2nd Caesium Workshop:
Meeting challenges for Fukushima recovery

Fukushima, October 6th - October 9th, 2014

Managing large volumes of liquid waste

Wolfgang Kickmaier (MCM)

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Outline

- Management of large volumes of liquid waste overview
- Management of radioactive liquid radioactive waste
  - USA
  - Russia
- Direct release to sea – example of UK experience
- General findings and conclusions
- Liquid waste disposal - Options to be Evaluated: for discussion & expansion

Discussion: Lessons for Fukushima tritium management

Reserve & reference – not presented given the short time available

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Large Volumes of Liquid Waste

- Worldwide data on liquid waste produced / disposed / dispersed / discharged are not available - or reliable

BUT

- The volume and complexity of liquid wastes have increased exponentially during the last decades
- Beside liquid wastes from the oil industry, today all kinds of industrial and municipal hazardous (and radioactive) liquid wastes have to de disposed of
- International conventions (e.g. no sea dumping of rad waste) and national regulations offer opportunities for - or restrictions on - the management and disposal of liquid hazardous wastes

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Liquid Waste Management Options

- Dilution with non contaminated water and discharge
- Direct discharge into surface waters / rivers / seas
- Injection in shallow boreholes /"soakaway" in desert areas
- Injection in deep boreholes (with or without conditioning)
- Solidification and disposal
- Decay storage (for short lived radioactive liquid waste)
  - Open pond storage
  - Tank storage on the surface
  - Subsurface tank storage

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Mining and Liquid Waste

Uranium mines

- The production of 1 Gw year electricity results in 3.6M m^3 of liquid waste
- Liquid radioactive waste, in the absence of other management solutions, has to be stored in ponds at the surface or mixed with cement and injected as sludge

Olympic dam mine australia http://www.nuclear-heritage.net/index.php/Uranium_Mining

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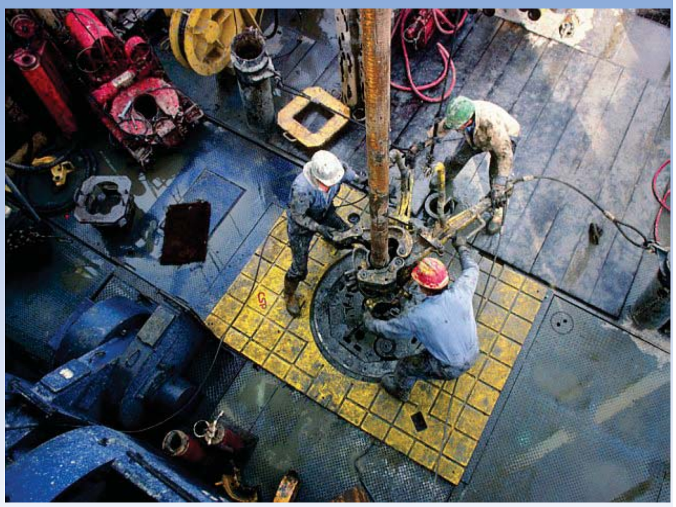
TENORM Waste - Oil Industry

- More than 18 billion barrels = (2.9 M m^3) of liquid/fluid waste are generated annually in the US from oil and gas production
- The radioactivity levels in produced waters are generally low but the volumes to be handled at each site are large
- Produced waste waters are:
  - re-injected into deep wells
  - discharged into non-potable coastal waters
  - discharged into lagoons or the sea



http://www.dailymail.co.uk/sciencetech/article-2163265/The-poison-beneath-How-toxic-waste-injection-wells-endangering-U-S-water-supply-years-come.html#p-6-1

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Well injection of hazardous waste:

USA

US – Well Classification

Class 1 HW: Most dangerous liquid waste, stringently regulated

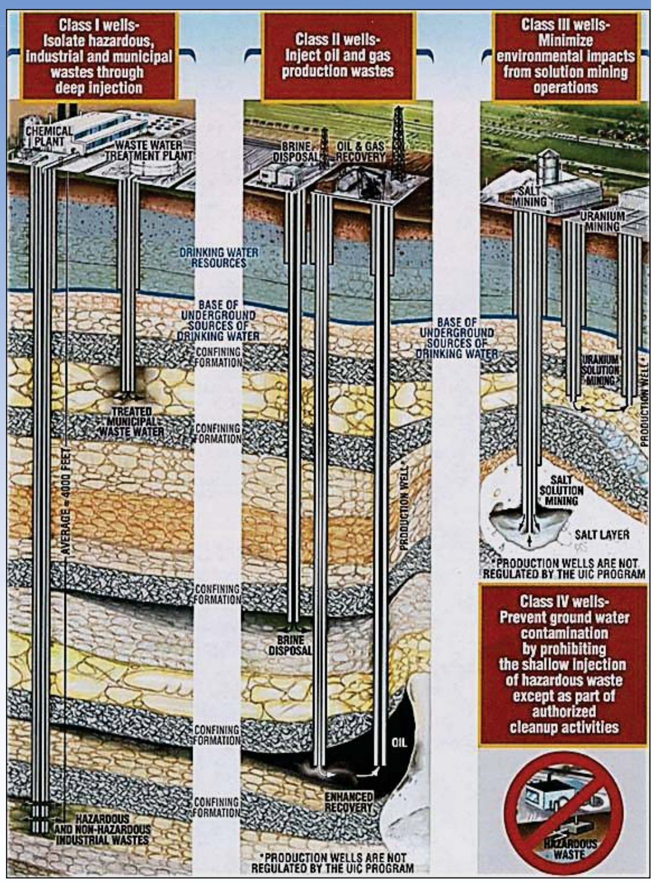
Class 1 Other: Waste from industry, oil and gas, some municipal waste. Generally less dangerous, defined by law as "non-hazardous"

Class 2: Enhanced recovery wells (oil and gas) and wells used for oil and gas-related waste

Class 3: Solution mining (e.g. salt/uranium)

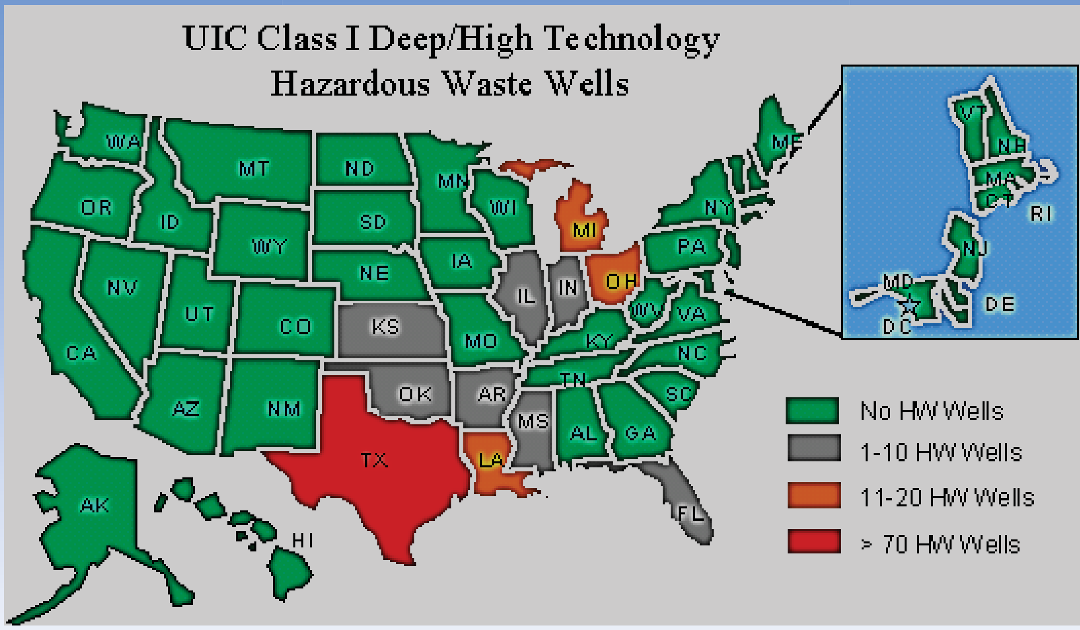
Class 4: Banned in 1984. Injection into shallow rock formations near to, or containing, drinking water aquifers
Some class 4 wells still exist as parts of government-run groundwater clean-up plans

Class 5: The catch-all category for almost everything else that is injected underground
Viewed by the EPA as a substantial risk to water supplies



http://water.epa.gov/type/groundwater/uic/wells_class1.cfm

Class 1 Wells



Most of the wells are located along the Gulf coast, the Great Lakes and Florida. Texas has 78 facilities and Louisiana has 18

In several States, Class 1 wells are banned

http://people.uwec.edu/piercech/HazwasteWebsSp04/DeepWellInjection/DeepWellInjection.htm

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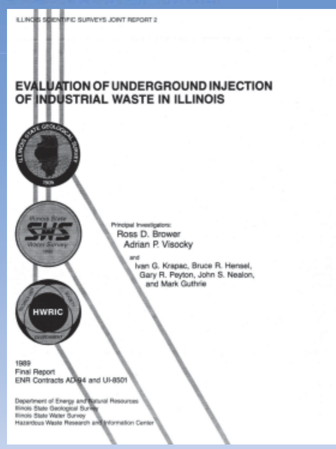
Evaluation of Underground Injection of Industrial Waste



- Alternative disposal options are available for most hazardous and non-hazardous waste components
- Each option has its own economic, environmental, and societal impacts, and each option poses some risks to public health and safety
- Deep well injection ranks among the least costly options and has a less severe impact on USDW and the surface environment than does the land burial option
- If contamination should occur detection and clean-up may be more difficult, costly, and uncertain than for contamination from surface or near-surface sources
- Banning deep well injection as such appears to be an inappropriate option in light of the increased risk resulting from disposal of some waste components in or near the surface environment

http://stateimpact.npr.org/texas/files/2012/03/IW.png

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The Opponents

- "In 10 to 100 years we are going to find out that most of our groundwater is polluted…The practice of injecting waste underground arose as "a solution" to an environmental crisis…"
- 1987 GAO reported 10 Class 1 cases in which waste migrated into underground aquifers; two were considered potential drinking water sources - 1989
  23 cases were reported where oil and gas injection wells failed
- In South Florida, 20 of the nation's most stringently regulated disposal wells failed in the 1990s, releasing sewage into aquifers that may one day be needed to supply Miami's drinking water
- Despite new regulations accidents keep cropping up from early 80th In late 2008, samples contain radium municipal drinking water
- In 2010, contaminants bubbled up in a west Los Angeles dog park.
- The GAO concluded that most of the contaminated aquifers could not be reclaimed because fixing the damage was "too costly" or "technically infeasible"

http://stateimpact.npr.org/pennsylvania/2014/02/page/2/

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Liquid Waste from Nuclear Installations:

Examples USA

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Hanford (tank storage)

- Hanford has accumulated a large fraction, both by activity and volume, of the HLW generated by the US defence programme
- Up to 1988, Hanford reprocessing operations generated about 2 M m^3 of liquid HLW, containing 1.5 x 10^7 TBq
- Wastes, often initially placed in storage tanks, were later removed and conditioned for disposal – including leakage to ground ("soakaway")
- Total remediation costs:
  FY 2013 $876,612,000

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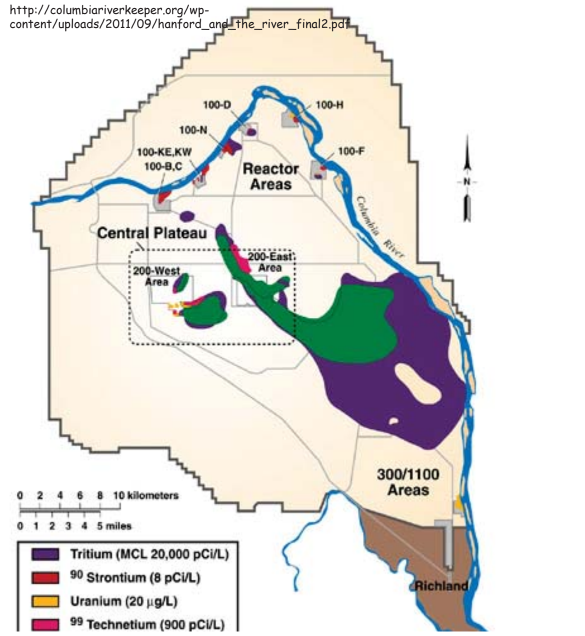
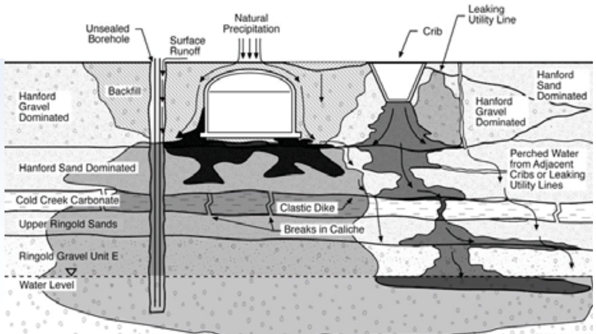
http://columbiariverkeeper.org/wp-content/uploads/2011/09/hanford_and_the_river_final2.pdf





http://essd.pnnl.gov/projects/project_description.asp?id=358

ORNL (slurry injection)

- IWL Liquid waste blended with cement / fly ash and other additives was injected in a shale formation at 240 m depth
- Hydrofracture facilities operated between 1964 and 1984
- E.g. between 1977 and 1979 a total of 1.2 million l of waste solution containing 81,780 Ci of radionuclides was injected
- Operation stopped in 1984 - potential leaching into groundwater

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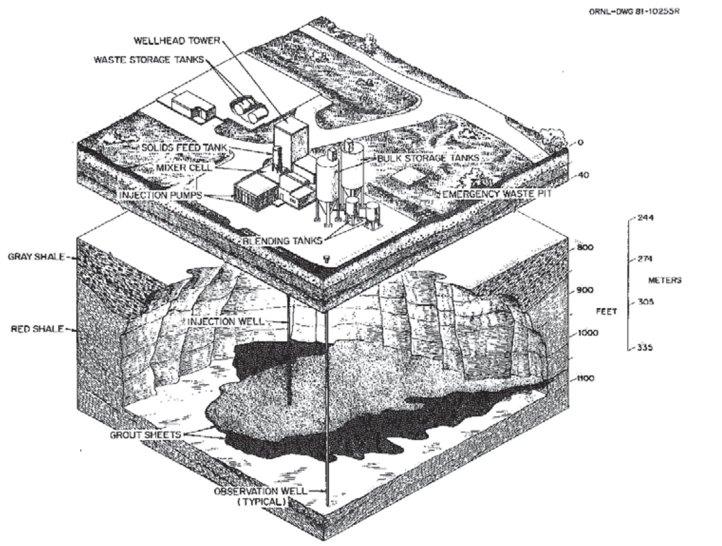
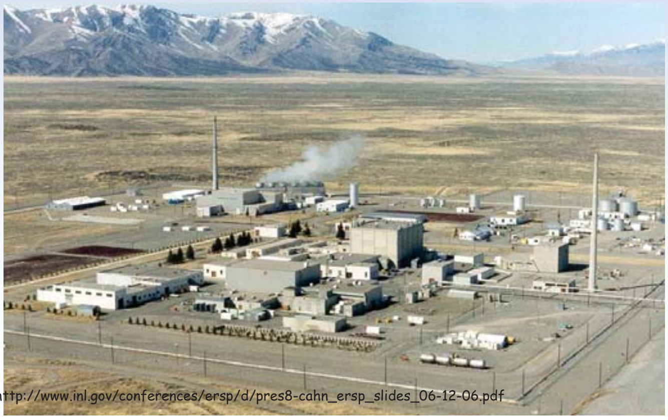


Injection	Date	Volume of waste (ℓ)	Volume of waste (gal)	Volume of grout (ℓ)	Volume of grout (gal)	Activity (Ci)
ILW-15	6-30-77	344,400	91,000	549,000	145,037	26,528
ILW-16	11-17-77	208,200	55,000	301,000	79,500	15,982
ILW-17	9-1-78	311,500	82,300	520,400	137,500	22,362
ILW-18	5-19-79	325,600	86,014	526,100	139,000	16,908
		1,189,700	314,314	1,896,500	501,037	81,780

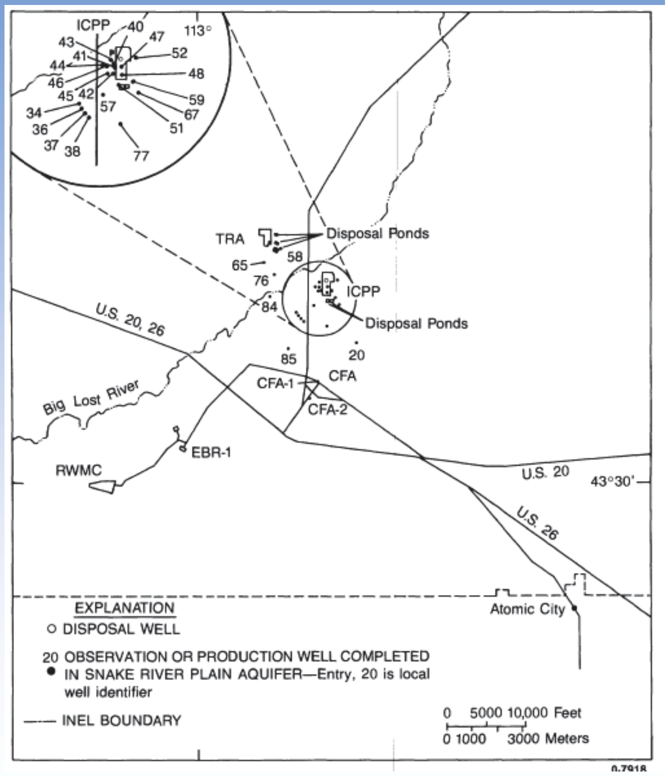
Idaho National Engineering Laboratory

(Tritium injections)

- Wastewater containing tritium was routinely injected into the Snake River Plain aquifer (177 m borehole) from 1953 to 1984
- Beginning 1984/85, wastewater was routinely disposed to infiltration ponds
- The Snake River Aquifer is of economic importance as used for the irrigations of farmlands



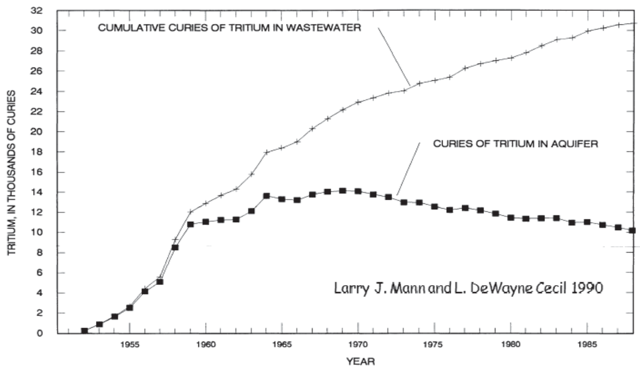
http://www.inl.gov/conferences/ersp/d/pres8-cahn_ersp_slides_06-12-06.pdf

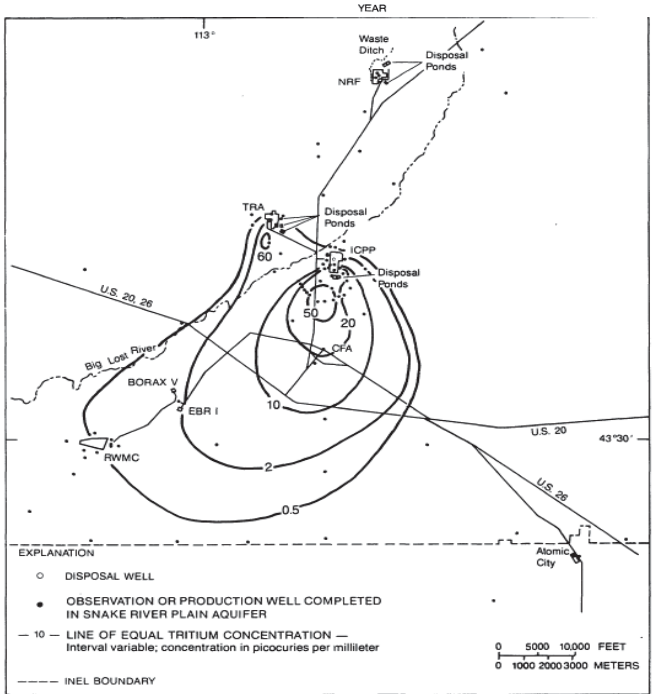


Larry J. Mann and L. DeWayne Cecil 1990

INEL

- Between 1952 and 1988, approx. 31 kCi of tritium were injected, an average of about 800 Ci/year (30 TBq)
- Given the half-life of tritium, the maximum estimated amount of tritium that could be in the aquifer is 15 kCi
- The average annual concentration of tritium from 26 wells decreased from 250 pCi/mL (10 kBq/l) in 1961 to 18 pCi/mL (660Bq/l) in 1988, or 93 percent
- In 1988, water from only one production well had with 27 pCi/mL (1 kBq/l), a tritium concentration exceeding the maximum contaminant level of 20 pCi/mL (740 Bq/l) set by the U.S. EPA





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Liquid Waste from Nuclear Installations:

Examples Russia

Russia: River and Lake Discharge

- Majak from 1948 to 1951, 78 M m^3 high level radioactive waste ($1{,}1 \cdot 10^{17}$ Bq) were discharged into the river: Since 1953, liquid HLW stored in tanks
- LLW and ILW waste are further discharged to the Karatschai-lake
- 12 M m^3 of the liquid waste have been injected in Krasnoyarsk-26

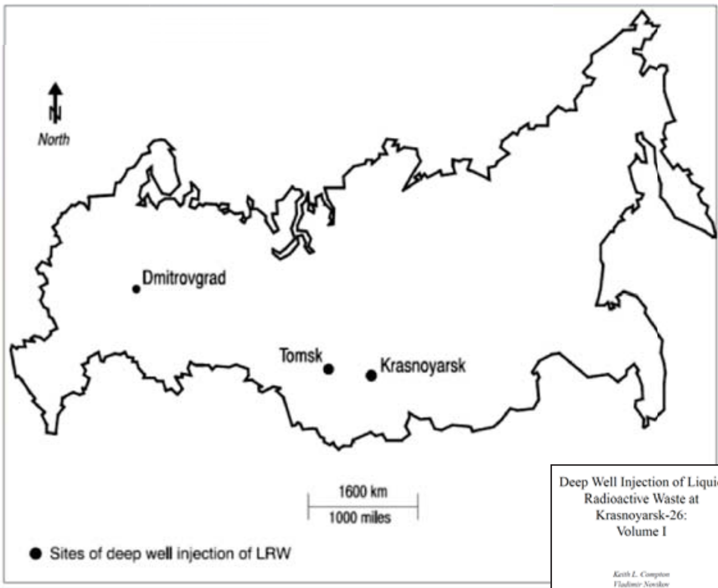
http://de.wikipedia.org/wiki/Kerntechnische_Anlage_Majak#mediaviewer/File:Majak_Satellitenkarte.jpg

TABLE 9. STATUS OF RADIOACTIVE WASTE FROM REPROCESSING IN THE RUSSIAN FEDERATION [16, 28]

	Industrial Association, Mayak (Ozersk)	Siberian Chemical Combine, Tomsk-7 (Seversk)	Mining & Chemical Combine, Krasnoyarsk-26 (Zheleznogorsk)
SOLID WASTE			
Volume (1000 m^3)	451	72	43
Activity (TBq)	1.1 E7	1.1 E3	not available
LIQUID WASTE			
High level			
Volume (1000 m^3)	30.7	not available	not available
Activity (TBq)	1.4 E7	not available	not available
Intermediate level			
Volume (1000 m^3)	220	188	138
Activity (TBq)	4.4 E6	4.6 E6	3.9 E6
Low level			
Volume (1000 m^3)	19,400	3000	not available
Activity (TBq)	5.2 E3	2.1 E7	not available
Underground disposal			
Volume (1000 m^3)	not available	7000	5000
Activity (TBq)		2.1 E7	1.1 E7

Well Injection - Three Sites

- In 1957, three sites were identified, Krasnoyarsk-26, Tomsk-7, and Dimitrovgrad
- Krasnoyarsk-26 and Tomsk- 7: injection into sandstone beds at depths up to 400 m
- At Dimitrovgrad: Sand- and limestone at a depth of 1400 m
- Injection of (L/ILW) is ongoing but efforts to solidify waste are now made



Deep Well Injection of Liquid Radioactive Waste at Krasnoyarsk-26: Volume I

TABLE 1. ESTIMATES OF INJECTED WASTE PROPERTIES AT KRASNOYARSK, DECAY CORRECTED TO 1 JANUARY 1995 [18] AND [17]

Type of waste / parameters	HLW	ILW	LLW
Volume of disposed waste, m^3	6.8×10^4	2.136×10^6	2.78×10^6
Total activity of the waste, Bq	4.2×10^{18}	5.4×10^{18}	5.7×10^{14}
pH	2-3	10-12	8-10
Salt content, g/L	250-350	30-350	1-30

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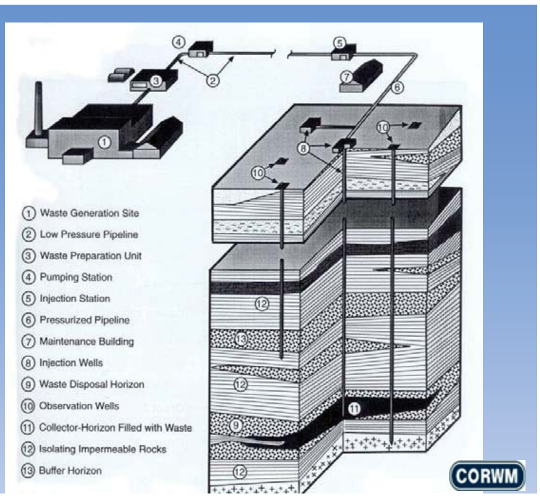
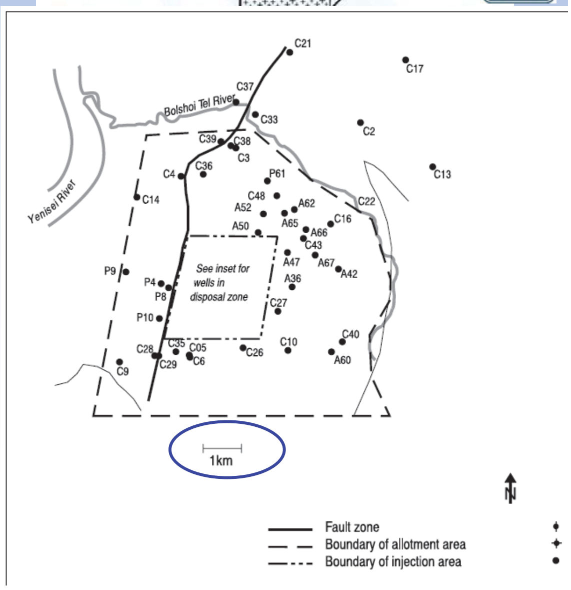
The Principle

- Surface installations pre-treatment facilities and dense monitoring system
- Site - operational areas and "Exclusion" areas
- Numerous boreholes: Injection, relief and monitoring boreholes
- Injection into sandstones or limestones with low or stagnant GW flow
- Injection layers confined by low permeable clay layers
- "Institutional controls" until contaminants will decay to permissible levels before reaching the site boundary"





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Conclusions

- " . . . Underground deep injection does not appear to present any major short-term risk of public exposure or of significant contamination of surface waters . . . because of the slow groundwater velocities, the degree of sorption expected, potential for groundwater dilution (Compton et al., 2000)
- For a time period of 1000 years, the geological and hydrogeological boundary conditions would assure confinement of injected radioactive wastes. This would certainly allow disposal of short-lived liquid ILW and LLW

But

Long institutional control periods and a closure concept are critical

And

The IAEA is critical of deep-well injection because the method "has no packaging or engineered barriers, and relies on the geology alone for safe isolation"

And

Not an acceptable option for Member States of the European Union

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Liquid Waste Discharge to Sea: example from UK

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Sea Discharge

Discharge routes

- Direct to coastal waters, estuaries
- Direct discharges to rivers and streams
- Through pipelines and sewers at industrial / nuclear sites

Discharge from ships / platforms etc. is now banned by national and international agreements / conventions

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Sellafield Sea Discharge

- Sellafield discharges are regulated by the Environmental Permit for Radioactive Substances (EPR 2010)
- Radioactive liquids arise from fuel reprocessing and storage operations; on-site decommissioning operations, and Sellafield Ltd laboratories
- Where practicable, the waste streams are now routed via the Medium Active Evaporator, or the Salt Evaporator, to interim decay storage pending treatment in the Enhanced Actinide Removal Plant (EARP) prior to discharge
- The remaining low-level liquid wastes are discharged to sea, after monitoring, via the Sellafield pipeline pipelines extending 2.5 km seaward

Key discharges to Irish Sea

- Mid-1970s:
  - 4000 TBq/y of caesium-137
  - 50 TBq/y of plutonium-alpha
- 2007:
  - 7 TBq/y of caesium-137
  - 0.1 TBq/y of plutonium-alpha

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Sellafield

- Discharges of radioactivity to sea have declined significantly since the 1970s
- These reductions in discharges have been effected by:
  - decommissioning older facilities and replacement
  - use of specific waste treatment plants
  - storage medium active waste - further treatment

Figure 1a : Historic liquid discharges from the Sellafield site (alpha discharges)

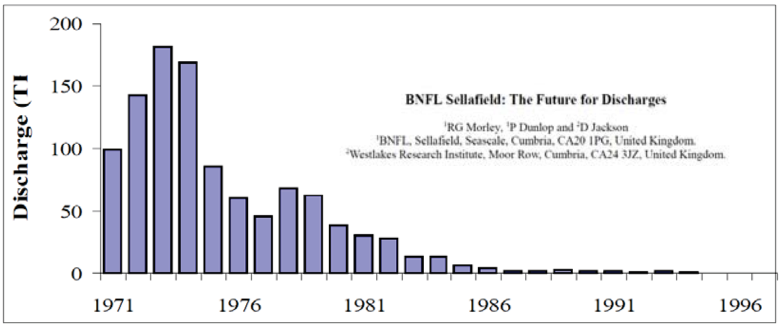
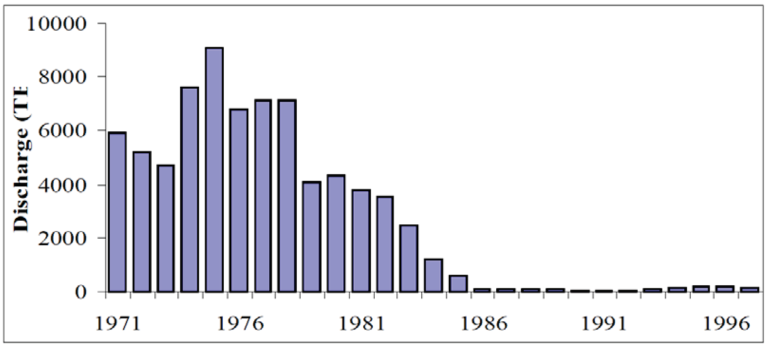


Figure 1b : Historic liquid discharges from the Sellafield site (beta activity)



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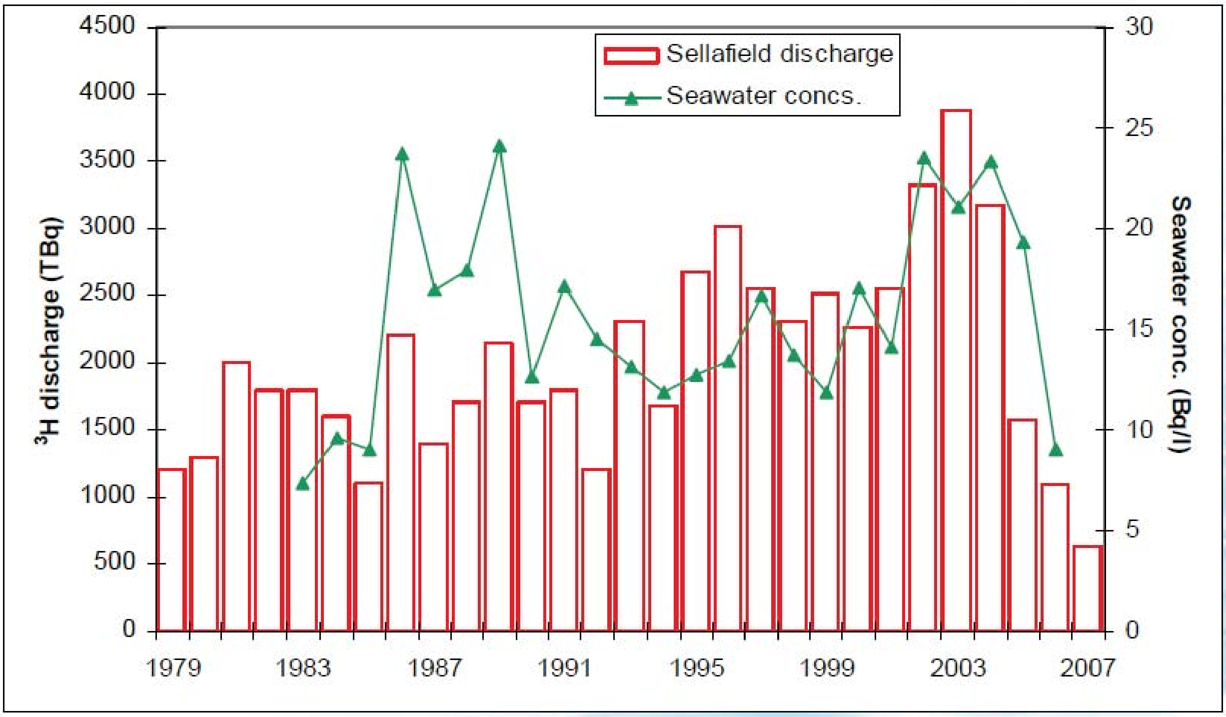
Sellafield – seawater

- Tritium discharges – relatively high - ~2000 TBq per year
- Mean seawater concentrations – ~10 – 20 Bq per litre



ww.sfrp.asso.fr/IMG/pdf/11-SJenkinson.pdf.

Release of Contaminated Water to the Sea

- Extremely high national and international profile
- Extreme sensitivity of local stakeholders
- Effective technical management is seriously constrained by political restriction of release of low contaminated water to sea
- Sea discharge properly managed and controlled has a low radiological impact but there are also uncertainties to be addressed
- Very sensitive in Japan, safety of release of such contaminated water may need to be communicated by using past experience – e.g. Sellafield releases into Irish Sea – What are the actual risks of sea discharge?
- What are the risks for alternative disposal routes?
- Such past experience also highlights potential concerns to be addressed

There is a common agreement that discharge of liquid radioactive waste has to be minimised
Radiological Protection Institute of Ireland concluded that:
"Doses resulting from operational discharges are low and, on the basis of current scientific understanding, do not pose a significant health risk at this time" but the potential risk of contamination which might occur as a result of accidents remains a cause for concern"

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Management of Liquid waste

General findings and first conclusions

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General Findings and Conclusions (1)

- Managing large volumes of liquid waste is a challenge for all producers: nuclear, non-nuclear industries, municipalities and R&D institutions
- The volume and complexity of liquid waste increased exponentially during the last decades
- Early solutions were often simple dumping on the surface, to rivers, water bodies and are now not acceptable to the scientific community regulatory bodies and the public
- The list of operational failures / accidents, unexpected behaviour of the discharged / disposed waste and operational failures resulting in major environmental impact is long – too long
- International and national regulations focus on waste minimisation, solidification and the application of best available techniques

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General Findings and Conclusions (2)

- Selected options must be consistent with national policies for waste management and need to consider interdependencies with other predisposal and final disposal options
- The complexity of the waste (rock water biosphere waste interactions) often does not allow a comprehensive risk and environmental impact assessment due to the lack of process understanding
- Site assessment and aquifer characterization are required to determine suitability of site for wastewater injection / releases
- Extensive assessments must be completed prior to receiving approval from regulatory authorities
- A well defined inventory of materials & radionuclide activity levels forms the basis of a transparent and structured disposal plan
- Several disposal options are available for most hazardous and non-hazardous waste components but
- Each option has its own economic, environmental, and societal impacts, and each option poses some risks to public health and safety

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General Findings and Conclusions (3)

- For hazardous waste, the US regulations state that:
  - the waste should not affect an underground water supply for 10,000 years or until the waste is not harmful (a couple of hundred years in the case of tritium)
- Specifically for radioactive contaminated liquid waste:
  - for land based disposal, a comprehensive site characterisation programme is needed (geology, geochemistry, hydrogeology, long term site evolution……)
  - for sea discharge a detailed assessment of e.g. the rate of input discharges, their chemical speciation in contact with seawater, the hydrographic conditions and their interactions with suspended particles, sediments and biota is a prerequisite for a licence and public acceptance
  - Both options are time consuming and resource intensive

General Findings and Conclusions (4)

- Regulatory guidelines will set priority on the protection of drinking water resources (land disposal → see footnote below)
- and the general protection of the marine environment for sea disposal (→ international conventions and opposition to be expected)
- The public worries when they receive mixed messages from the scientific community on the potential risks of managing liquid waste
- A transparent open discussion outlining all options, opportunities, uncertainties and risks is required

Japanese town uses regulations to protect groundwater from nuclear waste
Tochigi town passes water-protection ordinance to block nuclear waste plans
September 20, 2014

THE ASAHI SHIMBUN

A town in Tochigi Prefecture has found a novel way to block the construction of a final disposal site for radioactive waste from the 2011 Fukushima nuclear crisis by passing an ordinance that will protect its natural resources.
The ordinance, passed unanimously by the Shioya town assembly on Sept. 19, will protect an area that includes local springs, as well as mountain forest that was designated by the Environment Ministry as a candidate for the final disposal facility

General Findings and Conclusions (5)

- Near-surface sites were often perturbed within periods of decades
- Liquid / easily-leached waste migrated much further distances than expected (effects of complexation, colloids, microbes, …)
- Extensive remediation and / or very long periods of institutional control needed (…indefinite site exclusion) for several disposal routes
- Despite of significant discharges to the sea (Sellafield / La Hague and others), independent institutes concluded that the resulting radiation dose is unlikely to have had a detrimental effect on health.
- The regulators will asks for alternatives, but treatment (concentration and solidification) of contaminated water is often impracticable (large volume of waste) or impossible (especially for tritium)

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Management of Tritiated Water Options to be evaluated: for discussion / expansion

	Geological disposal				Sea discharge
	Tank Storage Surface and subsurface	Open Pond Storage	Well injection	Concentration / Solidification and geological disposal	Sea discharge (pipelines)
Technical feasibility / Technology available				Possible in principle	
Institutional control period	As long as the waste is hazardous	As long as the waste is hazardous	At least till borehole closure concept is licenced and implemented	Depending on the repository concept and licence	NA
Environmental impact (short term)	None - assuming no operational accidents and protection against surface impacts (floods, earthquakes, tsunamis)	High	None assuming no operational accidents	None	
Potential for environmental impact at the surface (long term)	Tank leakage - soil contamination	High			
Site characterisation	NA	?	A full site characterisation programme required	A full site characterisation programme required	NA but detailed assessments required
Geological constraints	NA	?	Limited to specific geologies	Wide range of geologies suitable	
Safety / Safety Assessment	Regular inspections and replacements required		Depending on the geol.-hydrogeol. boundary conditions - no EBS	Extensive international experience in long-term SA	Done for several major facilities
Confidence in SA	?	?	Difficult to prove		
Licencing / regulatory boundary conditions			Depending on national regulations	Depending on national regulations	
Remediation options	Possible	Possible	Almost impossible	Retrieval possible	Impossible
Acceptance		None	?		Difficult
Costs			Medium		
Time required for implementation			Licencing / Public Acceptance	Only need to assess Fukushima site	

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The End

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Thank You

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