# Terralog Technologies Inc
# PT Terralog Teknologi Indonesia

*Slurry Fracture Injection (SFI)*
*Zero Discharge Deep Well Disposal*

*Considerations for the*
*Fukushima Daiichi Nuclear Power Plant Site Clean-Up*

## Presentation Overview

- *Terralog Technologies Inc.*
- *Deep Well Disposal Concepts*
  - What is Slurry Fracture Injection (SFI)
  - Best Practices for Deep Well Disposal
  - Geology & Technical Aspects of SFI
  - Zero Discharge Operations
- *Field Cases*
  - SFI & NORM disposal
- *Disposal of Waste Streams – Summary*
- *Considerations for the Fukushima Daiichi Nuclear Power Plant Site Clean-Up*
- *Discussion*

## Introduction

- **Terralog Technologies Inc. ("TTI") is an international environmental services company headquartered in Calgary.**
  - TTI is a leader in clean-energy geomechanics & deep well disposal technology.
  - TTI has developed an innovative, long-term, large volume, sustainable fracturing process - Slurry Fracture Injection (SFI)
    - ✓ SFI with 'Process Control'
  - SFI is an advanced deep well disposal process
- **TTI's Slurry Fracture Injection ("SFI") process is a technology for environmentally sustainable resource management & waste management.**
- **SFI disposes of waste streams securely and permanently:**
  - SFI is a permanent Zero Discharge disposal solution for petroleum industry E&P waste, NORM and contaminated soils
  - SFI results in 'Zero Discharge E&P' operations
  - SFI is viable for many types of waste streams & applications
- **TTI is currently deploying its SFI technology with projects in USA, SE Asia and the Middle East.**

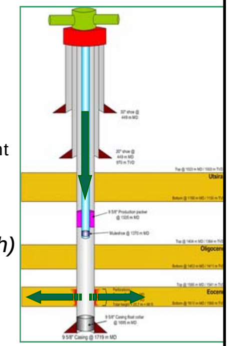

## SFI - Advanced Deep Well Disposal

- TTI's Slurry Fracture Injection ("SFI") is an Environmentally Sustainable HF technology. SFI is used as an advanced deep well disposal process:
  - Large volume of waste disposal (10,000+ m3/month)
  - Disposal of multiple wastes: contaminated soil, oily sludge, NORM, E&P wastes
  - Fast implementation allowing for rapid deployment and start-up
  - Environmentally sustainable disposal process - Zero Discharge waste management
  - Life-cycle cost effectiveness
- TTI is the leader in deep well disposal services, with the proven capability to provide the SFI process to clients worldwide.
- Significant environmental advantages for SFI as a waste management strategy:
  - Process Control systems to mitigate risks (OOZI, loss of wellbore integrity, groundwater impact)
  - Permanent disposal: no risk future environmental liabilities
  - Zero Discharge: no interaction of disposed waste with the surface biosphere
    - ✓ No ground water contamination, protects soil and air quality
  - Disposal operations do not impair surface lands &water resources
  - Cost effective and time effective waste disposal.
  - Safeguard public health by reducing & removing pollution

## Surface Disposal of E&P Wastes


## SFI Characteristics

- *Deep well disposal: granular/fines or viscous fluid waste streams*
  - Produced solids, granular fines, and oily sludge
  - These waste streams are slurried into a pumpable slurry
- Heavy slurry - Different 'slurry design' for different waste-types
  - 15-25% by volume waste concentration
  - 1.15-1.3 SG & FV < 60 sec
  - Waste water is the mix-water
- Hydraulic fracturing in 'soft rock' - Different strategies for different wastes
  - Injection rates and pressures ~> FER & FEP
  - Long-term, continuous - cyclic injection (cycle design is v. important)
- *Injection of large waste volumes (3,000 -17,000 $m^3$/month)*
- Deep geological sequestration (350-2000m) – 'Soft Rock'.
- Multiple waste streams
- Process Control for operational & environmental assurance
- *Excellent long-term security & Environmental Advantages*

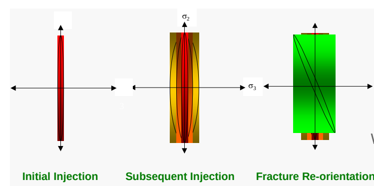


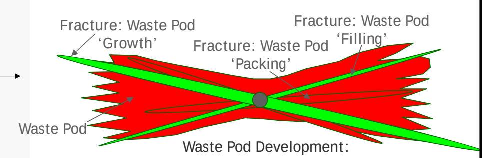
## SFI Disposal of Waste Streams

- **TTI's proprietary SFI technology provides its clients with its zero discharge solutions based on the following four 'Process Control' factors:**
  1. **Formation Containment.**
     - TTI's SFI process guarantees the integrity of containment of the disposed slurry.
  2. **Optimization Formation Response.**
     - Ensures optimum sustainable pressures and rates of injection
     - Dissipation of stress/pressure gradients.
  3. **Maximization of Storage Capacity.**
     - With strong backgrounds in geomechanics & reservoir engineering, TTI maximizes formation storage capacity.
  4. **Maintenance of Wellbore Integrity.**
     - TTI's SFI process also ensures mechanical and hydraulic integrity.

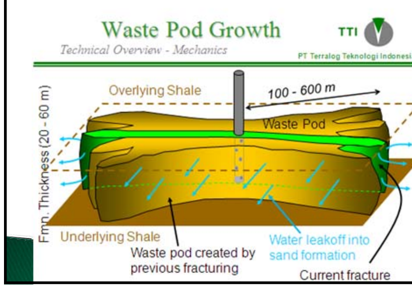

**TTI applies the science of geo-mechanics in providing customized, long-term & permanent waste disposal solutions to E&P companies ("Bottoms Up vs. Pump & Pray").**

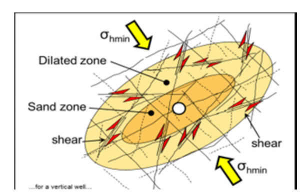
## SFI Characteristics: 'Soft-Rock' Geomechanics




Waste Pod Development:
Cumulative impact of solids/ waste placement, fluid flow, and fracture rotation is to create a waste pod'




Volumetric Dilation:
Differential pressure & stress changes cause shear displacement &volume enhancement

## SFI Characteristics: Daily SFI Cycle

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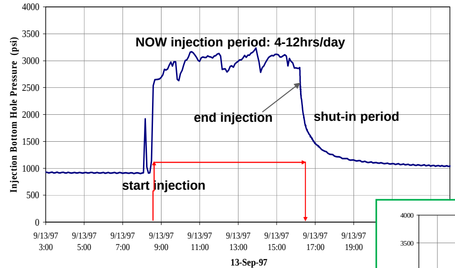
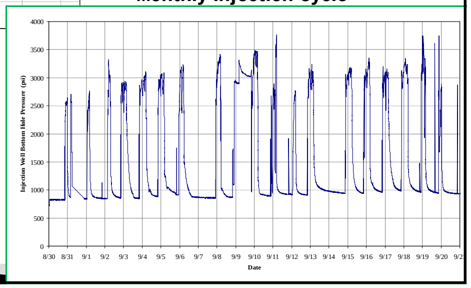
Daily Pressure vs. Time




Monthly Injection Cycle




## Formation Response to SFI

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*Need to 'Get it Right'*

- *Very powerful disposal process*
  - *Volumes/waste types/Zero Discharge*
- *Get it wrong....*
  - *Loss of formation injectivity*
  - *OOZI*
  - *Well bore plugging*
  - *Loss of wellbore integrity*

*Formation Response = f(slurry composition, operating strategy, lithology, stratigraphy)*

## Best Practices for Deep Well Disposal

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- **'Best Practices' implementation for SFI field operations...** *to 'get it right':*
  - Formation selection – geology considerations
  - Well design
  - Injection strategy
  - Process monitoring & process control
  - Operations management & technical support
  - Formation storage capacity & waste pod development

## Best Practices for Deep Well Disposal

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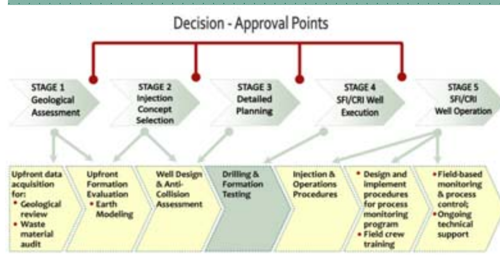
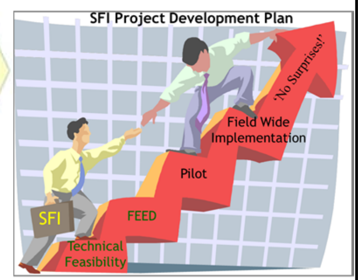



*Best Practices are essential for ensuring controlled & successful injection operations*

## Best Practices - SFI Project Development Structure

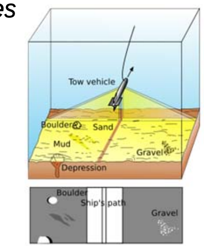
**TTI Project Development**

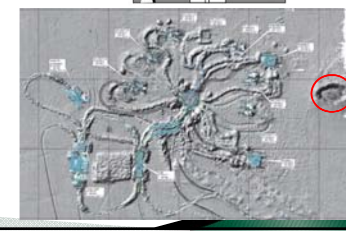
- **Phase 1 – Technical Feasibility Study (TFS)**
  - Geological Assessment
  - Waste Material Audit
  - Slurry Fracture Mechanics
  - Slurry Design
  - Disposal Well Design
  - Prelim SFI Project Design & Recommendations
  - Prelim SFI Project Estimates
- **Phase 2a – SFI Front End Engineering & Design (FEED)**
  - Field Site Assessment & Location Selection
  - Formation Testing
  - SFI Start-up, Operating Strategies & Emergency Procedures
  - SFI Process Control Monitoring Program
  - Final Process Design Specifications
  - Final SFI Facility Design
  - CAPEX & OPEX Cost Structure
  - Comprehensive SFI Project Implementation Schedule
- **Phase 2b – Regulatory Approval**
  - Identify Relevant Government Regulatory Agency
  - Comprehensive SFI Project Application
  - Liaison with Regulatory Agency & Address Concerns
  - Letter of Approval / Project Permit
- **Phase 3 – SFI Field Operations**
  - Entire SDU Equipment System
  - Field Operating Personnel
  - SFI Engineering Personnel & Technical Support
  - SFI Project Management Personnel & Project Management Support

## Best Practices to Reduce Risks

*'Best Practices' for Deep Well Disposal mitigates these risks:*

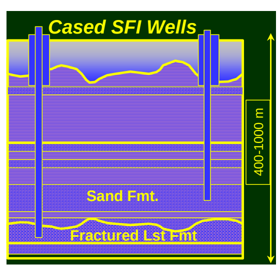
- **Out-Of- Zone-Injection (OOZI)**
  - Injected material breaking the permitted interval
  - Injected fluids to surface
    - ✓ effect on ground water resources
  - waste breaching to sea floor
    - ✓ offshore operations
- **Off-set well communication and leakage**
  - Due to cement or casing impairment
- **Breach of injection well integrity**
  - Due to cement or casing impairment
- **Injection well performance**
  - Formation backflow and well plugging



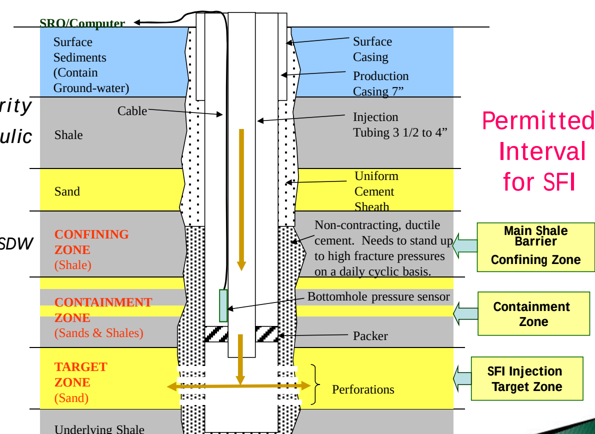
## SFI Geology - Best Practices

- Target Zone: main formation selected for injection-disposal operations
- Target Zone should be poorly consolidated and high permeability sand (Soft Rock)
- High compressibility
  - Formation yields easily to allow insertion of waste volume
- High permeability
  - Fluids drain off quickly preventing high pressures which can cause inadvertent fracturing or shearing
  - prevents damage to wellbore
  - reduced potential of uphole fluid migration
- In these types of formations the high in situ stresses and the high pressure bleed off capacity of the formation ensures the waste is permanently immobilized.




## SFI Well, Geology & HydroGeology
### Best Practices

- *Ensures wellbore integrity*
  - *Mechanical & hydraulic*
- *No surface and groundwater contamination.*
  - *Multiple barriers to USDW*
  - *Wellbore & geologic barriers*
- *Allows for wellbore monitoring & control*



# SFI Process Monitoring- Best Practices

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Process Monitoring of High Volume SFI Operations for Process Control:

- **Continuous Monitoring**
  - Daily Pump Reports (DPRs)
  - Bottom Hole Pressure
  - Wellhead Pressure
  - Casing Pressure
  - Slurry Density & Viscosity (FV)
  - Slurry Composition
  - Injection Rate & Volumes
  - Surface movements & fracture mapping
    - ✓ (tiltmeters)
- **Periodic Formation Testing**
  - Step Rate Test
  - Pressure Fall-Off Test (PFOT)
  - Temperature & Tracer Logs
- **Indicator Pressures**
  - Instant Shut-in Pressure (ISIP)
  - Average Injection Pressure
  - Minimum Shut-in Pressure
  - Closure Pressure

*Process Monitoring = Process Control = SFI to attain high efficiencies & mitigate risks in the field*

# SFI Process Control - Best Practices

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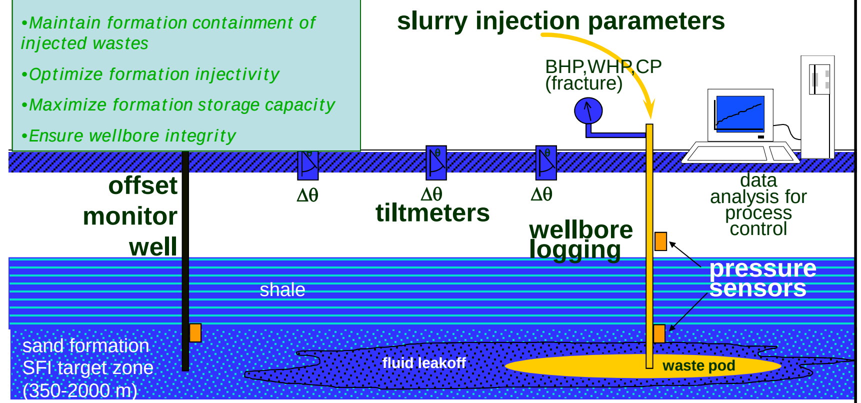
*Process Control*

*•Maintain formation containment of injected wastes*

*•Optimize formation injectivity*

*•Maximize formation storage capacity*

*•Ensure wellbore integrity*




*Assessment of formation response = SFI process control*

# Engineering Analyses – Early Warning

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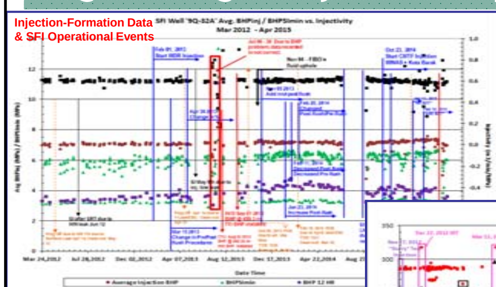
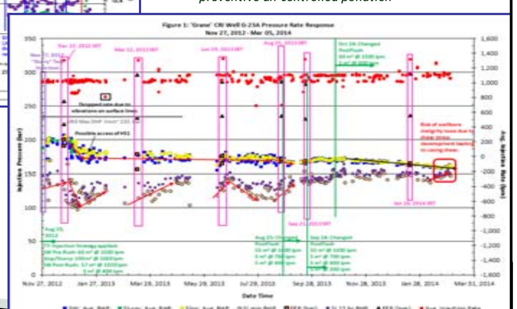



*Early Warning*

*' What are we looking for….? '*

- *Consistent change in formation response*
  - *Loss of formation injectivity (fluid flow system)*
  - *Change in Closure Pressure (geomechanic system)*
- *Wellbore plugging*
- *Loss of wellbore integrity*
- *OOZI*
  - *Prevent potential ground-water contamination or preventive un-controlled pollution*



# SFI Analyses – Waste Pod Development

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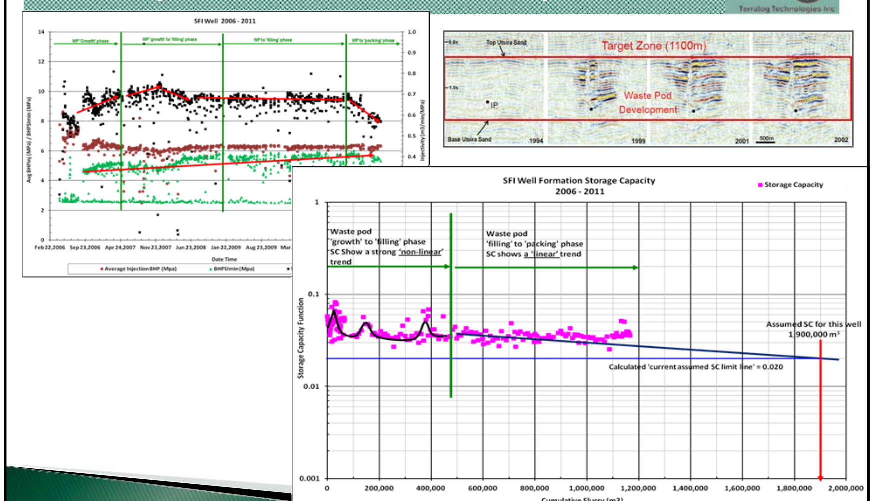
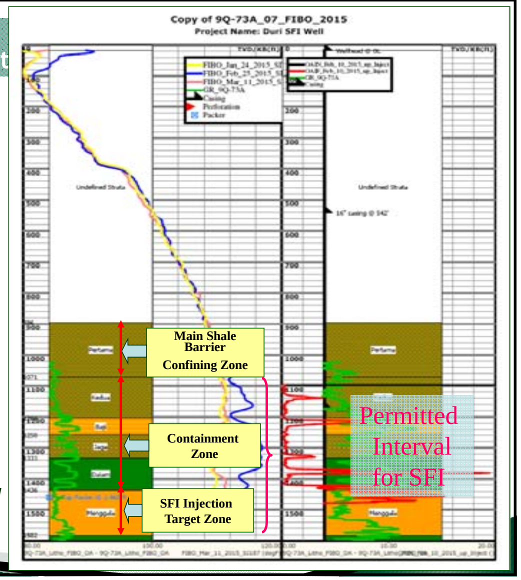


## SFI Data: Wellbore Integrity Assessment

- Wellbore integrity
  - Mechanical & hydraulic
- Assessment process
  - Engineering Plots
  - Temperature log
  - OA log
- Usually loss of cement
  - Very difficult to remediate.
  - Need to ensure good cementing program and cement job during well construction !!!

*DON'T save money on the well!!!*




## The SFI Solution

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*Slurry Fracture Injection is an ideal solution for permanent & zero discharge disposal of multiple waste streams*

**Petroleum Industry**

- ✓ Disposal of E&P wastes
- ✓ Drilling wastes
- ✓ Oilfield produced solids
- ✓ Oily viscous fluids/sludge
- ✓ NORM
- ✓ Tanks bottoms
- ✓ Contaminated soils

**Municipalities**

- ✓ Wastewater treatment sludge (i.e. Biosolids)
- ✓ Sulfur, fly ash, incinerator residue
- ✓ Industrial effluent, sludge
- ✓ Other waste streams
- ✓ Carbon sequestration (CCS)




## SFI Field Case #1: KSA - NORM

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**NORM Storage & Waste**
**30+ pCi/gm Radium 226/228 (1.5 Bq/gm)**

*5,000 m³ NORM was not pre-treated prior to injection*

## SFI Field Case #1 - NORM: PFD

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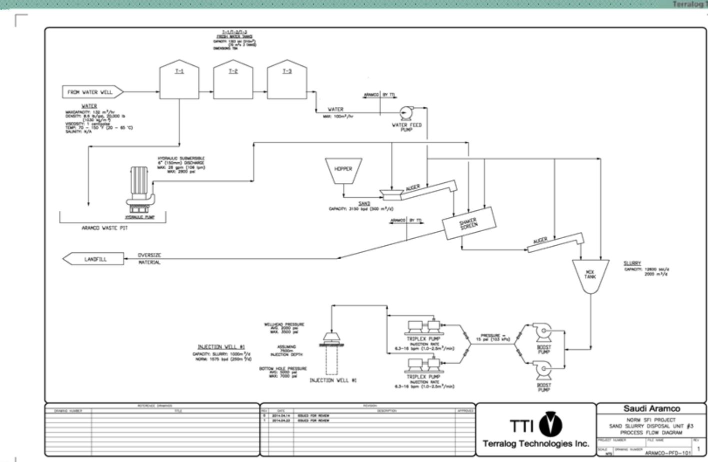


## SFI Field Case #1 – NORM: Project Site

## SFI Field Case #1 - NORM: Project Site

## SFI Field Case #2 - NORM

*Louisiana, Chevron Port Fourchon Project*

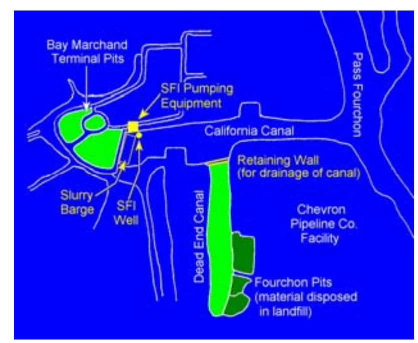
*(Summary from SPE 71434, 53821)*

- Port Fourchon, Bay Marchand terminal facility
- Processed oil from nearby offshore platforms since 1949
- Facility cleaned up 1997-2000:
  - NORM: Naturally occurring radioactive material
  - NOW: Non-hazardous oilfield waste
  - Processing pits: Contained drill cuttings, drilling mud, produced sand, pipe scale (barium/calcium precipitate), oily wastes
  - Canal: Sediments were contaminated by overflows from processing pits

## SFI Field Case #2 - NORM


**Location of Port Fourchon**

**Fourchon Site Map**



## SFI Field Case #2 - NORM

NORM:

- Contamination level
  - Maximum ~ 110 pCi/gm Radium 226 (4.1 Bq/gm)
  - Average ~ 40 pCi/gm Radium 226 (1.5 Bq/gm)
  - U238 and Th 234/Ra 228
- Area
  - Bay Marchand Terminal: Pits #1, #2, #3 and some land area
  - storage pits for drill cuttings, spent drilling fluids, oily waste, pipe scale, etc
- Depth of contamination
  - Maximum ~ 12 ft ( 3.6 meters)
  - Average ~ 8 ft ( 2.4 meters)

## SFI Field Case #2 - NORM

*SFI Project – Site Remediation*


....Before

....During

After....

Final closure criteria:

- upper 15cm soil < 7 pCi/g $Ra^{226/228}$
- below 15cm soil ~17pCi/g $Ra^{226/228}$
- unrestricted land use permitted

## SFI Field Case #2 - NORM

| Location | Waste Volume (bbls) |
|---|---|
| Bay Marchand Pits (Oct 1997 – Sept 1998) | 371,600 |
| Dead End Canal (Feb 1999 – Mar 2000) | 623,100 |
| Other NOW Solids | 6,120 |
| Total | 1,000,800 |

**(160,000 $m^3$)**

## SFI Field Case - Alberta HO Production

## SFI Field Case #3 - Indonesia


## SFI Field Case: Indonesia

- PT Terralog Teknologi Indonesia (PT TTI) has been working in Duri, Indonesia for 14 years to dispose of oily sludge & drilling waste from heavy oil production operations.
- SFI disposal operations are integrated with oil production operations.

SFI Facility
Duri Oilfield
Indonesia


Terralog's Deep Well Disposal Best Practices adopted by the operator.

## SFI Field Case - Indonesia

- Duri SFI Project has disposed of oily sludge & drilling waste from oil production operations (December 2002 – June 2017):
  - ~ 1.6 million m³ (10.1 million bbls)
  - ~ 5.9 million m³ (37 million bbls) produced water
- July 2003: SFI achieves Zero Discharge of E&P wastes into the environment



In 2016 Terralog achieved 5,000 days 'Incident & Injury Free'(IIF) and Zero MVA

## Risks…..

The most common risks/problems effecting overall performance of SFI projects are:

- Loss of wellbore integrity during injection operations.
  - Typically related to poor cementing of the disposal-injection well above the disposal zone.
    - ✓ loss of hydraulic integrity
  - Injection well collapse/shear above injection formation
    - ✓ loss of mechanical integrity
- Inter-well communication
  - Hydraulic communication between injection well and offset well (s)
    - ✓ containment breach due to intersecting nearby poorly cemented wells
  - Potential for OOZI
- Poor well design wrt the waste type, waste volumes to be injected and disposal zone geology.
  - This factor can results in wellbore plugging and poor formation injectivity.
  - Potential for wellbore integrity problems & OOZI
  - DON'T 'Save' money on the well…..!!!
- Poor geological characterization of the injection zone and target zones.
- Poor (or no) integration of geological assessment, well design, slurry design & injection strategy

*Poor integration = poor performance…guaranteed !!!*

# Risk Mitigation

1. Use 'Best Practices' Workflow.
   - Integration of geology, waste stream, well design, slurry design, & injection strategy
2. Key Process Monitoring Tools:
   - BHP monitoring at injection well
     - ✓ Pump Pressure and WHP are NOT enough
     - ✓ Assess formation response to injection operations
     - ✓ Formation Testing
       - Evaluate formation flow behavior and in-situ stress:
       - SRT to assess stress state & FEP/FER
       - Pressure Fall-off Analyses
   - Tracer & Temperature Logs
     - ✓ Evaluate near-well fluid flow & wellbore integrity
3. Process Control….always!!!
   - ✓ Maintaining fracture/waste pod containment
   - ✓ Optimizing formation response ( injectivity & leak-off)
   - ✓ Maximizing formation storage capacity
   - ✓ Ensure wellbore integrity

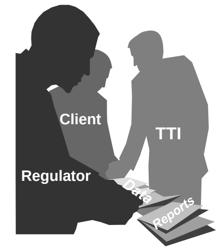

*Integration of monitoring data = tracking of injected material in situ & formation response.*

*No P&P*

# Risk Mitigation

Ground Water Protection:

- Geological evaluation and selection
  - ✓ Proper selection of Target, Containment & Confining Zones
- Disposal well design & performance
  - ✓ Multiple barriers to uphole fluid movements
  - ✓ Verify wellbore integrity
- SFI ops must continually monitor (Process Monitoring):
  - ✓ Formation geomechanics & fluid flow response
  - ✓ Slurry design & injection strategy
  - ✓ Wellbore mechanics/performance
  - ✓ Surface injection operations
- Process Control….always
  - ✓ Maintaining fracture/waste pod containment
  - ✓ Optimizing formation injectivity
  - ✓ Maximizing formation storage capacity
  - ✓ Ensure wellbore integrity




# SFI Disposal of Waste Streams

Environmental Benefits of SFI

- SFI achieves 'Zero Discharge' of wastes
  - ✓ No negative biosphere interaction
  - ✓ protection of USDW, soil quality , air quality
  - ✓ prevents surface water and ground water contamination
- Does not impair future land use
  - ✓ Protects environmentally sensitive areas
- Acceptable to society & community
  - ✓ reduces pollution to safeguard human health
- Safe and secure disposal approach
  - ✓ NORM wastes are safely sequestered
  - ✓ multiple waste stream disposal
- Efficient & economical waste management strategy
- Permanent & secure disposal is best!
  - ✓ long-term liability to operator/generator is greatly reduced

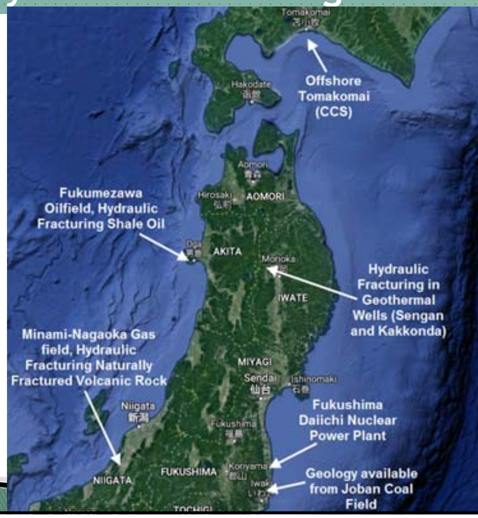
*To help Clients achieve Zero Discharge Operations….*

*…Greater environmental security with SFI*

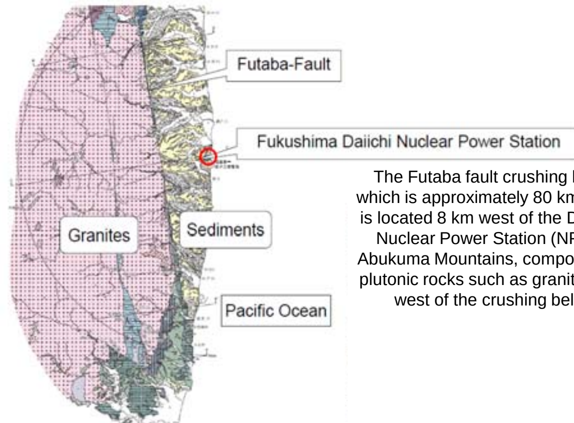
# Japan Geology Overview

- **Complex Geology:**
  - Japan is in a subduction zone, sits on top 4 tectonic plates and is in an active crustal movement zone.
  - It is in a zone of active seismicity, active faults, and active volcanoes.
  - However there are many records of hydraulic fracturing events, as well as geomechanics data.
- **Some of Japan's Hydraulic Fracturing Applications:**
  - Hydraulic fracturing operations in geothermal fields including Nigorikawa, Kakkonda, and Sengan.
  - Multi-stage fracturing for stimulation of naturally fractured volcanic rock in Minami-Nagaoka Gas Field.
  - Tight shale oil stimulation in Fukumezawa oil field in Akita in 2014-2017.
  - No environmental issues were reported.
- **Carbon Capture & Storage (CCS):**
  - The Minami-Nagaoka gas field, 10,400 tonnes of $CO_2$ injected in saline aquifer.
  - Offshore Tomakomai has suitable geology & is a candidate for CCS.

# Japan Hydraulic Fracturing & CCS



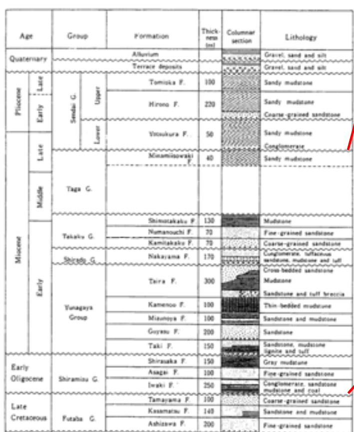

# Geological Map



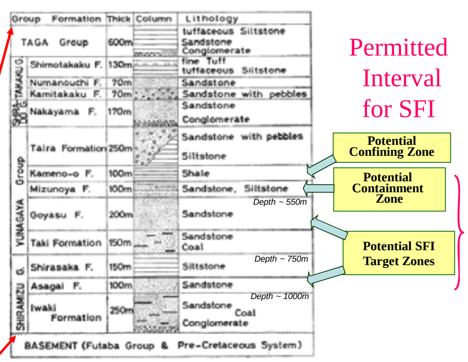

The Futaba fault crushing belt, which is approximately 80 km long, is located 8 km west of the Daiichi Nuclear Power Station (NPS). Abukuma Mountains, composed of plutonic rocks such as granite, are west of the crushing belt.

Source: Atsunao Marui, *Geomorphology & geology around the Fukushima Daiichi NPS*

# Fukushima Stratigraphy (Joban Coalfield Data)



Source: *Yanagisawa, et. al., 1989*




Source: *Sugai, Matsui, 1957*

# SFI & Fukushima (1)

- **SFI is well-understood, safe, and suitable for …**
  - Water/liquids, fine grained solids, sludge containing radionuclides:
    - Step 1: Demonstration project for disposal of liquid waste streams
    - Step 2: Finely ground solids with low levels - after the liquid wastes are shown to be injectable safely
  - A high degree of containment and safety certainty can be achieved by:
    - TFS- FEED: Proper choice of the number of wells, the monitoring systems (wells, sensors)…Best Practices for Project Development.
    - Process Monitoring & Process Control: A staged, well-monitored process starting with demo project for liquid injection & technical review.
    - Batch injection: Start each waste stream with small batches, in order to assure the design parameters, then larger batches of injection
    - Controlled Injection: Contaminated liquid injection in a "continuous" mode
      - Then, consideration of small batches of low solids content slurry interspersed between liquid injection
    - Progressive development approach: Never moving to the next stage without confidence based on the on-going stages and data collection and analyses.
      - Technical Committee Oversight – from Stakeholders

## SFI & Fukushima (2)

- **The sedimentary basin is favorable because of…**
  - Suitable layered sand/shale strata leading to lateral flow, not vertical flow.
    - Sediments are ductile, especially the high-porosity clayey strata, not susceptible to brittle fracture
    - Any "down-to-the-sea" listric faults are likely sealing faults
  - High gradients that are "to the sea" because of the proximity of the hills to the west that give high elevation recharge .
  - Presence of significant storage capacity because of good porosity in the potential disposal zones
    - The large pore volumes, accompanied by high rock compressibility, mean that the system has capacity to take and store slurried wastes streams.
  - Relatively strong deep regional flow in the easterly direction (seaward).
    - Natural flow dispersion and dilution help the process, always reducing the concentration along the flow path
    - The liquids are retained in the sediments for many kilometers eastward, the deep waters do not interact with the shallow groundwater systems
    - The efflux is under the ocean
  - Extensive presence of clays and adsorptive minerals are found throughout the sedimentary column.
    - These adsorb radioactive cations very effectively
    - The volume of adsorbent minerals is very large, so adsorption capacity is high
    - Radioactive dissolved constituents are immobilized and retained at depth where they can decay safely…and any radioactive species that has not been adsorbed will decay or be diluted to almost background conditions over time
    - The cations are adsorbed permanently, the release of any significant quantity of the adsorbed cations is geochemically unlikely.

## SFI & Fukushima (3)

- **Induced Seismicity** – What is the chance of increasing the risk of large-scale seismicity?
  - Pressures will be shown to dissipate rapidly so there is minimal risk of large-scale pressurization & stress development of the sediments.
  - There are likely no additional "loads" (stresses) being placed on the dangerous distant fault lines
    - The dangerous fault lines are many kilometers distant and deep, so the injection activity is not capable of interacting with the seismic sources
  - There is likely no significant seismicity arising in the soft ductile sediments of the sedimentary wedge in front of Fukushima Daiichi.
  - The stimulated rock volume that SFI is affecting will be small in relationship to faulting and to the volume of sediments in the sedimentary basin .
  - The sediments into which injection would take place are ductile .
    - Sediments cannot store strain energy in sufficient amounts to generate appreciable levels of seismicity
- The geological, hydrogeological, geomechanics, and geophysics conditions of the Fukushima project are likely suitable for the SFI process to be tested & implemented.
  - Need to follow SFI project development Best Practices & Stakeholder technical support to verify

## SFI & Fukushima (4)

- **Considerations for moving forward:**
  - Verify that SFI deep well disposal is 'conceptually viable' under the conditions at Fukushima.
  - SFI can be done as safely as required by any regulator .
  - TTI has the expertise…. +20 years of SFI project design and field experience.
    - Important to ensure Best Practices for positive outcomes
  - SFI must be done with all of the monitoring tools and management tools that TTI has developed over decades of advanced deep well disposal field operations.
  - TTI can work with project stakeholders to design a facility that will be safe in all aspects.
  - Process monitoring can be implemented to the degree required…
    - Extensive arrays of monitor wellbores, upstream and downstream
    - Microseismic array
    - Individual injection wellbores are installed with pressure and temperature monitoring systems
    - All aspects of the surface activities are fully monitored by flow meters, radioactivity sensors, vibration devices, T, P, density, etc. - can be easily implemented to increase the level of containment assurance
  - High safety level training and QA/QC system for all workers is important for handling Fukushima waste streams and for SFI operations.
    - TTI has a very strong record in terms of QHSE standards for SFI operations

## Terralog Technologies Inc
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**Thank-you for your attention**

**Mr. Roman Bilak, President**

**Terralog Technologies Inc. (TTI)**