molybdenum @-@ 99 has a half @-@ life of 67 hours , so short @-@ lived technetium @-@ 99m (half @-@ life : 6 hours) , which results from its decay , is being constantly produced . The soluble pertechnetate TcO ?
4 can then be chemically extracted by elution using a saline solution . A drawback of this process is that it requires targets containing uranium @-@ 235 , which are subject to the security precautions of fissile materials .
Almost two @-@ thirds of the world 's supply comes from two reactors ; the National Research Universal Reactor at Chalk River Laboratories in Ontario , Canada , and the High Flux Reactor at Nuclear Research and Consultancy Group in Petten , Netherlands . All major reactors that produce technetium @-@ 99m were built in the 1960s and are close to the end of life . The two new Canadian Multipurpose Applied Physics Lattice Experiment reactors planned and built to produce 200 % of the demand of technetium @-@ 99m relieved all other producers from building their own reactors . With the cancellation of the already tested reactors in 2008 , the future supply of technetium @-@ 99m became problematic .
The Chalk River reactor was shut down for maintenance in August 2009 , and reopened in August 2010 . The Petten reactor had a 6 @-@ month scheduled maintenance shutdown on Friday , February 19 , 2010 , and reopened September 2010 . With millions of procedures relying on technetium @-@ 99m every year , the low supply has left a gap , leaving some practitioners to revert to techniques not used for 20 years . Somewhat allaying this issue is an announcement from the Polish Maria research reactor that they have developed a technique to isolate technetium .

= = = Waste disposal = = =

The long half @-@ life of technetium @-@ 99 and its potential to form anionic species creates a major concern for long @-@ term disposal of radioactive waste . Many of the processes designed to remove fission products in reprocessing plants aim at cationic species such as caesium (e.g. , caesium @-@ 137) and strontium (e.g. , strontium @-@ 90) . Hence the pertechnetate escapes through those processes . Current disposal options favor burial in continental , geologically stable rock . The primary danger with such practice is the likelihood that the waste will contact water , which could leach radioactive contamination into the environment . The anionic pertechnetate and iodide tend not to adsorb into the surfaces of minerals , and are likely to be washed away . By comparison plutonium , uranium , and caesium are tend to bind to soil particles . Technetium could be immobilized by some environments , such as microbial activity in lake bottom sediments , and the environmental chemistry of technetium is an area of active research .
An alternative disposal method , transmutation , has been demonstrated at CERN for technetium @-@ 99 . In this process , the technetium (technetium @-@ 99 as a metal target) is bombarded with neutrons to form the short @-@ lived technetium @-@ 100 (half @-@ life = 16 seconds) which decays by beta decay to ruthenium @-@ 100 . If recovery of usable ruthenium is a goal , an

extremely pure technetium target is needed ; if small traces of the minor actinides such as americium and curium are present in the target , they are likely to undergo fission and form more fission products which increase the radioactivity of the irradiated target . The formation of ruthenium @-@ 106 (half @-@ life 374 days) from the ' fresh fission ' is likely to increase the activity of the final ruthenium metal , which will then require a longer cooling time after irradiation before the ruthenium can be used .

The actual separation of technetium @-@ 99 from spent nuclear fuel is a long process . During fuel reprocessing , it comes out as a component of the highly radioactive waste liquid . After sitting for several years , the radioactivity reduces to a level where extraction of the long @-@ lived isotopes , including technetium @-@ 99 , becomes feasible . A series of chemical processes yields technetium @-@ 99 metal of high purity .

= = = Neutron activation = = =

Molybdenum @-@ 99 , which decays to form technetium @-@ 99m , can be formed by the neutron activation of molybdenum @-@ 98 . When needed , other technetium isotopes are not produced in significant quantities by fission , but are manufactured by neutron irradiation of parent isotopes (for example , technetium @-@ 97 can be made by neutron irradiation of ruthenium @-@ 96) .

= = = Particle accelerators = = =

The feasibility of technetium @-@ 99m production with the 22 @-@ MeV @-@ proton bombardment of a molybdenum @-@ 100 target in medical cyclotrons following the reaction 100Mo (p , 2n) 99mTc was demonstrated in 1971 . The recent shortages of medical technetium @-@ 99m reignited the interest in its production by proton bombardment of isotopically @-@ enriched (> 99 @.@ 5 %) molybdenum @-@ 100 targets . Other techniques are being investigated for obtaining molybdenum @-@ 99 from molybdenum @-@ 100 via (n , 2n) or (? , n) reactions in particle accelerators .

= = Applications = =

= = = Nuclear medicine and biology = = =

Technetium @-@ 99m (" m " indicates that this is a metastable nuclear isomer) is used in radioactive isotope medical tests . For example Technetium @-@ 99m is a radioactive tracer that medical imaging equipment tracks in the human body . It is well suited to the role because it emits readily detectable 140 keV gamma rays , and its half @-@ life is 6 @.@ 01 hours (meaning that about 94 % of it decays to technetium @-@ 99 in 24 hours) . The chemistry of technetium allows it to be bound to a variety of biochemical compounds , each of which determines how it is metabolized and deposited in the body , and this single single isotope can be used for a multitude of diagnostic tests . More than 50 common radiopharmaceuticals are based on technetium @-@ 99m for imaging and functional studies of the brain , heart muscle , thyroid , lungs , liver , gall bladder , kidneys , skeleton , blood , and tumors .

The longer @-@ lived isotope , technetium @-@ 95m with a half @-@ life of 61 days , is used as a radioactive tracer to study the movement of technetium in the environment and in plant and animal systems .

= = = Industrial and chemical = = =

Technetium @-@ 99 decays almost entirely by beta decay , emitting beta particles with consistent low energies and no accompanying gamma rays . Moreover , its long half @-@ life means that this emission decreases very slowly with time . It can also be extracted to a high chemical and isotopic

purity from radioactive waste . For these reasons , it is a National Institute of Standards and Technology (NIST) standard beta emitter , and is used for equipment calibration . Technetium @-@ 99 has also been proposed for optoelectronic devices and nanoscale nuclear batteries .

Like rhenium and palladium , technetium can serve as a catalyst . In processes such as the dehydrogenation of isopropyl alcohol , it is a far more effective catalyst than either rhenium or palladium . However , its radioactivity is a major problem in safe catalytic applications .

When steel is immersed in water , adding a small concentration (55 ppm) of potassium pertechnetate (VII) to the water protects the steel from corrosion , even if the temperature is raised to 250 ° C (523 K) . For this reason , pertechnetate has been used as an anodic corrosion inhibitor for steel , although technetium 's radioactivity poses problems that limit this application to self @-@ contained systems . While (for example) CrO2 ?

4 can also inhibit corrosion , it requires a concentration ten times as high . In one experiment , a specimen of carbon steel was kept in an aqueous solution of pertechnetate for 20 years and was still uncorroded . The mechanism by which pertechnetate prevents corrosion is not well understood , but seems to involve the reversible formation of a thin surface layer (passivation) . One theory holds that the pertechnetate reacts with the steel surface to form a layer of technetium dioxide which prevents further corrosion ; the same effect explains how iron powder can be used to remove pertechnetate from water . (Activated carbon can also be used for the same purpose .) The effect disappears rapidly if the concentration of pertechnetate falls below the minimum concentration or if too high a concentration of other ions is added .

As noted , the radioactive nature of technetium (3 MBq / L at the concentrations required) makes this corrosion protection impractical in almost all situations . Nevertheless , corrosion protection by pertechnetate ions was proposed (but never adopted) for use in boiling water reactors .

= = Precautions = =

Technetium plays no natural biological role and is not normally found in the human body . Technetium is produced in quantity by nuclear fission , and spreads more readily than many radionuclides . It appears to have low chemical toxicity . For example , no significant change in blood formula , body and organ weights , and food consumption could be detected for rats which ingested up to 15 µg of technetium @-@ 99 per gram of food for several weeks . The radiological toxicity of technetium (per unit of mass) is a function of compound , type of radiation for the isotope in question , and the isotope 's half @-@ life .

All isotopes of technetium must be handled carefully . The most common isotope , technetium @-@ 99 , is a weak beta emitter ; such radiation is stopped by the walls of laboratory glassware . The primary hazard when working with technetium is inhalation of dust ; such radioactive contamination in the lungs can pose a significant cancer risk . For most work , careful handling in a fume hood is sufficient , and a glove box is not needed .