In Situ Radio Frequency Heating: The Hottest New Thing?

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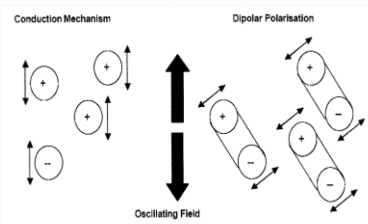
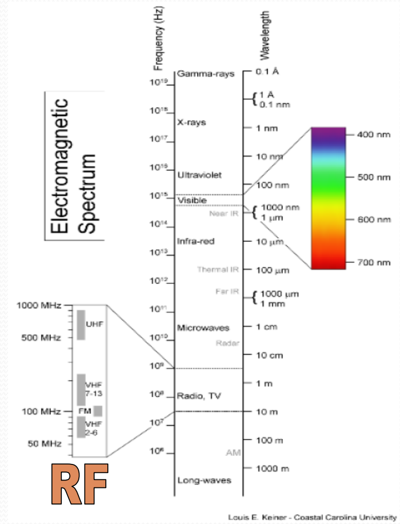
Overview

- What is Radio Frequency Heating (RFH)?
- Why and how is RF applied to in situ thermal remediation?
- For what sites and contaminants may RFH be appropriate?
- What are the limitations and costs of RFH?
- Case Study - TCA DNAPL Abatement in Fractured Bedrock

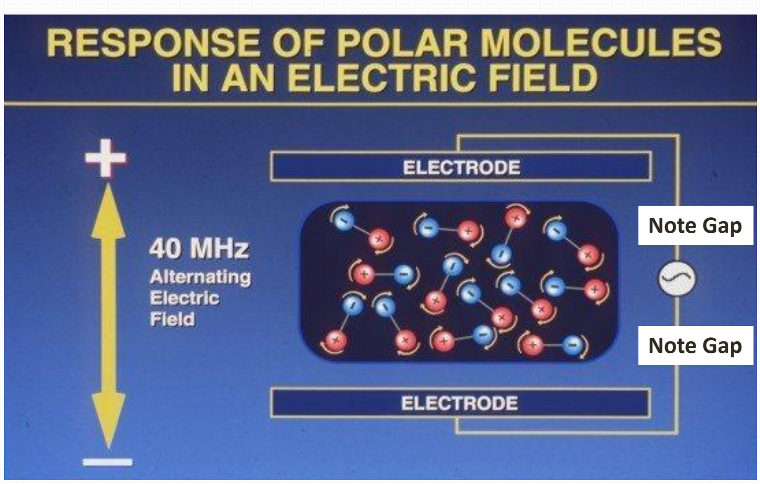
What is RFH?

- Radio wave = type of electromagnetic radiation
- RFH is generated by propagation of radio waves at 30-300MHz
- RFH is heat generated at a molecular level due to a "rubbing effect" similar to a microwave oven, but at lower frequency





The Rubbing Effect = Heat



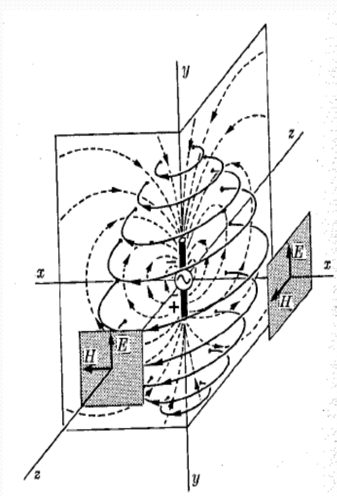
Source: http://www.radiofrequency.com/rftech.html

Is RFH the hottest new thing?

- It certainly is **hot (Temps up to 400 °C)**
- "Innovative" or "new" as a remedial technology
- Is a well established technology:
  - The use of high-frequency electric fields for heating dielectric materials had been proposed in the **1930s**. For example, US patent 2,147,689 (application by **Bell Telephone Laboratories**, dated 1937)
  - De-infestation of food stocks (grains, flour, walnuts)
  - Medical applications (muscle relaxation, control bleeding, medical waste sterilization)
  - Industrial drying of inks, paper, yarns, biscuits, crackers and other food products

Source: (http://en.wikipedia.org/wiki/Dielectric_heating

Why Use RF for in In Situ Thermal Remediation?



- RF energy propagates through all media (solid, liquid and gas) over a volume = heats evenly and quickly over relatively large volume
- The distribution of RF energy is not limited by structural features, permeability or heterogeneity of the host (overburden or bedrock)
- RF energy preferentially heats the target = polar molecules such as water, oil, contaminants over the host (OB and rock)

For What Applications/Contaminants May RFH Be Appropriate?

Thermally Degrade 40 – 60 °C Hydrolysis, Enhance Bio. CVOCs, BTEX
Reduce Viscosity 40 – 100 °C Enhance Liquid Recovery LNAPL, Oils, Coal Tar
Volatilize/Desorb 100 to 250 °C En. Vapor/Liquid Rec. BTEX, CVOCs, PCBs
Stabilize/Destroy 250 to 400 °C SVOCs, Coal Tar

- RF energy can be directionally focused, tuned in frequency and power to achieve spatial and thermal control for a full range of low to high temperature thermal applications (Bio, Abiotic, SVE, DPE, NAPL recovery)
- RF energy can be applied in dry soil or below the water table from the surface to depth, vertically or horizontally
- RFH systems can be operated beneath buildings, around utilities and configured to operate at active facilities with minimal surface expression or interference to site operations

RFH System Components

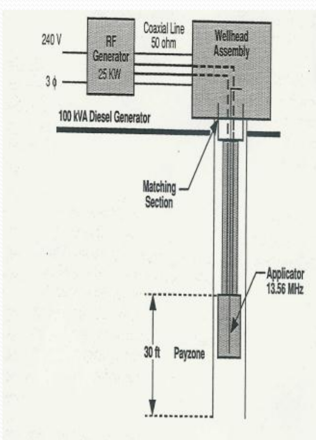
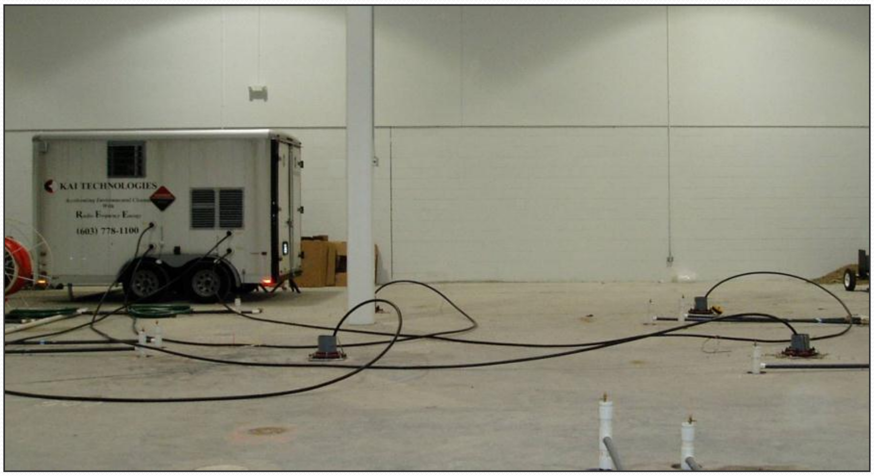


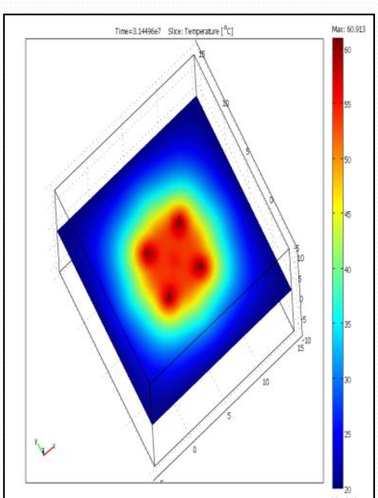
FIG. 4 · Radio frequency heater and system.

- **RF Generator** – Grid or Gen Set Powered – 25 to 500 kW
- **Antenna Array**– Single antenna range from 3 to 100+ meters, deployed in vertical or horizontal wells - spacing may vary from to 3 to 15 meters
- **Conventional Coaxial Transmission Lines** – rigid, flexible, commercially available

How is RFH applied?



RFH System Design & Operation



- **Engineer Design** based on computer modeling of target, host and cleanup objectives
- **Treatability Testing** of site samples to determine heating rates, loss tangent and time to reach target temperature
- **Construction, Start-up, O&M** – 4 to 8 weeks construction and start-up

General Cost Range for In Situ RFH

- Costs are very site/application specific
- Cost data per unit volume is determined based on application – to date- limited number of remedial applications limit cost data
- General low end of cost range = $100 to $150 per cubic yard (RFH only, excluding investigation, drilling, monitoring, etc.)- may be higher
- Cost are scaled to project needs and available resources – JR Technologies LLC maximizes existing consultant/client resources to reduce cost

RFH Limitations/Considerations

- **Innovative** - limited performance data - preference for "proven" technologies
- **Limited availability**- No known US vendors other than JR Technologies LLC in Great Barrington, MA
- **Customization** - RFH generators and transmission cables are "off-the-shelf" components- antenna are customized for the specific application
- **Safety**- operation is within FCC Guidelines
- **Control of Vapor Phase** – often a necessary element

RFH Case Study

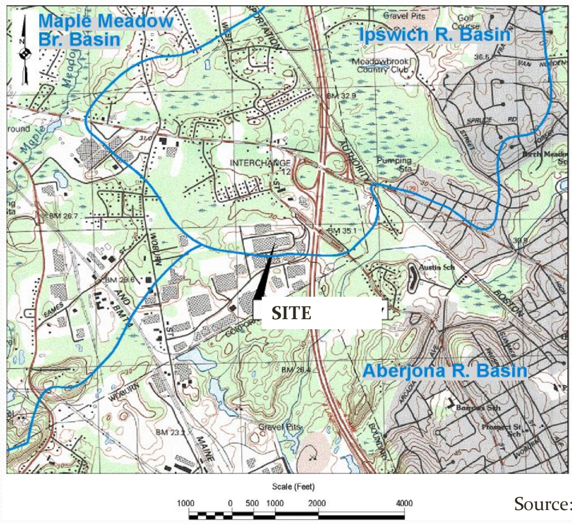
RFH of TCA DNAPL Source Area - Fractured Bedrock- 2003-2011

Link to Federal Remediation Technologies Roundtable Website:
http://costperformance.org/profile.cfm?ID=438&CaseID=436

RFH of TCA DNAPL In Fractured Crystalline Bedrock

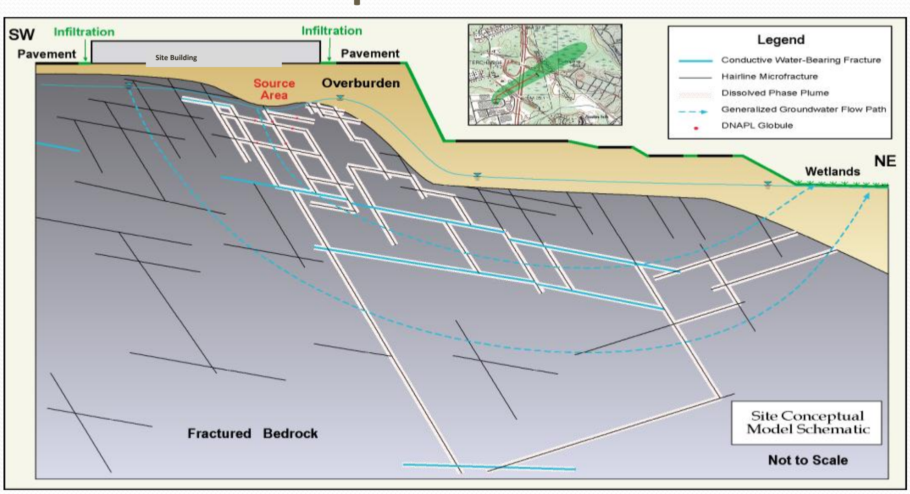
- Printed circuit board manufacturing operation from 1960s to late 1990s
- 1998 discovered a release of 1,1,1-trichloroethane (TCA) beneath building
- Regulated under **M**assachusetts **C**ontingency **P**lan
- Facility decommissioned – all sources removed
- Degreasing operations, TCA storage tanks, piping and acid neutralization tanks probable sources
- Zone II – Drinking Water Source Area down-gradient

Site Locus



Source: USGS Quad.

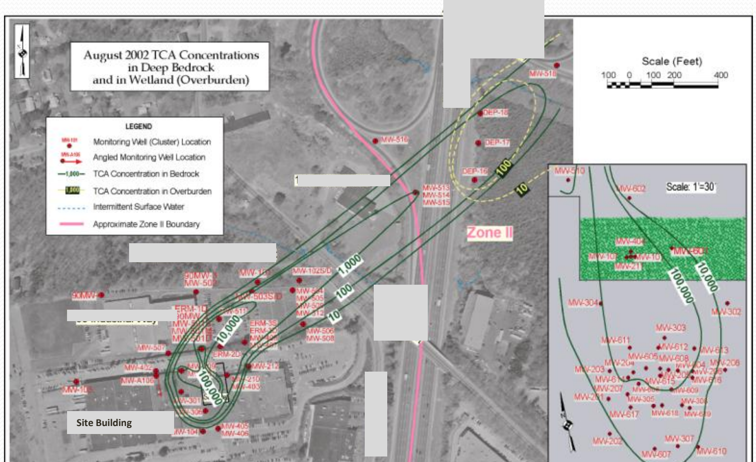
Conceptual Site Model



Systematic Characterization 1999 - 2002
Outside-In/Top-Down

- Lineament Analysis – Fracture Trends in Bedrock
- Seismic & VLF Geophysical Surveys – Well Selection
- Drilling by Coring & Air Rotary
- Five Geophysical Borehole Logs to Identify water-bearing fractures
- 38 Discrete Interval/Packer Tests of Chemistry & Flow
- Hydraulic Testing- 24 Slug, 4 Step & 3 Pump
- 102 Wells – Conventional, Open & Flute Multiport
- DNAPL Identification Using Hydrophobic borehole liners in 75% of source area wells

TCA Concentrations Pre-Treatment August 2002



Remedial Program – Key Considerations

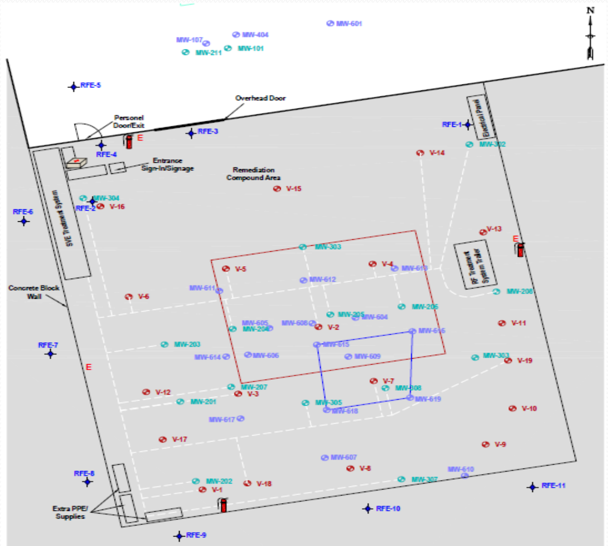
- ISCO Pilot 2000 – Fenton's Reagent – Reduction but Rebound
- TCA DNAPL identified w/ Flute Liners – 9 of 12 SA Wells
- Remedial success = f(TCA DNAPL abatement)
- Goal = Source Abatement – Not MCLs
- DNAPL as residual ganglia– not pooled, recoverable or mobile
- Bedrock (gneiss) fractures poorly connected, low yield (<0.5 gpm) = push-pull technologies ineffective
- SA beneath building/pavement – at edge of basin divide = limited flushing
- TCA half-life~ 3 years at 20°C is reduced to days at 50-60°C
- Resistive heating cost prohibitive, steam limited by structure

WHY RFH Was A Good Match For Site Characteristics

- RF propagates over volume- overcomes structural limitations of low yield, poorly connected bedrock
- RF preferentially heats the target (polar molecules) verses the host (bedrock)
- TCA half-life is days at 50-60°C = low temp. thermal
- TCA degrades by hydrolysis → DCE + acetic acid (vinegar)
- Building & Basin Divide → Reduced flushing, easier to heat target
- Occupied Building – Control vapor w/SVE and SSDS & operate RF Exposure w/in FCC TLVs

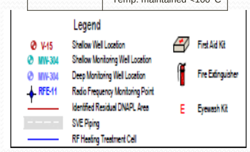
Selected Remedy = Source abatement by RFH/SVE & MNA down-gradient

RFH/SVE Engineering Design – Plan View

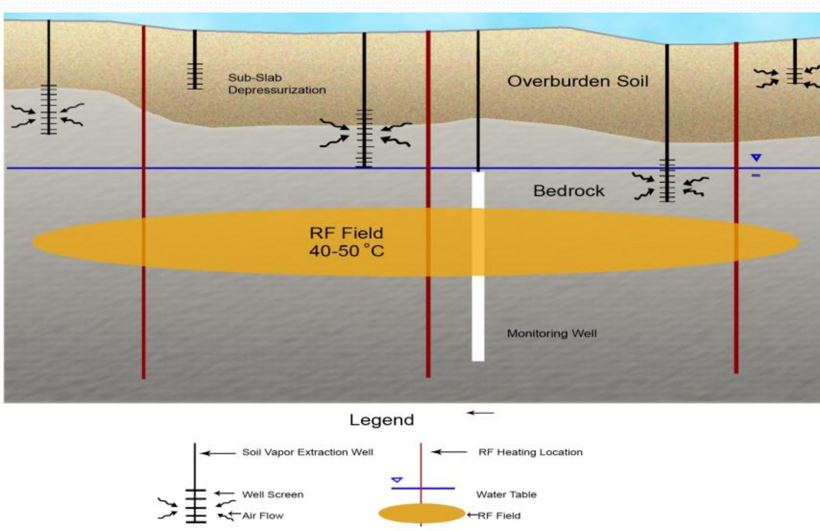


Target DNAPL Area = 750 ft²
Depth 30 to 80 feet
4 Antenna Per 15 x 15 ft. Cell
3 Treatment Cells / X Lifts/Cell

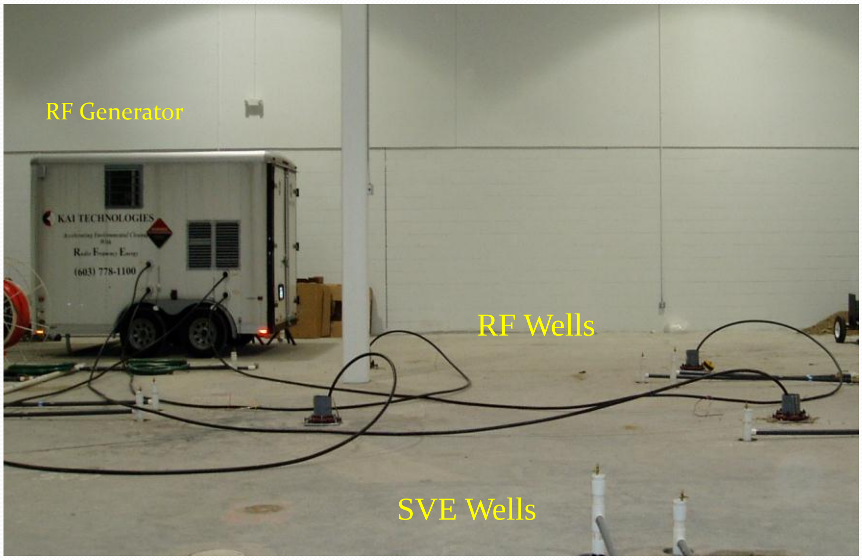
RF Field	
Frequency	27.12 MHz
Power	~ 3.5 kW / antenna ~20kW System
Antennae	
Arrangement	3 square array cells
Distance	~ 6 m
Length	4 m
Diameter	6.5 cm
Wells	
SVE	Screened between top of bedrock (11) & 0.5 m bgs
RF Antennae	Open borehole 30 m deep – 25 cm Ø Temp. maintained <100°C



RFH/SVE Engineering Design – Cross-Section



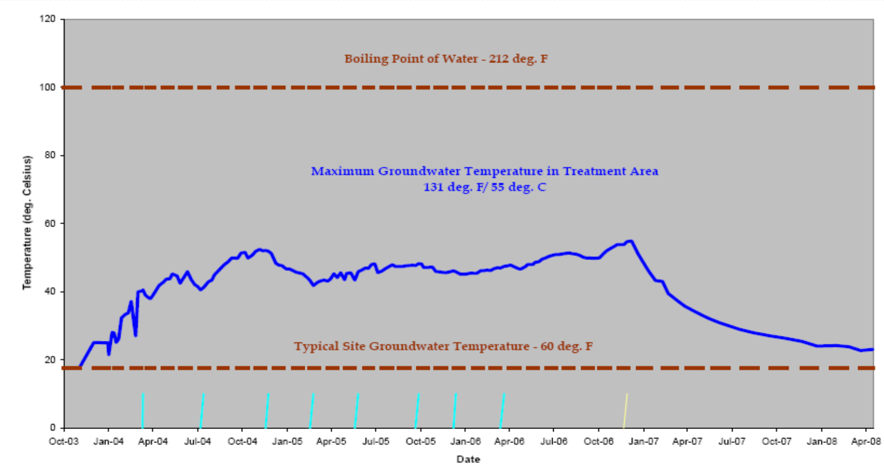
RFH/SVE System



Results

- 2003-2006 RFH/SVE operated safely and largely remotely for 36 months
- No VOCs in building/No RF above FCC TLVs
- SVE Removed 145 lbs. VOCs
- Achieved 52°C maximum temp.
- Cost \$100-\$150 RFH only – does not include investigation, drilling, SVE, or monitoring costs

Groundwater Temperatures

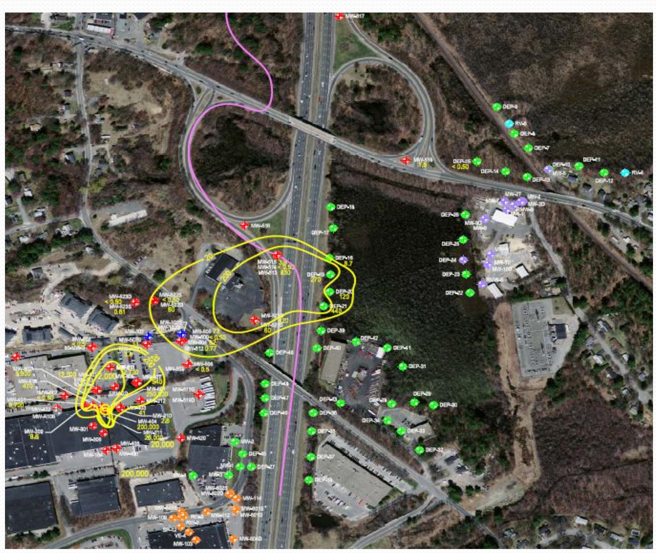


Results

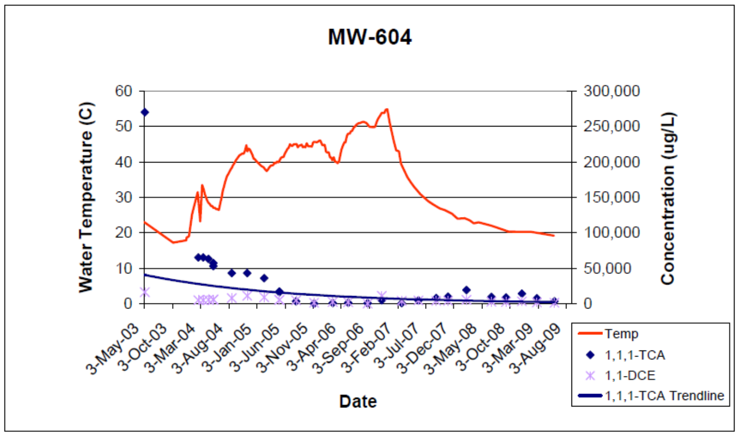
- Five years (2007- 2011) of post-treatment monitoring:
  - Head and Tail of Plume Detached
  - **99%** Avg. Decrease in TCA **Treatment Area** (221,000 ug/L to 2,300 ug/L)
  - **92%** Avg. Decrease in TCA **Down-gradient** (23,000 ug/L to 2,000 ug/L)
  - **67%** Avg. Decrease TCA in **Zone II** (900 ug/L to 300 ug/L)
  - VOCs reduced to ND in SW & SED in GW discharge areas

Pre-Treatment May 2003

Post-Treatment June 2008



Temperature & TCA Trend in Source Area



Thank You!

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