Managing large volumes of liquid waste

Wolfgang Kickmaier (MCM)

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
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 be 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

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
Mining and Liquid Waste

Uranium mines

- The production of 1 Gw year electricity results in 3.6M m³ 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)

TENORM Waste - Oil Industry

- More than 18 billion barrels = (2.9 M m³) 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

![Produced waste waters](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)
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
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.

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.
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".

Liquid Waste from Nuclear Installations:
Examples USA
**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 m³ of liquid HLW, containing $1.5 \times 10^7$ 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

**ORNL (slurry injection)**

- IWL Liquid waste blended with cement / fly ash and other additives was injected in a shale formation at 240 m depth.
- 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.
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.

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 (660 Bq/l) in 1988, or 93 percent.

In 1988, water from only one production well had 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.
Liquid Waste from Nuclear Installations:

Examples Russia

Russia: River and Lake Discharge

- Majak from 1948 to 1951, 78 M m³ high level radioactive waste \((1.1 \cdot 10^{17} \text{ Bq})\) were discharged into the river: Since 1953, liquid HLW stored in tanks

- LLW and ILW waste are further discharged to the Karatschayi-lake

- 12 M m³ of the liquid waste have been injected in Krasnoyarsk-26

---

**TABLE 9**

<table>
<thead>
<tr>
<th>SOLID WASTE</th>
<th>Industrial Association, Marsch (Orekh)</th>
<th>Siberian Chemical Combine, Tomsk-7 (Orekh)</th>
<th>Mining &amp; Chemical Combine, Krasnoyarsk-26 (Zheleznogorski)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (1000 m³)</td>
<td>451</td>
<td>72</td>
<td>43</td>
</tr>
<tr>
<td>Activity (TBq)</td>
<td>1.1 E7</td>
<td>1.1 E7</td>
<td>not available</td>
</tr>
<tr>
<td><strong>LIQUID WASTE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (1000 m³)</td>
<td>30.7</td>
<td>not available</td>
<td>not available</td>
</tr>
<tr>
<td>Activity (TBq)</td>
<td>1.4 E7</td>
<td>not available</td>
<td>not available</td>
</tr>
<tr>
<td>Intermediate level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (1000 m³)</td>
<td>220</td>
<td>118</td>
<td>128</td>
</tr>
<tr>
<td>Activity (TBq)</td>
<td>4.4 E6</td>
<td>4.6 E6</td>
<td>3.9 E6</td>
</tr>
<tr>
<td>Law level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (1000 m³)</td>
<td>19,400</td>
<td>3000</td>
<td>not available</td>
</tr>
<tr>
<td>Activity (TBq)</td>
<td>5.2 E3</td>
<td>2.1 E7</td>
<td>not available</td>
</tr>
<tr>
<td>Underground disposal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (1000 m³)</td>
<td>not available</td>
<td>7000</td>
<td>5000</td>
</tr>
<tr>
<td>Activity (TBq)</td>
<td></td>
<td>2.1 E7</td>
<td>1.1 E7</td>
</tr>
</tbody>
</table>
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.

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

<table>
<thead>
<tr>
<th>Type of waste / parameters</th>
<th>HLW</th>
<th>ILW</th>
<th>LLW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of disposed waste, m³</td>
<td>6.8 x 10⁴</td>
<td>2.136 x 10⁶</td>
<td>2.78 x 10⁶</td>
</tr>
<tr>
<td>Total activity of the waste, Bq</td>
<td>4.2 x 10¹⁴</td>
<td>5.4 x 10¹⁴</td>
<td>5.7 x 10¹⁴</td>
</tr>
<tr>
<td>pH</td>
<td>2-3</td>
<td>10-12</td>
<td>8-10</td>
</tr>
<tr>
<td>Salt content, g/L</td>
<td>250-350</td>
<td>30-350</td>
<td>1-30</td>
</tr>
</tbody>
</table>

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.
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

Liquid Waste Discharge to Sea: example from UK
**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**

---

**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
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

Sellafield – seawater

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

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.
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

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)

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

<table>
<thead>
<tr>
<th>Geological disposal</th>
<th>Sea discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Storage</td>
<td>Sea discharge (pipelines)</td>
</tr>
<tr>
<td>Surface and subsurface</td>
<td></td>
</tr>
<tr>
<td>Open Pond Storage</td>
<td></td>
</tr>
<tr>
<td>Well injection</td>
<td></td>
</tr>
<tr>
<td>Concentration / Solidification and geological disposal</td>
<td></td>
</tr>
</tbody>
</table>

- **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, tsunami)
  - 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

- **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**
  - Possible
  - None
  - ?
  - Retrieval possible
  - Difficult

- **Costs**
  - Medium

- **Time required for implementation**
  - Licensing / Public Acceptance
  - Only need to assess Fukushima site
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 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”

The End

&

Thank You
References


EPA. Land disposal. www.epa.gov/osw/hazard/tsd/td/disposal.htm


References


References

- Radiation and Tritium Use at the NTLF. http://www2.lbl.gov/ehs/esg/tritium/tritium/TritCh2.html