WASTE GENERATED FROM LMR-AMTEC REACTOR CONCEPT

Ahmed Hasan, Yasser T. Mohamed and Tarek F. Mohammaden
New Mexico Tech. University
901 University Blvd., S.E., Albuquerque, NM 87106

ABSTRACT

The candidate Liquid Metal Reactor-Alkali Metal Thermal -to- Electric Converter (LMR-AMTEC) is considered to be the first reactor that would use pure liquid potassium as a secondary coolant, in which potassium vapor aids in the conversion of thermal energy to electric energy. As with all energy production, the thermal generation of electricity produces wastes. These wastes must be managed in ways which safeguard human health and minimize their impact on the environment. Nuclear power is the only energy industry, which takes full responsibility for all its wastes.

Based on the candidate design of the LMR-AMTEC components and the coolant types, different wastes will be generated from LMR. These wastes must be classified and characterized according to the U.S. Code of Federal Regulation, CFR. This paper defines the waste generation and waste characterization from LMR-AMTEC and reviews the applicable U.S. regulations that govern waste transportation, treatment, storage and final disposition. The wastes generated from LMR-AMTEC are characterized as: (1) mixed waste which is generated from liquid sodium contaminated by fission products and activated corrosion products; (2) hazardous waste which is generated from liquid potassium contaminated by corrosion products; (3) spent nuclear fuel; and (4) low-level radioactive waste which is generated from the packing materials (e.g. activated carbon in cold trap and purification units). The regulations and management of these wastes are summarized in this paper.

INTRODUCTION

In an ideal nuclear reactor all fission products and actinides are contained in the fuel elements. There are four processes in nuclear power plants through which radioactivity leaves the reactor vessel, and in all cases the coolant usually is the carrier of radioactivity:

Inducing radioactivity in the cooling medium
Corrosion products containing induced radioactivity
Leaked fission products and actinides from faulty fuel elements
Fission products of actinides deposited on surfaces in the core

The waste generated from the LMR could be classified according to waste characteristics as hazardous waste, mixed waste and/or radioactive waste. Corrosion and fission products are in the form of dissolved ions and precipitate in the crud, depending on the chemistry of corrosion, fission products and sodium conditions. Corrosion products are the major contributor to the induced radioactivity in the coolant. Most common activated corrosion products are ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn and ^{124}Sb, while the main fission products are ^{3}H, ^{131}I, ^{134}Cs and ^{137}Cs. Other fission products and actinides are released in minor amount depending on type, size, and leak age of the fuel element. These products are continually removed by cleaning circuits. Eventually radioactive material accumulates in the purification systems, until filters are backwashed and the adsorbing materials in purification systems are changed through remotely controlled systems. Therefore, solid radioactive wastes are produced from the purification circuits of the LMR station, as well as from other parts of the reactor.

Most of the waste generated from decommissioned nuclear reactors is non-radioactive. Also, large volumes can be decontaminated and declassified which permits them to be treated as normal industrial waste. Of the remaining waste, most contains low-levels of relatively short-lived nuclides; hence it can be treated and disposed of. Some internal parts of the reactor have relatively high activity. When spent fuel is removed from a reactor, it is stored into a pool of water at the reactor site where the water serves as a radiation shield and coolant. Storing the spent fuel in pools is intended only as a temporary measure until a permanent disposal place is found (1).

1. WASTE GENERATED FROM LMR-AMTEC

Sodium and potassium were selected as the most suitable working fluids in the LMR-AMTEC. Sodium was selected to be the core working fluid (1^{ry} coolant) because of its better neutronic performance and the experience associated with sodium-cooled reactors. Potassium was selected as a coolant agent in the secondary circuit due to its higher efficiency than sodium. Figure (1) illustrates a simplified description of the Indirect Coupled (IC) plant with boiler (the selected design of LMR-AMTEC) where the primary and secondary loops show independent working fluids.

1.1 LIQUID POTASSIUM

1.1.1 POTASSIUM CONTAMINATION BY CORROSIVE PRODUCTS

The corrosion rate of alkali metal is typically dependent on the type of structural material, oxygen content and flow rate where, (2)

Corrosion of stainless steel and super alloys includes preferential dissolution of nickel and chromium.

Increasing oxygen content and temperature increase corrosion rate.

Increasing nickel content typically increases corrosion rate but decreases the differentials of oxygen content on corrosion rate.

Experimental results and observations have shown clearly that corrosion by liquid metal is a strong function of oxygen content and is accelerated due to the presence of certain metallic elements, such as nickel. Cold trapping has been shown to be an effective method of controlling the oxygen and impurities levels, like in the Experimental Breeder Reactor (EBR-II), to the acceptable level (2). Figure (2) indicates that potassium liquid can corrode Fe, Ni, Mo and Cr elements especially in a high oxygen content and high temperature. High temperatures increase the oxygen dissolution, which result in failing of

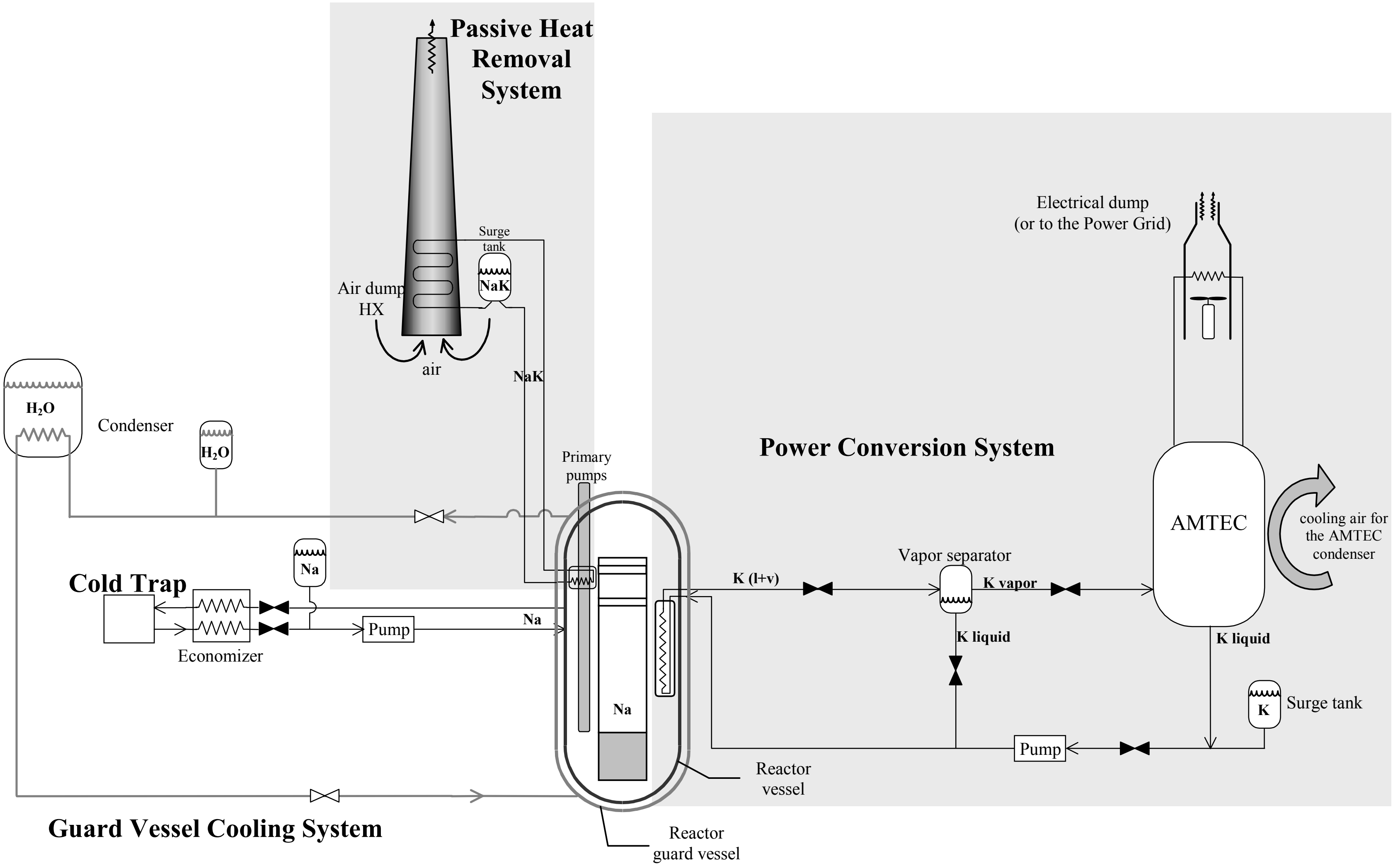

Figure 1. Power Conversion System, Passive Heat Removal System (PHRS), Water Cooling Guard Vessel (WCGVS), and Primary Cold Trap, system components of the candidate LMR-AMTEC.

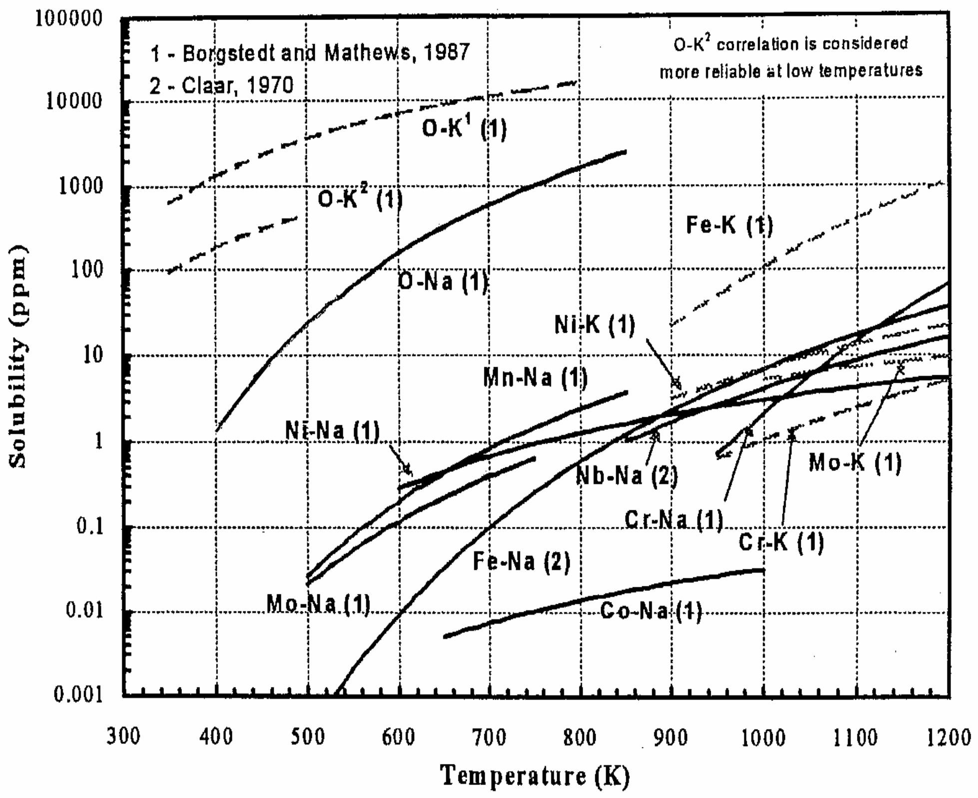

Figure 2. Solubility of Oxygen and Metallic impurities in Liquid sodium and potassium.

cold trapping at 425 K to reduce the oxygen content of liquid potassium below ~ 200 ppm. Hot trapping with oxygen gathering materials such as zirconium, hafnium or yttrium will be needed to maintain the oxygen concentration in liquid potassium at the desired levels (< 5 ppm) (2).

1.1.2 POTASSIUM CONTAMINATION BY RADIOACTIVE PRODUCTS

Generally, there is no probability of contaminating liquid potassium by the fission products except for probable contamination with tritium (^3H). Potassium liquid takes an independent route in LMR-AMTEC with no contact with sources of fission products contamination such as reactor fuel or the fission products carrier like liquid sodium.

Tritium is a radioactive hydrogen gas, it is a tiny atom and very difficult to be contained. Tritium can escape from some metal containers by slipping right through the metal walls. Tritium is produced as a fission product from a fuel, and in the reactor operating temperature it can go through the fuel cladding and reach the liquid sodium. Because of its high penetration capability, tritium may diffuse into liquid potassium through heat exchange between sodium and potassium liquids (3).

1.2 LIQUID SODIUM

Sodium has been universally chosen as a coolant for the modern Liquid Metal Fast Breeder Reactor (LMFBR). Because of its small size, sodium does not appreciably slow down neutrons by elastic scattering. Therefore, sodium is an excellent heat transfer material and the LMFBR can be operated at high power density, which means that an LMFBR core can be comparatively small. Furthermore, because sodium has a very high boiling point, the reactor coolant loops can be operated at high temperature and at essentially atmospheric pressure without boiling, and no heavy pressure vessel is required. Hot sodium reacts violently with water and catches fire, when it comes in contact with air, emitting dense clouds of white sodium peroxide smoke. Accordingly, LMFBRs are inherently very tight systems and emit far less radiation to the environment than comparable LWRs.

1.2.1 SOURCES OF CONTAMINATION AND RADIOACTIVITY

Behavior of radionuclides in an LMFBR is very complex and cannot be described by one simple model. Nuclides of many elements with different chemical properties are involved with a wide range of concentrations. Chemical reactions may alter their behavior due to the isotopic exchange processes that may take place as well as diffusion processes into the walls of the enclosing system. Selective leaching of single elements (i.e. ferritic surface formation on austenitic stainless steels by selective dissolution of nickel) could change the inner wall material composition. Leaching processes result in radionuclides that may be present in a hot flowing sodium liquid either as true solutes or included into more or less small particles.

Some radionuclides are volatile at operating temperatures (noble gases, cesium, antimony) and enter the cover gas system.

The main sources of radioactivity in the first coolant are:

Activation of the coolant
Activation of dissolved or entrained impurities in the coolant as they pass through the core. These impurities include existing impurities such as. Li, U and entrained impurities due to corrosion. Specifying the purity of sodium can control the activation of impurities.
Activation of corrosion products, which subsequently enter the coolant. Examples of important components are: fuel cladding, core structural materials, control rods and wear resistant.
Release of active fission products and fuel components from failed pins.
Release of Tritium from ^{6}Li reactions in the coolant, ternary fission in fuel and activation of boron in control rod materials.

It is obvious that neutrons are the cause of all of these sources of long-lived system contamination. Neutrons however are available only in and around the reactor core, and only the primary sodium coolant comes into contact with core region. Under normal reactor operation some radionuclides can be separated from the coolant and distributed between coolants, cover gas, cold tarp and the exposed steel surfaces.

1.2.1.1 ACTIVATION OF THE COOLANT

^{24}Na, with a half-life of 15 h, is one of the major radioactive isotopes in the coolant. It is produced from the reaction ^{23}Na (n,) ^{24}Na. Additional activities, but lower extent, come from ^{22}Na (half-life 2.6 a) produced by (n, 2n) reactions as well as from ^{23}Ne (half-life 38 s), which is produced from ^{23}Na (n, p) ^{23}Ne reactions. Covering component removed from reactor should only present short-term problems because of the short half-life of ^{24}Na present in the sodium wetted film, and over the long term the lower energy isotope ^{22}Na will be the dominant species (1,3) Table 1.

Controlling of impurities in a coolant during normal plant operation, by continuous or periodic cold trapping of coolant, should ensure that the increasing levels of impurities would only occur if contaminants enter the circuit either during core changes, or from failed components or replacement items of plant. The presence of Li and U impurities in a coolant, although the capability to produce extra tritium and fissile materials, have negligible effects on activity levels compared to levels produced from ternary fission and failed pins respectively (1,3).

1.2.1.2 ACTIVATION OF CORROSION PRODUCTS

Unless a reactor has been operated for a long time with defective fuel elements, radioactive corrosion products are the major sources for system contamination. They can be formed in two ways:

Transportation of non-radioactive corrosion products mainly from heat exchanger into core region and followed by activation.

Corrosion of already activated material in the core region like cladding and other core structure materials.

Although the first process is the most important for system contamination of water-cooled nuclear reactors, it is considered to be insignificant for LMFBRs. The second process is important in primary liquid sodium systems.

The major radionuclides produced by neutron-induced reactions in the core are ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co and ^{182}Ta. The relatively short half-lives of ^{51}Cr and ^{59}Fe (27.8 and 45 d, respectively) and low-level of Ta in steels (0.1%) means that activity levels produced by these isotopes are only of interest during normal plant operation. Once a plant is shutdown, longer-lived isotopes ^{58}Co, ^{60}Co and ^{54}Mn become the radionuclides of concern.

1.2.1.3 ACTIVE FISSION PRODUCTS FROM FAILED PINS

Fission products are generated inside the fuel during operation of a nuclear reactor. The nuclear fuel is usually enclosed in gastight fuel cladding tubes e.g. Zr-Nb alloy. During regular operation all fission products (except tritium) remain within the fuel pins. The inventories of fission products at any time in the life of particular fuel pin can be calculated with a good certainty. For fast neutron fission, yielding of the most abundant mass chains for ^{235}U, ^{238}U and ^{239}Pu are known within a few percent. During the operation of several thousand-fuel pins in large sodium cooled power reactor, one or several fuel pin cladding may fail. The amount of activity released from failed pin has been shown to depend upon the isotopic content of fuel prior to failure, quantity of elements present in the fuel clad gas gap, and rating of pin and reactor history (14). Irrespective of defect size, noble gases (Xe, Kr) are released fairly quickly and their limited solubility in sodium ensures rapid removal to gas space. Fission products of highly volatility behave in a similar manner and those elements of high yielding, namely Cs, I, Ba and Sr can also be released during the initial stages of fuel clad failures.

The level of activity circulating in a coolant depends upon the solubility behavior of various isotopes. In principle, levels of activity produced by partly soluble Te, Sb, Sn, Ag radionuclides and I can be reduced by operation of cold trap. However, if fuel pin failures become excessive, there is possibility that cold trap may become a relatively ineffective sink and plate-out of various products may occur elsewhere in a circuit.

Isotopes of major concern are ^{134}Cs and ^{137}Cs which have half-lives of 2 and 30 a, respectively. Both isotopes can produce radiation fields comparable to those produced by deposited corrosion products. The complete miscibility of Cs in sodium coupled with its high volatility points to complex behavior in sodium system. Other fission products such as lanthanides, Zr, Nb, Ru, Mo and fuel products have very low solubility in sodium.

Table I: Maximum activity levels measured in sodium of LMFBRs (1).

Isotope		^{24}Na	^{22}Na	^{65}Zn	^{124}Sb	^{131}I	^{137}Cs	^{134}Cs
Half-life		15 h	2.6 a	244 d	60.3 d	8 d	30 a	2.2 a
Reactor Type	Unit	MBq/kg	MBq/kg	MBq/kg	MBq/kg	MBq/kg	MBq/kg	MBq/kg
	Ref.							
EBR-II	(4)	*100*	*5*		*21*	*11*	*13*	*1.6*
FFTF	(4)	*410*	*20*		*0.026*	*1.8*	*8.1*	*5.5*
KNK-II	(5, 6)	*2500*	*25*	*6.4*	*1.4*	*38*	*34*	
PFR	(7, 8)		*14*				*11.7*	*2.2*
RAPSODIE	(9)		*40*				*55*	
PHENIX	(9,10)		*22*				*1.7*	*0.33*
BOR-60	(11, 12)		*22*	*0.74*		*103*	*777*	*66*
BN-350	(13)	*370*	*28*					
BN-600	(12)	*750*	*26*		*0.15*	*13*	*150*	*50*

1.2.1.4 TRITIUM IN LMR

Although tritium is unlikely to present a major hazard during normal plant operation, the element is of biological importance and therefore knowledge of its transport behavior in operating plant is required. In sodium-cooled reactors, tritium originated principally in two locations, in the fuel pins and in the control rods. It is created in fuel by ternary fission and in control rods by neutron interactions with boron found in B_4C. In addition, it will be produced by neutron activation of Li and boron impurities in fuel and in primary sodium (3).

At reactor operating temperatures tritium can permeate through fuel cladding and the walls of cooling systems. As a result, the possibility of tritium escaping must be considered. Tritium is very well fixed in cold traps by co-precipitation with hydrogen (NaH). In a reactor system tritium may escape from sodium coolant into:

helium cover gas where the equilibrium is assumed to be instantaneous,
potassium coolant, by diffusion through the walls of heat exchangers.
inter-space gas between the vessels, by diffusion through the steel of the vessel and pipe work
cold trap by crystallization of sodium tritide, or by isotopic exchange

1.3 WASTE GENERATION FROM COLD TRAP

Cold trap is used as purification method for sodium in the first loop of LMFBRs as well as for potassium in the second loop. Although the principal role of cold trap in LMFBRs is to control the concentration of dissolved oxygen impurity and hence maintain acceptable levels of radioactive corrosion products, a number of traps have been known to collect radioactive impurities. Decreasing of sodium temperature in cold trap causes crystallization of Na_2O on the wires of steel mesh. It is also established that cold traps are effective in controlling hydrogen impurities by precipitating sodium hydride NaH. Certain number of radioactive impurities has been observed to be cold trapped too, although cold traps are not designed with this intension. For the removal of certain radioactive constituents such as, Cesium, Iodine, Oxide forming fission product and radioactive corrosion products, a number of factors have to be considered in relation to this trapping behavior. Cold trap packing material which contaminated by radioactive fission products, corrosion products and Na_2O and NaH, is considered a low-level waste after its removal from the cold trap unit (3).

1.4 WASTE GENERATION FROM COVER GAS PURIFICATION UNITS

Although the resulting activity from corrosion products and other deposited species is contained within the primary vessel of pool-type LMFBRs, it is still necessary to control the build up of radioactivity in operating systems. Radioactive isotopes in cover gas, for example, are passed through gas purification units as part of normal reactor operations. The dominant radionuclides in the cover gas come from argon, isotopes of cesium and sodium and the noble gases such as, ^{87}Kr, ^{88}Kr, ^{85m}Kr, ^{135}Xe, ^{133m}Xe and ^{133}Xe, Table II. At RAPSOIDE (France), using helium for the cover gas allowed krypton to be trapped on charcoal in cooled charcoal gas purification unit with efficiency greater than 80% (100% for Xe) (15). On PHENIX and SUPER PHENIX, a gas purification unit is installed to trap radio-xenon on charcoal cooled by nitrogen while retention tank allows for the decay of radio-krypton. Charcoal or activated carbon that used in a purification unit, which is contaminated by isotopes of Cs, Na and noble gases, is considered low-level waste. Table III, illustrates the materials and techniques used in different LMFBRs around the world.

1.5 WASTE GENERATION FROM SPECIAL TRAPS

Due to deposition of radionuclides on the walls of primary coolant system of LMFBRs, when liquid sodium is circulating at low temperatures, the gamma radiation fields may be high in primary cell even when sodium was drained into dump tank. Fission products especially ^{134}Cs, ^{137}Cs, ^{58}Co and ^{60}Co are mainly responsible for high

Table II: Maximum activity levels measured in the cover gas of LMFBRs in GBq/m^3 (1).

Reactor Name	Isotope	^{23}Ne	^{41}Ar	^{133}Xe	^{135}Xe	^{85m}Kr	^{88}Kr	^{87}Kr	Ref.
	Half-life	38 s	1.8 h	5.2 d	9 h	4.5 h	2.8 h	1.3 h	
FFTF		74000	15	1900	800	200	200	75	(16)
KNK-II			7	1240	134	11	13	6	(17,18)
PHENIX		7000	1.5	2500	1500	300		200	(10, 15)
BR-5		26000	5.5	7400	4400		3700	1800	(19)
BOR-60				25000	2000	200	70		(20)
BN-350		18000	0.74	4000					(21)
BN-600			5.3	4800					(12)

Table III: Different techniques for removal of radioactivity in the cover gas (22).

Reactor	Country	Purification Techniques
RAPSODIE	*France*	Active carbon filter before discharge
KNK-II	*Germany*	Active carbon filter
MONJU	*Japan*	Charcoal delay bed
EBR-II	*USA*	Cryo distillation
FFTF	*USA*	Carbon delay bed and cold trap
PHENIX	*France*	Active carbon bed and cryogenic effect
ALMR	*USA*	Activated carbon bed
SUPER-PHENIX1	*France*	Active carbon bed and cryogenic effect
SUPER-PHENIX2	*France*	Sweeping and filtering
BN-1600	*Russia*	Aerosol filter
BN-800	*Russia*	Aerosol filter

gamma radiation in the primary sodium system. A cesium trap was designed for operation in the EBR-II primary sodium purification system. The trap contains 0.01 m^3 of reticulated vitreous carbon, is about 26 cm in diameter and 34 cm long. It is thermally insulated and shielded with 11 cm of lead. The vitreous carbon that used in the trap which is contaminated with isotopes of Cs, is considered low-level waste.

1.6 SPENT NUCLEAR FUEL

Spent nuclear fuel and high-level radioactive waste are by-products of making electricity at commercial nuclear power plants and from reprocessing spent nuclear fuel. LMR-AMTEC fuel cycle is a once through fuel cycle (i.e. no reprocessing of the spent fuel of LMR-AMTEC). In PWR and BWR, once the spent fuel is removed from the reactor, it will be stored under a pool of water at the reactor site. Water is a radiation shield and coolant. Storing spent fuel in pools is intended only as a temporary measure until a permanent disposal place is found. In LMFBRS, spent fuel contains elemental sodium, which is a reactive material according to 40 CFR 261.23 so it is very dangerous to be in contact with water or even with air. The spent fuel that will be produced from LMR-AMTEC must not be stored in contact with water or with air. As an alternative for storing in pools, some spent fuel are being stored above ground at reactor sites in concrete or steel containers called dry casks or shipped to dry storage locations such as, ANL-W, Hanford Site, INEEL and Savannah River Site awaiting for final disposal in deep geological repository. The management of spent nuclear fuel must be complied with 10 CFR 72.108, 10 CFR 72.126, 10 CFR 72.128, 10 CFR 72.130, 10 CFR 72.166 and 10 CFR 60.135. Safe disposal and isolation of spent fuel from reactors is a current concern. Under the Nuclear Waste Policy Act of 1982; the U.S. Department of Energy, DOE has responsibility for the development of a national waste disposal system for spent nuclear fuel and high-level radioactive waste. Current plans call for the ultimate disposal of high-level wastes in solid form in deep and stable geological structures such as the proposed Yucca Mountain site in Nevada, 10 CFR 63. Recently, the congress and the president of the U.S. approved the site for high-level waste disposal and it is going through the final phase of licensing application.

Table IV: fuel chemical composition of different types of reactors

Reactor type	**Fuel-chemical composition**
Light Water Reactor	*Uranium Dioxide*
Heavy Water Reactor	*Uranium dioxide or metal*
Graphite Moderate Reactor	*Uranium dicarbide or uranium metal*
Fast Breeder Reactor	*Plutonium dioxide and uranium dioxide in various arrangements*
LMR- AMTEC	*Uranium Nitride and Plutonium Nitride*

2.0 CONCLUSIONS

The aim of this paper is to define waste generation and characterization from Liquid Metal Reactor LMR-AMTEC as well as to identify applicable U.S. regulations that govern waste transportation, treatment, storage and final disposition. Waste generated from LMR-AMTEC is characterized as (1) mixed waste, which is generated from liquid sodium contaminated by fission products and activated corrosion products (2) hazardous waste, which is generated from liquid potassium contaminated by corrosion products (3) spent nuclear fuel (4) low-level radioactive waste, which is generated from packing materials e.g. activated carbon in cold trap and purification units. The regulations of these wastes will be summarized in hereafter.

2.1 MIXED WASTE

Sodium liquid metal coolant, which contaminated with fission products and activated corrosion products from the core meltdown of LMR, is classified as a mixed waste. The principal regulatory agencies involved in the treatment and disposal of mixed waste are the EPA and NRC. DOE is subject to regulations promulgated by these agencies through the Federal Facility Compliance Act. of 1992 (FFCA), which requires federal facilities to comply with the same regulations of non-federal facilities (FFCA, 1992). Thus, in dealing with its mixed waste, DOE's Office of Environmental Management (EM) must comply with EPA regulations for hazardous wastes and with NRC regulations for radioactive wastes. Further, the FFCA requires DOE to comply with applicable state regulations if they are more restrictive than federal regulations. EPA has developed regulations for hazardous waste management and disposal principally under authority of RCRA, and amended in 1984. RCRA provides for the cradle to grave control of hazardous wastes by imposing management requirements on generators, transporters, owners and operators of treatment and storage facilities of hazardous waste. The RCRA hazardous waste regulations are found in Title 40 of the Code of Federal Regulations, parts 260 to 265. EPA's land disposal restrictions are given in 40 CFR 268 and its permit programs in 40 CFR 270. NRC operates under the authority of the Atomic Energy Act of 1954 (AEA) and its subsequent amendments. NRC regulations that affect management of DOE mixed waste includes 10 CFR 61, low level waste disposal regulation and 10 CFR 20 and radiation Protection Standards. NRC closely regulates the waste form stability and radioactive characteristics of low-level waste materials acceptable for near-surface land disposal through a combination of prescriptive and performance based requirements 10 CFR 61.55-56.

Liquid sodium coolant containing high activity of corrosion and fission products is considered a mixed waste and regulated under RCRA and NRC. Waste with hazardous components prohibited from land disposal according to 40 CFR 268 " Land Disposal Restrictions" must be treated as specified according to 40 CFR 268, Subpart D, "Treatment Standards" prior to disposal or interim storage. Sodium Process Facility SPF at Argonne National Laboratory-West was designed and constructed to convert the elemental sodium from EBR-II primary and secondary systems to sodium carbonate that is not RCRA regulated. This waste is acceptable for land disposal at Radioactive Waste Management Complex at Idaho National Engineering and Environment Laboratory INEEL as low-level radioactive waste. Treatment of sodium involves converting sodium to its respective hydroxide via reaction with air and water, followed by conversion to its respective carbonate via reaction with carbon dioxide. The resultant aqueous carbonate solution was solidified in 55-gallon drums using Aquaset II-H (a product of Fluid Tech. Inc.) (23,24). Treatment of EBR-I NaK and EBR-II sodium was successful accomplished by converting mixed waste to a non-hazardous form and land disposal of the treated waste at sodium facility in Argonne National Laboratory –West (ANL-W) as LLW. The NaK of EBR-I containers consisting of two 55-gallon MIN Safety Appliance (MSA) drums, one 60 gallon and another 10-gallon closed pipe section. Sodium carbonate, which contaminated by fission products and activated corrosion products, is considered low-level radioactive waste and could be transported to the INEEL RWMC for disposal using type A container (55- gallon steel drum). Disposal criteria at RWMC don't allow liquids to be land disposed (25). Waste packages must meet all applicable provisions of DOT regulations in 49 CFR parts 171-178 and NRC regulation in 10 CFR 71. Transportation of mixed waste shall meet applicable DOT and EPA regulatory requirements for hazardous components in addition to meeting regulatory requirements for radioactive materials. Mixed waste must be classified according to requirements for hazardous material as defined by Title 49 CFR 173.2. The requirements of Title 40 CFR 264, subpart I "Use and management of Containers" shall be met for all MW packages.

2.2 HAZARDOUS WASTE

Potassium liquid coolant is considered as hazardous waste according to 40 CFR 261.21-23. The hazardous waste must be treated before it could be sent to an RCRA-permitted land disposal facility (Land Disposal Restrictions, LDR, 40 CFR 268). Also like the LLMW, Hanford Site currently does not have facilities to treat all types of hazardous waste, so untreated waste must be stored until it will be in compliance with RCRA and state regulations. Short-term storage for hazardous waste at Hanford Site is allowed for up to 90 days, which is the maximum allowed for a non-permitted storage facility. Storage of hazardous waste for more than 90 days requires RCRA- permitted storage facility that is engineered to prevent release of the wastes to the environment.

Treatment of liquid potassium coolant, which is considered as a hazardous waste, could be accomplished at the Argonne National Laboratory-West (ANL-W). Treatment of potassium involves converting it to its respective hydroxide via reaction with air and water, followed by conversion to its respective carbonate via reaction with carbon dioxide. The resultant aqueous carbonate solution could be solidified in 55-gallon drums using Aquaset II-H (a product of Fluid Tech. Inc.) (23,24). Potassium liquid coolant can be transported using 55-gallon steel drum to the ANL-W for treatment; containers must be shaken to determine if potassium super-oxide (KO_2) is present which might present an explosion hazard during shipment and handling at ANL-W. The presence of potassium super-oxide would have been noted by an increase in container temperature after shaken. Generator must follow the regulations of 40 CFR 264.176 and 264.281 about the special requirements for ignitable or reactive waste. Containers of hazardous wastes and their management will be chosen according to 40 CFR 264.170 to 175. Packaging and transportation of hazardous wastes must meet the requirements in 49 CFR 173 and 178. Each waste container must be labeled with the word "Hazardous Waste" in addition to the other general requirements, which are bar code, durability of labels and marks to remain intact and legible during management of waste before disposal. In addition, placement of labels, size of labels and labeling inner containers in lab packs, all must meet the acceptance criteria of Hanford Site Waste Acceptance Criteria.

Other requirements such as storage limitations under the regulation of 40 CFR 262.34 and perform record keeping and reporting, particularly the manifest under the regulation of 40 CFR 262.20 and 262.40 must be followed by generator.

2.3 SPENT NUCLEAR FUEL

Spent nuclear fuel would be transported in strong, thick-walled casks. DOE will use extremely durable and massive transportation casks whose designs are certified by the

NRC. The containers use multiple layers of lead and other materials to protect spent fuel and confine radiation. Typically, for every ton of spent fuel there are approximately four tons of protective shielding materials. Transport of spent nuclear fuel is highly regulated by DOT and NRC. DOT regulates all hazardous waste transportation, including radioactive materials, to ensure public health and safety. NRC regulates all commercial nuclear activities, transportation of spent nuclear fuel, design, manufacture, security of transportation casks, and any development and operation of Yucca Mountain (26).

DOE spent nuclear fuel shipments are always tracked and escorted. The Department's practice is to track and escort each shipment 24-hours a day. All spent nuclear fuel cask designs must be certified by NRC, and must safely contain radioactive contents under hypothetical accident conditions that simulate the conditions of severe accidents. These conditions must be evaluated in sequence, on the same cask design. To achieve certification, a cask must prevent harmful release of radioactive material even when subjected to each of these tests: free fall test, fire test, submerging test and puncture test. Fig. (3) illustrates the transportation cask of spent nuclear fuel.

Spent nuclear fuel generated from LMBFRs contains elemental sodium, which is a reactive material. Since reactive material is considered hazardous by EPA regulations and this fuel requires treatment before disposal in a geological repository. EBR-II spent fuel is converted to three different products, low enrichment uranium, ceramic waste and metallic waste. The fuel treatment processes are operating in the Fuel Conditioning Facility FCF at ANL-W, a shielded hot cell facility at the Argonne site Idaho. The treatment process steps, which include fuel assembly dismantling element chopping, electrorefining, cathode processing and casting, are installed in FCF at ANL (27,28,29).

Under 10 CFR 60, spent nuclear fuel is regulated as HLW. EPA has not yet determined whether SNF will be designated as mixed waste. When spent fuel is removed from a reactor, it should be placed in a dry storage awaiting treatment in ANL-W and final disposal in Yucca mountain site. Waste generators will follow the waste accep criteria of YMP site 10 CFR 63, such as, storing of SNF according to 10 CFR 73.51, packaging, storage and transportation of SNF in certified container and shipping regulations according to 10 CFR 961, 10 CFR 72.128, 10 CFR 72.108 and 10 CFR 60.135.

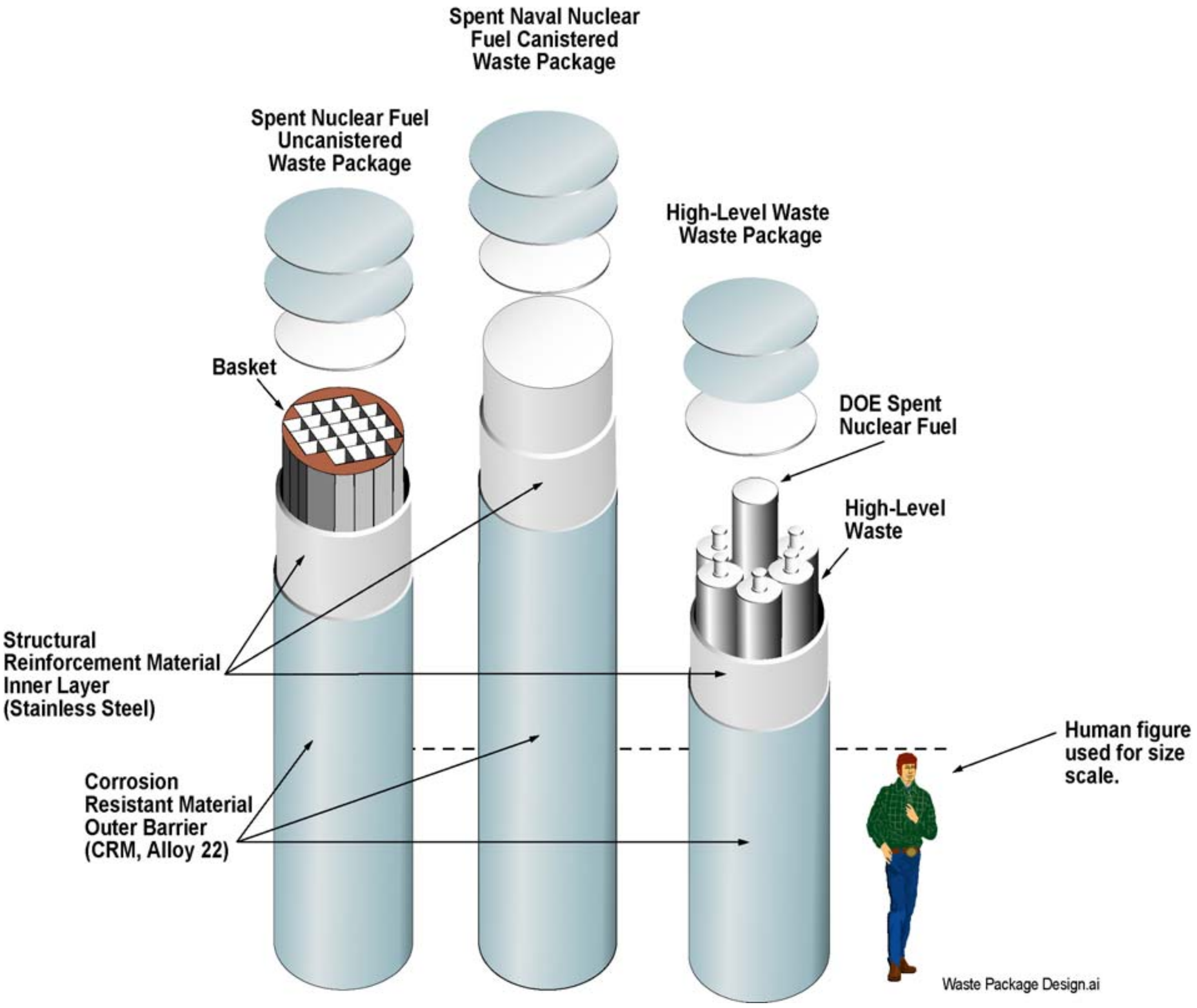

Figure 3. Yucca Mountain Wastes and Packages

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ABBREVIATIONS

Abv.	
AMTEC	Alkali Metal Thermal –to- Electric Converter
ANL-W	Argonne National Laboratory-West
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EBR	Experimental Breeder Reactor
HNF	Hanford Nuclear Facility
IAEA	International Atomic Energy Agency
IC	Indirect Coupled
IFR	Integral Fast Reactor
INEEL	Idaho National Engineering and Environment Laboratory
LDR	Land Disposal Restrictions
LLMW	Low-Level Mixed waste
LLW	Low Level Waste
LMFBR	Liquid Metal Fast Breeder Reactor
LMR	Liquid Metal Reactor
LWR	Light Water Reactor
MOX	Mixed Oxide Fuel
MW	Mixed Waste
NRC	U.S. Nuclear Regulatory Commission
Abv.	
PWR	Pressurized Water Reactor
RCRA	Resource Conservation and Recovery Act
SNF	Spent Nuclear Fuel
SPF	Sodium Process Facility
SRS	Savannah River Site
TRU	Transuranic
WIPP	Waste Isolation Plant Project
YMP	Yucca Mountain Project