Lubomir Zikovsky, Nuclear Engineering Institute
Ecole Polytechnique of Montreal

Radioactive waste management

Definition, Oregon legislature: burial of radioactive materials; <recognized by regulatory authorities> risk to health, isolation from the biosphere, excludes routine releases, Ra, `de minimis' below regulatory concern (BRC)

RW problem : scope, decay, volume :1% of toxic waste, NY: barge 3100 tons of garbage-NC-gulf of Mexico-NY, incineration; NIMBY

LLW 1986:60000 m3=30000 t, HLW:8 km2 site, LLW site for 1 Mm3:0.8 km2

NYS garbage = 15 Mt/y; Hazard: decay, Pb, As, Hg

Basic management principles* : disposable/dispersible form, immobilisation of RI, storage, transport, safe disposal; conditionning : stability + resistance, leaching, $

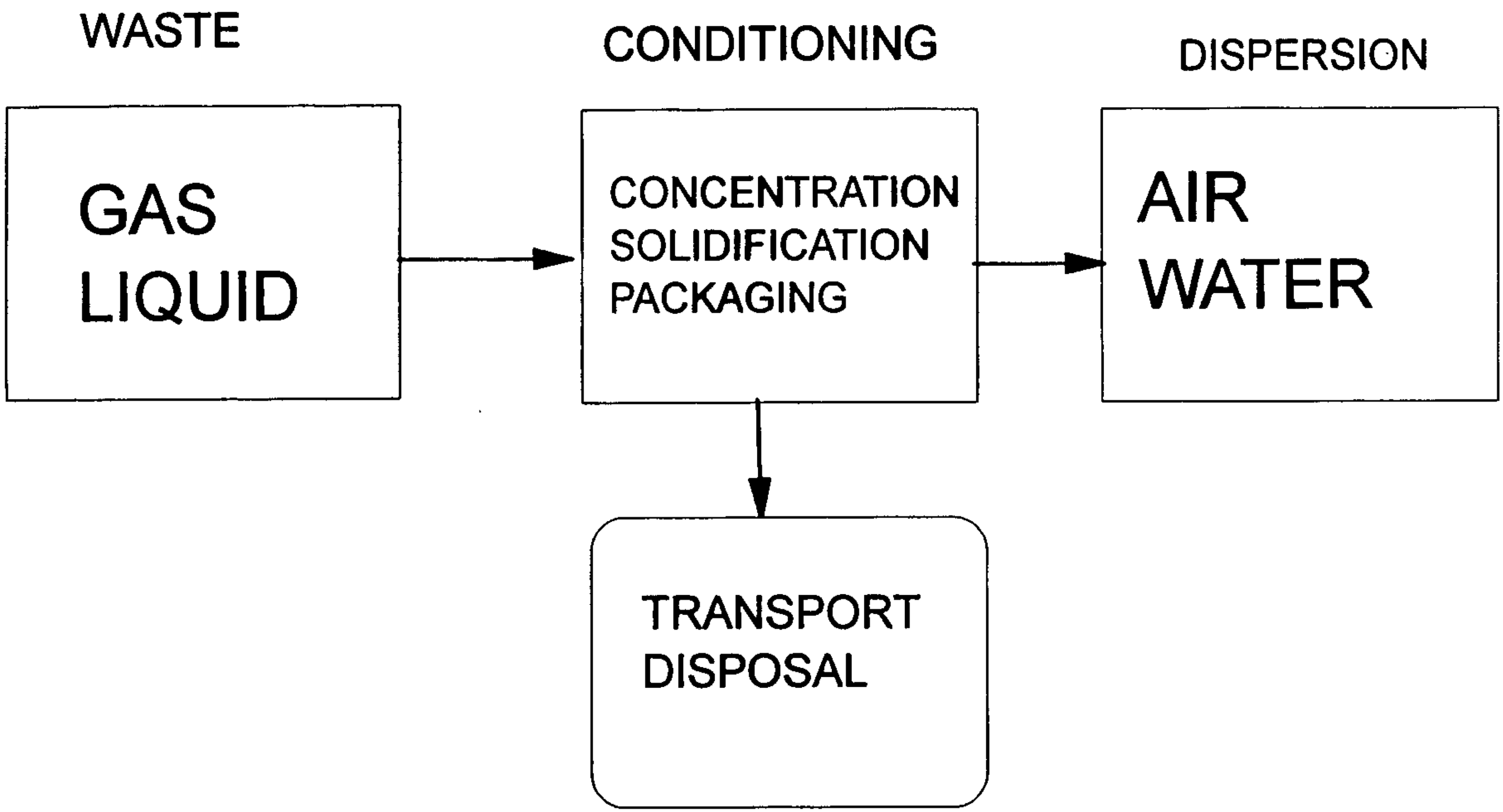
Classification: activity, phase, source, lifetime, property,designation; confusion, communication, US Standard Institute: MPC; premises: health +

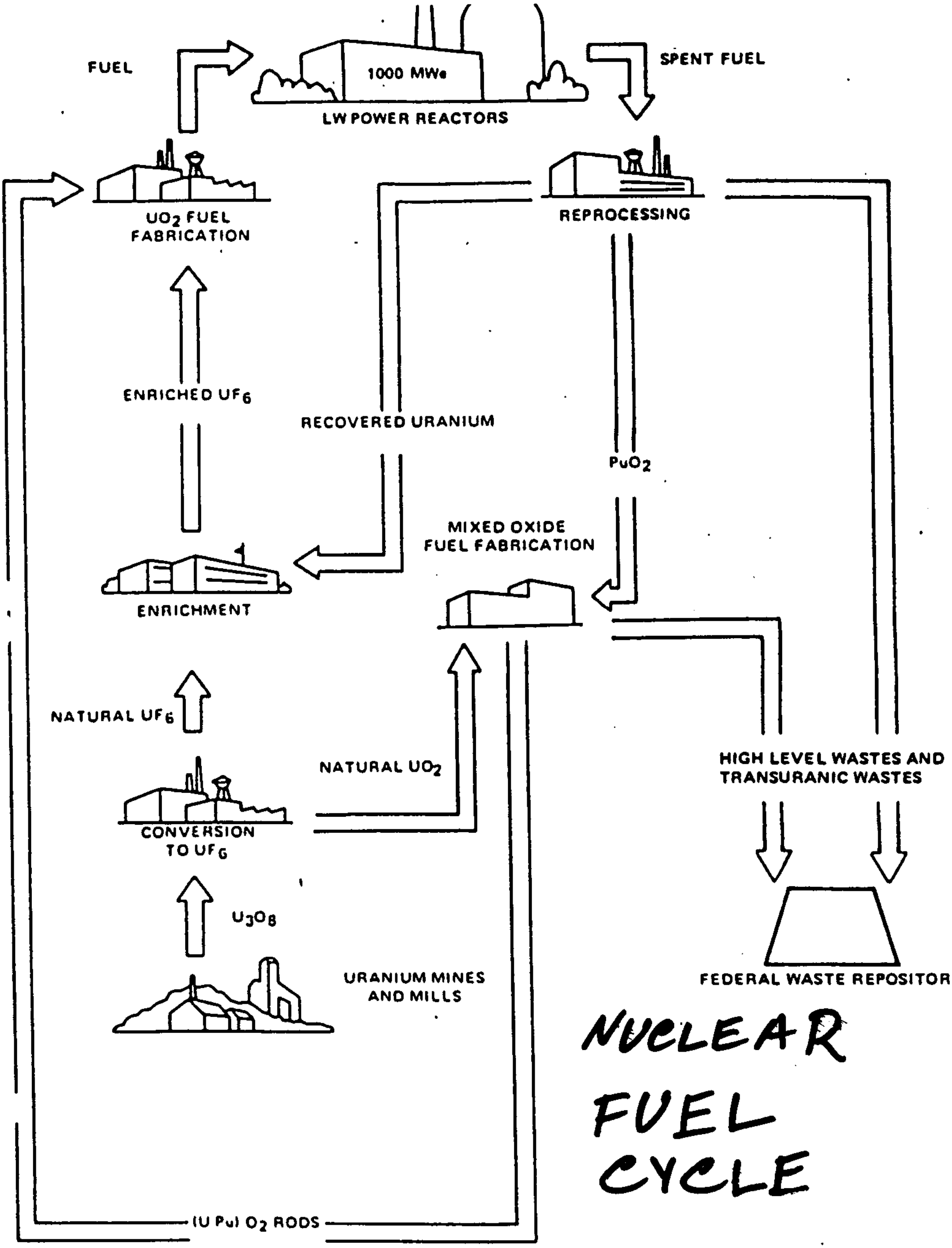
safety
Solid RW: France - 200 mr/h at 0 m, 10 mR/h at 1 m, Japan : 1,0.001, 0.000001 mcCi/cm3, Sweden: activity/container; premises : composition, specific activity, treatment, handling, transportation; problems : mixtures, detection, errors, criticality > 4 categories R/h 0.2, 2 alpha : mcCi/ml
Liquid RW : low, medium, high; high in Poland = low in UK = medium elsewhere > 5 categories mcCi/ml : 1E-6, 1E-3, 0.1, 10
Gaseous RW : total activity, atmospheric diffusion, ALARA > 3 categories mcCi/ml : 1E-10, 1E-6,

Category	gas	liquid	solid	treatment
1, BRC	<1E-10	<1E-6	<0.2 R/h	no, discharge
2, low	1E-10 1E-6	1E-6 1E-3	0.2 - 2 R/h	simple
3, medium	>1E-6	1E-3 0.1	> 2 R/h	conditioning
4, high	-	0.1 - 10		+ shielding
5, ?	-	> 10		+ + cooling

Forms + sources : many, HLW, LLW, TRU, tailings; nuclear fuel cycle*, industry: radiopharmaceutical, consumer products; Institutions : RI, medical, Co-60, Tc-99m, C-14,

BASIC PRINCIPLES OF MANAGEMENT





NUCLEAR FUEL CYCLE

vials , 10 Ci/y, academic, BRC
Mines : U, Sn, phosphates
HLW in the US: 10 CFR P-50/A-F: HLW = extraction solvent, 1981 HLW = spent fuel + PUREX, no reprocessing*, Carter, storage tank*
Spent fuel* : hot (6 % Mwth, FP+AP, TRU) + radioactive, cooling, shielding, fission and activation products, decay
Commercial HLW in US*: West Valley, NY, 2000 m3, 3 Mci, West Valley, PUREX, THOREX, liquid + sludge
Defense HLW in US: bombs + propulsion reactors, Hanford, SR, INEL, low RI concentration, large volume
TRU in US : Np-237, Pu-239, Am-241, Cm-243 231000 m3, 2636 kg, 3693 kCi, 87 kW <100 nCi/g TRU=LLW ore, >100 nCi TRU=TRU 40 CFR P-191, Np-239, remote handling
Generation of RW : characteristics > disposal
Reactor LLW : BWR : 2043 m3, 15 kCi; PWR : 1166 m3, 7 kCi
Other LLW : H-3, C-14, Tc-99m, Mo-99

TABLE 2-1 Radioactivity and Thermal Power (in watts) in Spent LWR Fuel per One Metric Ton of Uranium in Fresh Fuel[a]

	Years after Discharge		
	0	2	5
Radionuclide Content (curies)			
Important Activation Products			
^{14}C[b]	6.6×10^{-1}	6.6×10^{-1}	6.6×10^{-1}
^{55}Fe	2.0×10^{3}	1.2×10^{3}	5.2×10^{2}
^{60}Co	6.3×10^{3}	4.8×10^{3}	3.3×10^{3}
^{63}Ni	5.5×10^{2}	5.5×10^{2}	5.3×10^{2}
^{95}Zr	2.8×10^{4}	1.2×10^{1}	1.0×10^{-4}
Total Activation Products	1.4×10^{5}	6.7×10^{3}	4.3×10^{3}
Important Fission Products			
^{3}H	5.1×10^{2}	4.6×10^{2}	3.9×10^{2}
^{85}Kr	1.1×10^{4}	1.0×10^{4}	8.3×10^{3}
^{90}Sr	7.8×10^{4}	7.5×10^{4}	6.9×10^{4}
^{106}Ru	5.3×10^{5}	1.3×10^{5}	1.7×10^{4}
^{129}I	3.7×10^{-2}	3.7×10^{-2}	3.7×10^{-2}
^{137}Cs	1.1×10^{5}	1.0×10^{5}	9.6×10^{4}
Total Fission Products	1.4×10^{8}	1.2×10^{6}	4.8×10^{5}
Important Transuranium Products			
^{238}Pu	2.7×10^{3}	2.8×10^{3}	2.8×10^{3}
^{239}Pu	3.2×10^{2}	3.2×10^{2}	3.2×10^{2}
^{240}Pu	4.7×10^{2}	4.7×10^{2}	4.7×10^{2}
^{241}Pu	1.0×10^{5}	9.4×10^{4}	8.1×10^{4}
^{241}Am	8.4×10^{1}	4.0×10^{2}	8.0×10^{2}
^{244}Cm	2.2×10^{3}	2.1×10^{3}	1.8×10^{3}
Total Transuranium Products	3.8×10^{7}	1.0×10^{5}	8.7×10^{4}
Thermal Power (watts)			
	1.0×10^{6}	5.9×10^{3}	2.1×10^{3}

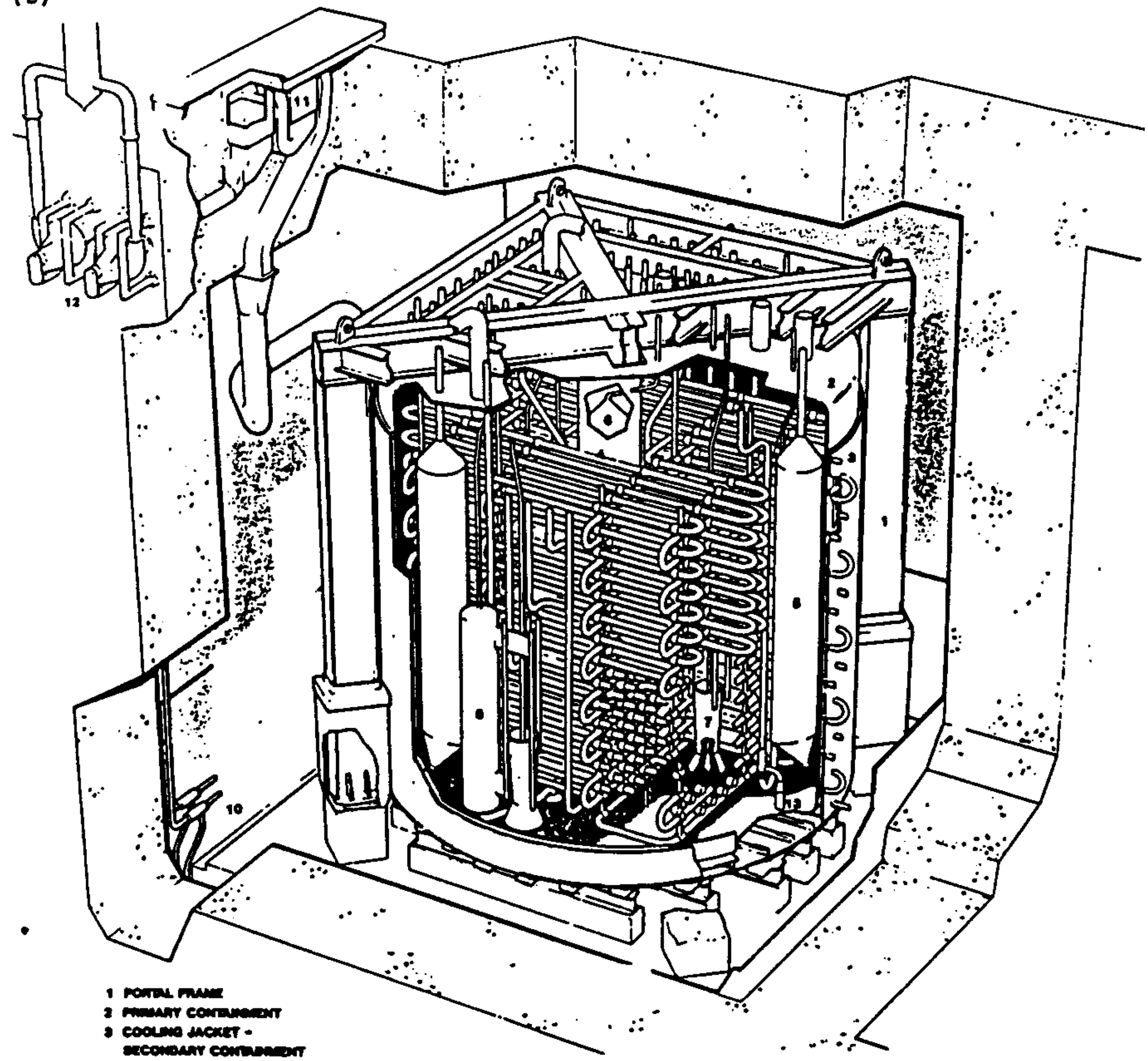
Source: (DOE 1980b).

[a]Calculated with the ORIGEN code for PWR fuel irradiated to 33,000 MWD/MTU at a specific power of 30 MW/MTU.

[b]Based upon 2.5 ppm nitrogen (by weight) in UO_2.

Figure 2.5 Metallic swarf stripped off Magnox fuel elements as a first step in reprocessing. Such fuel cladding debris can constitute one of the highest activity intermediate level waste streams. *Reproduced by permission of UKAEA*

(b)



1 PORTAL FRAME
2 PRIMARY CONTAINMENT
3 COOLING JACKET - SECONDARY CONTAINMENT
4 COOLING COILS
5 PERIPHERAL JET BALLAST
6 CENTRAL JET BALLAST
7 AIR LIFT RECIRCULATORS
8 FLUIDIC PUMP RESERVOIR
9 REVERSE FLOW DIVERTER
10 CELL SUMP EJECTORS
11 CELL EXTRACT FILTERS
12 CELL VENT EXTRACT FANS
13 INTERNAL HAST EMPTYING EJECTORS

Figure 2.4(b) Diagram of the internal equipment of a liquid high-level waste storage tank.
Reproduced by permission of British Nuclear Fuels plc

Decommissioning RW : 1 GW > 5000 - 15000 m3, options : dismantlement (5 y, 40 M$, 11700 m3), mothballing (6 M$ + 80 k$/y), encasement >10 m3/MW, 1 kCi/MW

Medical RW*: Tc-99m, I-123, In-111, I-125,Co-57, Yb-169 T>28 d, 14.6 m3, diagnostic (imaging - scintigrams, tumour detection) 12 M/y; H-3, C-14, P-32, S-35, I-125, 235 m3, research (in vitro radioassays 100 M/y) 50% of papers + 40 % of grants, WUMC 9 Ci/y ; Co-60, Y-90, P-32, I-125, Cs-137, Ir-192, 0.1 m3 therapy (injections, sealed sources) 400 k/y

RW inventories in the US* :

Radiotoxicity* : low, medium, high, effective half-life, type of emitter, energy, ingestion/

Laws and regulations : AEA 1946, NEPA 1969 (CEQ,EIS,EPA), ERA 1974 AEC=ERDA+NRC, EOA 1977 ERDA=DOE, LLWPA 1980, NWPA 1982 (0,1 C/KwH), LLRWPAA 1985, NWPAA 1987

Regulations on LLW : NRC 10 CFR P-61 classes: BRC, A, B, C (inadvertent intruder) , >C

TABLE 1-1 Summary of Radioactive Waste Inventories as of December 31, 198(

Waste Type	Volume (ft^3/m^3)	Activity (Ci)	Thermal Power (W)
	High-Level Waste (HLW)		
Defense	1.3(7)/3.7(5)[a]	1.4(6)	4.4(6)
Commercial	8.2(4)/2.3(3)	3.1(6)	9.1(3)
Spent fuel	2.1(5)/6.0(3) 1.4(4) metric tons heavy metal	1.6(10)	5.9(4)
	Transuranic Waste (TRU)		
Retrievably stored			
CH[b]	1.7(6)/4.9(4)	2.9(6) 1.8(3) kg	7.6(4)
RH[b]	4.8(4)/1.4(3)	4.7(5) 4.0(0) kg	4.5(3)
	Low-Level Waste (LLW)		
DOE sites	8.1(7)/2.3(6)	1.2(7)	1.7(4)
Commercial	4.3(7)/1.2(6)	4.6(6)	3.6(4)
Active	3.2(7)/9.0(5)		
Closed	1.2(7)/3.1(5)		
Remediation	3.3(6)/9.5(4)	Not available	
	Uranium Mill Tailings		
Active sites	3.6(9)/1.0(8)	Not available	
Remediation	3.7(7)/1.1(6)	Not available	
	Phosphogypsum Wastes		
Gypsum piles[c]	1.04(9) metric tons	Not available	

Source: DOE/RW-0006, Rev. 3, "Integrated Data Base for 1987: Spent Fuel and Radioactiv Inventories, Projections, and Characteristics," September 1987.

Table 4. **Low-Level Radioactive Waste Disposal Costs, Washington University, 1984**

Category	Method	Unit Cost	Annual Cc
Dry Solids	Burial	$1.00/lb	$ 59,000
	Incineration	$0.80/lb	1,000
Absorbed Liquids	Burial	$40.00/gal	228,000
Scintillation Vials and Contents	Burial	10.5 cents/vial	63,000
	Incineration	3.5 cents/vial	16,000
Animal Carcasses	Burial	$2.25/lb	14,000
			$ 381,000
		+ Labor Cost	28,000
		Total Annual Cost	$ 409,000

Table 5. **Forms of Low-Level Radioactive Waste, Washington University, 1984**

	Annual Quantity		
	Weight (lbs) (%)	Volume (ft^3) (%)	Activity (Ci)
Dry Solid	61,000 (28%)	2,200 (25%)	2.80 (30%)
Absorbed Liquid	71,000 (32%)	3,100 (35%)	5.80 (62%)
Scintillation Vials and Contents	78,000 (35%)	3,100 (35%)	0.31 (3%)
Animal Carcasses	11,000 (5%)	500 (6%)	0.47 (5%)
Total	221,000 (100%)	8,900 (100%)	9.38 (100%)

Toxicity of radioelements

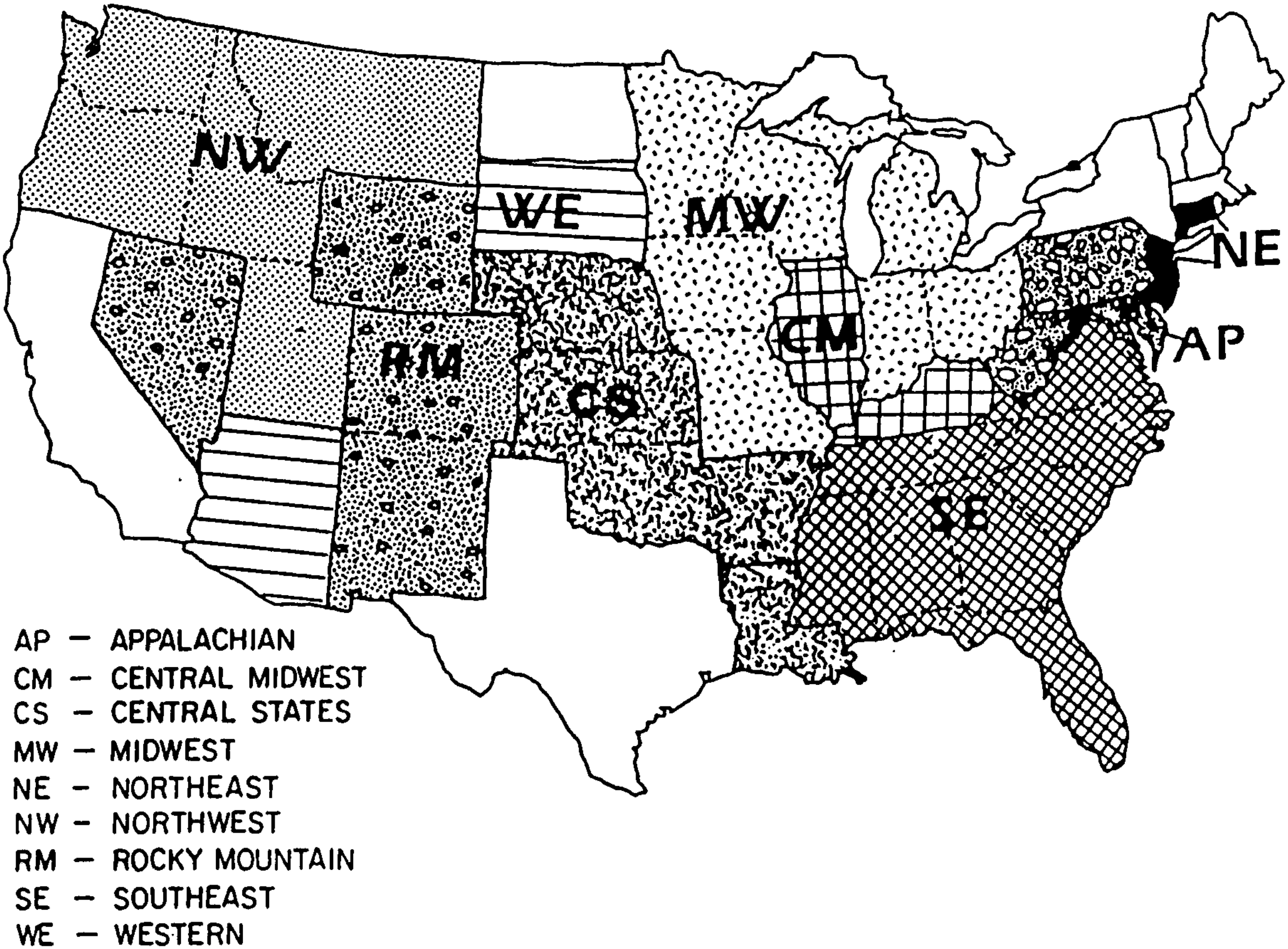
High
Pa-231, Cf-249, Th-Nat, Pu-239, Pu-240, Pu-242, Th-232, Pu-238, Ac-227, Th-230, Np-237, Th-228, Am-241, Am-243, Cm-243, Cm-245, Cm-246, Cf-250, Cf-252, Cm-244, U-232, Ra-226, Ra-228, Sm-147, U-Nat, Nd-147, U-238, Pu-241, Pb-210, U-230, U-233, U-234, U-235, U-236, Cm-242, Th-227, Po-210, Ra-223, Sr-90
Medium : group A
Ra-224, Pa-230, Bk-249, I-129, Eu-154, Ru-106, Ce-144, Bi-210, At-211, Na-22, Co-60, Ag-110m, I-126, I-131, Cs-134, Eu-152(13 ans), Cs-137, Bi-207, Pb-212, Ac-228, In-114m, Sb-124, Ta-182, Cl-36, Sc-46, Sb-125, Ir-192, Tl-204, Ca-45, Mn-54, Y-91, Zr-95, Sr-89, In-115, Cd-115m, Te-127m, Te-129m, I-133, Ba-440, Tb-160, Tm-170, Hf-181, Th-234.
Medium : group B
P-32, V-48, Fe-59, Co-58, Ni-63, Zn-65, Rb-86, Rb-87, Tc-99, Cd-109, Sn-113, Pm-147, Sm-151, Os-185, Hg-203, As-76, Y-90, Zr-97, Nb-95, Ru-103, Ag-105, Sn-125, Cs-135, Eu-155, Gd-153, Bi-212, K-42, As-74, Se-75, Sr-85, Nb-93m, Zr-93, Te-125m, Te-132, I-135, La-140, Tm-171, W-181, W-185, Na-24, Sc-48, Mn-52, Y-93, Tc-97m, Sb-122, Ce-141, Pr-142, Re-183, Ir-194, Bi-206, Ca-47, Co-57, Ga-72, Br-82, Cd-115, Te-131m, Cs-136, Pr-143, Ho-166, Re-188, Pa-233, Mo-99, Ce-143, Dy-166, Tc-96, Ag-111, I-132, Nd-147, Pm-149, Re-186, Au-198, Tl-202, S-35, Sr-91, Os-143, Zn-69m, As-73, As-77, Sr-92, Y-92, Tc-97, Pd-109, Ba-131, Sm-153, Eu-152(9h), Gd-159, Er-169, W-187, Os-191, Ir-190, Pt-193, Rn-220, Rn-222, Sc-47, Mn-56, Ni-59, Ni-65, Kr-87, Ru-105, Rh-105, I-134, Er-171, Yb-175, Lu-177, Re-187, Pt-191, Pt-197, Au-196, Np-239, Si-31, Fe-55, Pd-103, Te-127, Au-199, Hg-197m, Tl-200, Tl-201, Be-7, Ar-41, Cu-64, Hg-197, Th-231, Nd-149, Ru-97, In-115m, Pb-203, Cl-38, Dy-165, Cr-51, F-18, C-14, Kr-85m, Te-129, Xe-135, Cs-131.
Low
H-3, Zn-69, Ge-71, Nb-97, In-131m, Cs-134m, Pt-193m, Pt-197m, Tc-99m, Co-58m, Kr-83, Xe-133, Os-191m, Xe-131m, Y-91m, Sr-85m, Tc-96m, Rh-103m, Ar-37

boundaries = f(T, SA), H-3 40 Ci/m3 A-B, Cs-137 4600 Ci/m3 >C; site licence 20 - 30 y, monitoring 100 y, protection 500 y, interstate compacts*
Regulations on HLW : 10 CFR 60 : risk, safety, multiple barriers, performance objectives, geologic stability, population, ressources, retrivable for 50 y, inert waste, 300 y security, groundwater 1000 y, release < 0.001% of inventory, safety assessment , cumulative releases*
Environmental standards: EPA : 40 CFR, NRC, fuel cycle, public 25/75/25 mrems; 40 CFR 190 : air emissions (Ci) : Kr-85 50000, I-129 0.005, Pu-239 0.0005; 40 CFR 191 : groundwater (pCi/l) Ra 5; 40 CFR 192 : tailings Rn 20 pCi/m2, Ra 5 pCi/l; Bellow regulatory concern : CFR 30.14-30.19, 1 mcCi of Co-60 5 mcCi Cs-137, 0.05 pCi/g H-3 + C-14

Releases for 10,000 Years

Radionuclide	Release Limit per 1000 MTHM or Other Unit of Waste (Ci)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any α-emitting radionuclide with a half-life greater than 20 yr	100
Any other radionuclide with a half-life greater than 20 yr that does not emit α particles	1,000

Source: (EPA 1985).



Interstate compacts for low-level waste disposal. The states without shading have not joined a compact. (Courtesy of *Nuclear News*, American Nuclear Society.)