

Bionuclear Approaches for Unilateral Monitoring

**AFOSR 2018 Biophysics Program Review
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Research & Development**



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Threat Space

MOSCOW (Reuters) - Iran said on Saturday it would retaliate against new sanctions imposed by the United States after President Donald Trump set an ultimatum to fix “disastrous flaws” in a deal curbing Tehran’s nuclear program.
January 13, 2018 / 7:13 AM

“The nuclear future will not be a linear extrapolation of the past”
~Defense Science Board (2014)

- ❖ Motivations
- ❖ Capabilities
- ❖ Processes



'Test our resolve': Pakistan's challenge to India on nuclear war
TIMESOFINDIA.COM |
Updated: Jan 14, 2018



“North Korea’s nuclear weapons and missile programs will continue to pose a serious threat to US interests and to the security environment in East Asia in 2017. North Korea’s export of ballistic missiles and associated materials to several countries, including Iran and Syria, and its assistance to Syria’s construction of a nuclear reactor, destroyed in 2007, illustrate its willingness to proliferate dangerous technologies.”

*Director of National Intelligence, Daniel R. Coats,
Worldwide Threat Assessment, 2017*

**The growing threat of nuclear terrorism:
America and Russia must cooperate to
thwart rogue state attacks**
The Washington Times | March 23, 2017



Unconventional threats demand unconventional tactics.



Unilateral Monitoring

Country X ↓ Purpose/Means →	Negotiated and/or Cooperative Regimes	Unilateral Measures
Treaty Compliance, Building Alliances	Challenge inspections	Covert operations
Threat Assessment and Warning	Strategic warning	"Patterns of life"



Challenges:

- Long periods of observation
- Large geographic areas
- Short duration anomalous events
- Environmental changes that mask signals
- Non-permissive environments



Current Monitoring Technologies

- Satellite imagery



- Detection technologies



- Collections



Environmental attenuation
Data processing

Signal:noise ratios
Single analyte selectivity
Human intervention
Supporting infrastructure

Loss of signature
Expertise/equipment

Detection of small inventories, covert operations, and use of non-traditional processes requires more descriptive data.



What does “bionuclear” mean?

USE OF

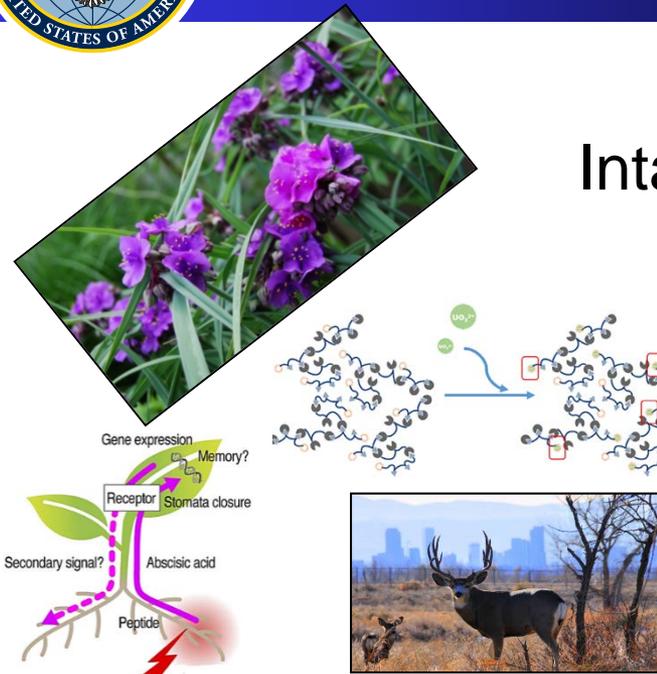
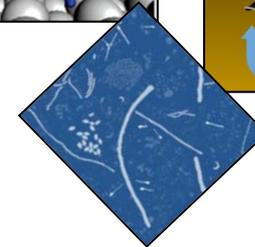
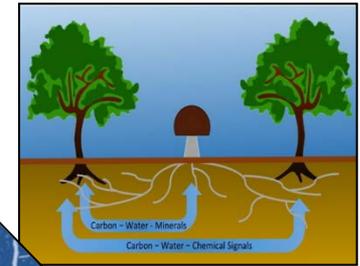
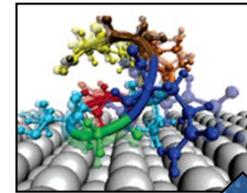
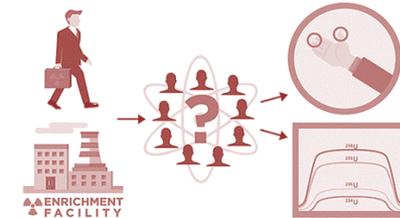
Intact living systems

Components

Pathways

Networks

TO

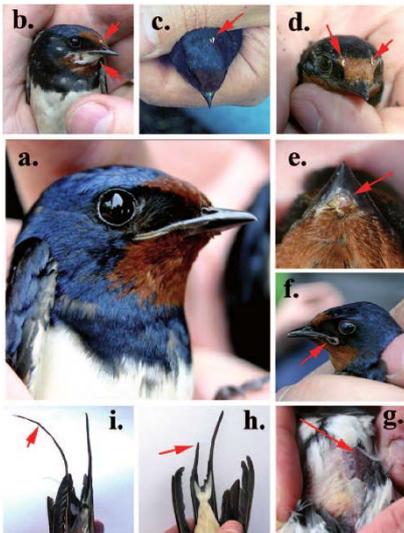


- Detect and characterize undeclared fissile material production
- Detect and characterize movement of undeclared fissile material
- Confirm the presence of fissile material in a facility
- Detect and characterize underground nuclear tests

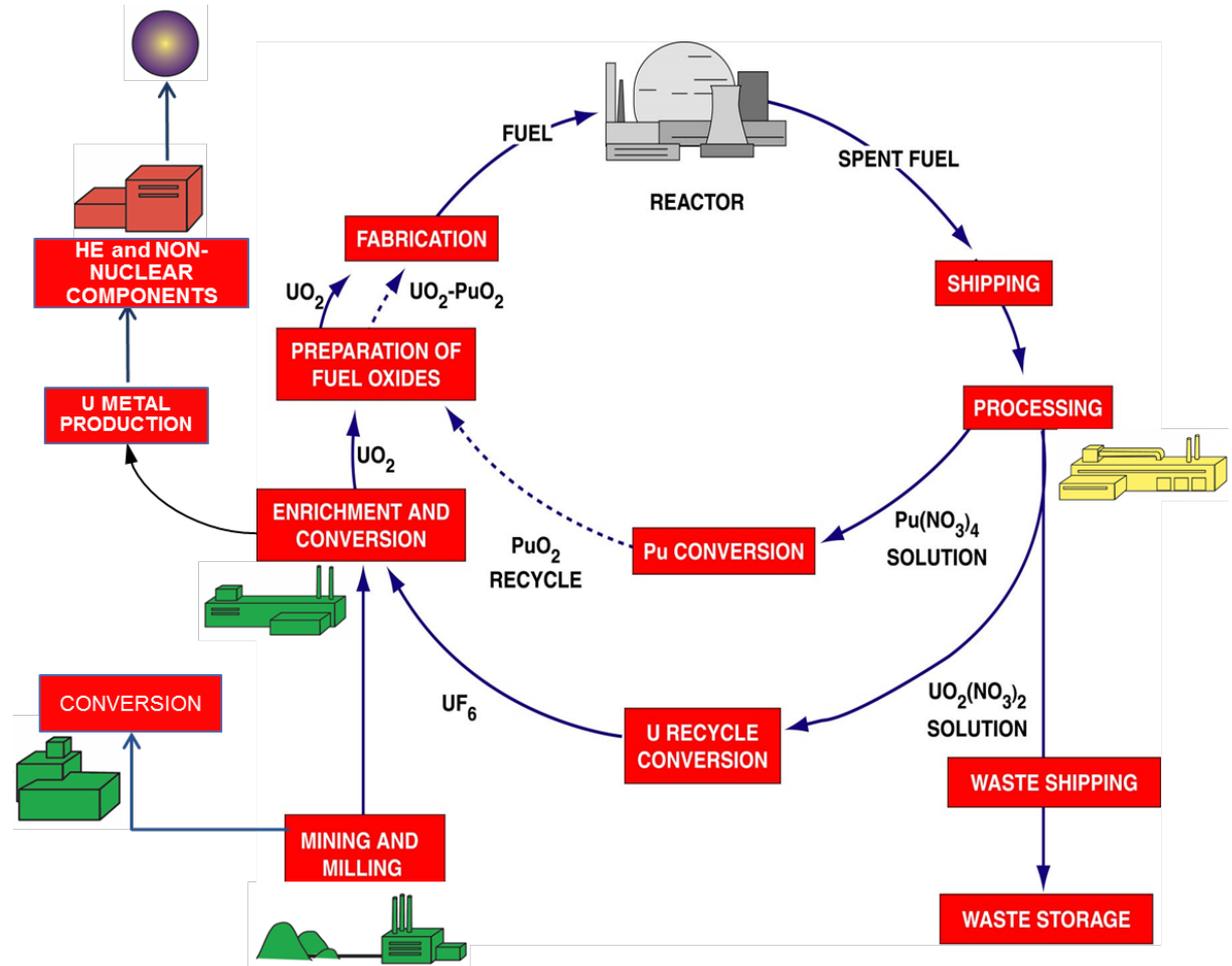


Many Type of Signatures

- Radioactivity
- Radionuclides
- Chemicals
- Heavy metals
- Biological changes



Mousseau and Moller.
2011. Bull At Sci 67:38-46



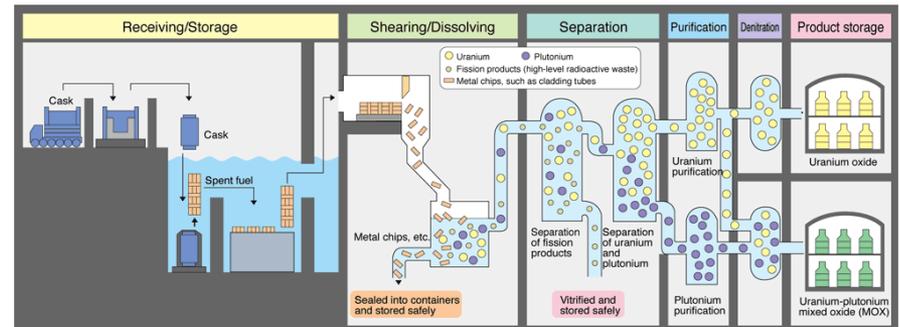
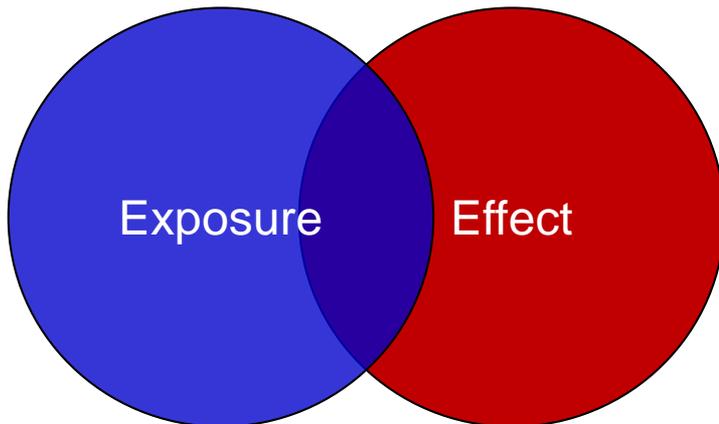
Credit: Oak Ridge National Laboratory



Reprocessing Example (Hypothetical)

Chemical	Amount Used	Normal Production Emissions	Emissions from Leaks and Losses	Estimated Emissions	Estimated Release Rates	Estimated Release Amount (ppm by mass)
Kerosene	12,000 gal	5.4 kg	21.6 kg	27 kg	0.0625 g/s	10,000
TBP	4,800 gal	1.8 kg	7.2 kg	9 kg	0.0208 g/s	3,300

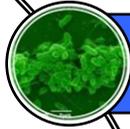
Degradation products are semi-volatile organic compounds that provide “sticky” residues which attach to piping, ducting, soil, water, and other surface media.



~After Potential Signatures of Semi-Volatile Compounds Associated with Nuclear Processes (Pacific Northwest National Laboratory 2002)



Advantages of Bionuclear Approaches



Built-in sample preparation



Hyperaccumulation and long-term storage



Responsiveness to small changes



Observable reactions



Long integration times



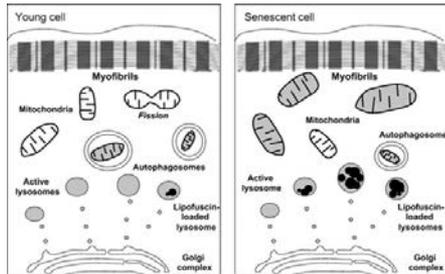
Lasting impressions



3.8 BILLION YEARS (+/- 300 MY) IN THE MAKING!



Convergence Amplifies Advantages



Metals incorporate into shell laminations of bivalves allowing them to “archive” annual metal inputs and their temporal patterns. Secondary ionization mass (SIM) spectroscopy allows highly sensitive surface analysis of composite materials.

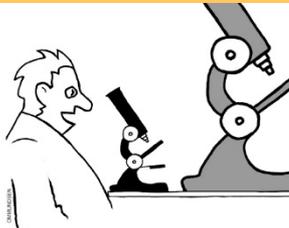


Improvements to fluorescence labeling allow more refined intracellular analysis that helps characterize the role of organelles in mediating cell responses to radiation and could help to develop more distinctive biomarker profiles.



“It has been said that the 21st century will become the “century of biology,” enabled by the impressive progress made in understanding the molecular basis of life.”

Chimeric spider silk-uranium binding proteins can be designed by bioengineering sequence repeats from spider silk with repeats of a uranium peptide recognition motif from a paramecium.



A major scientific advance was the invention of the light microscope, replacing the heavy one.

~Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond (National Academy of Sciences 2014)



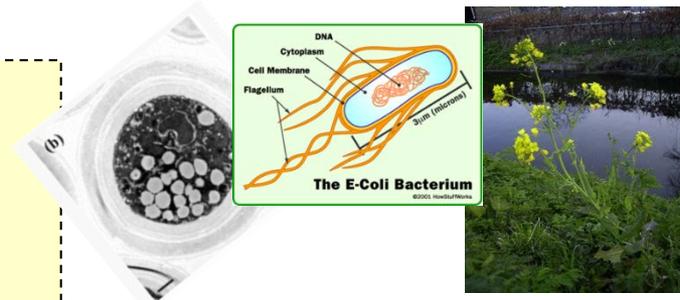
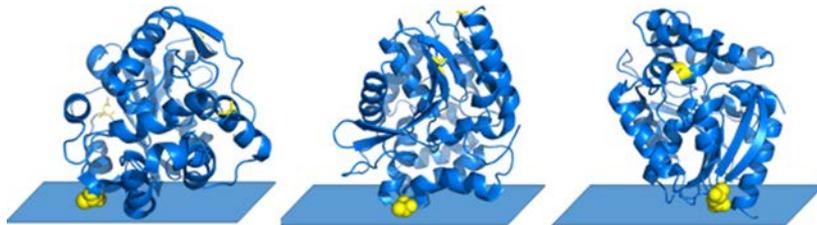
DTRA Bionuclear Research

Research Vision: Achieve maximum target specificity by identifying intrinsic mechanisms by which biomolecules recognize specific analytes and establish common principles for use.

Biological Recognition Elements

ENZYMES

- Effects of tethering / immobilization
- Compatibility with complex substrates
- Kinetic balance of multiple catalysts
- Controlled transport in multicatalyst systems



Intact Systems

BACTERIA, FUNGI, & PLANTS

- Mechanisms of accumulation
- Biochemical changes
- Multi-omic changes
- Phenotypic changes



Bionuclear Working Group: Inception

- 2012: A single team
- Covered the R&D spectrum
- Difficult to address in one venue
 - Classification issues
 - Available funding types and levels
 - Need for rapid turnaround versus acceptance of risk
- Untapped subject matter expertise
- Untapped pool of creativity

Long ago and far away,
we formed a group.



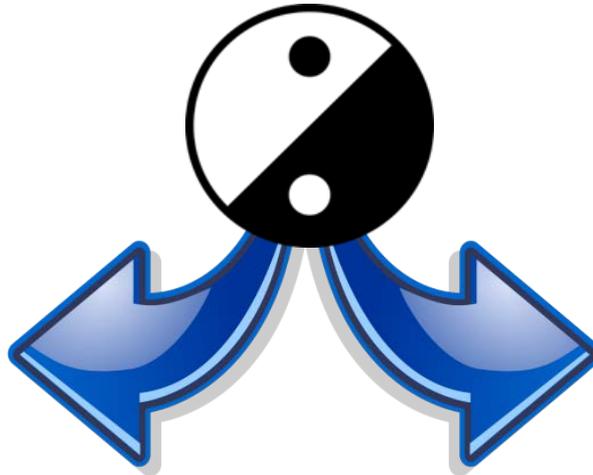


BNWG-North and BNWG-South:

Two distinct but unified elements

BNWG-N

- Rapid development
- Multidisciplinary
- Interagency leadership
- **Classified**
- **Circumscribed membership**



BNWG-S

- Fundamental research
- Multidisciplinary
- DoD leadership
- **Unclassified**
- **Broad membership**



BNWG-South: Functions and roles

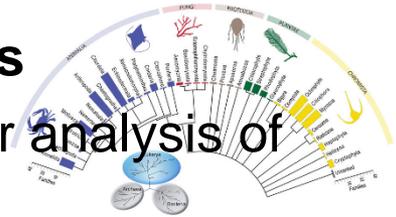
- Identify and review bionuclear related research
- Facilitate alignment of research with partners
- Ensure technology transition
- Envision 3-5 year R&D landscape

Our goal is to develop a community of experts that promotes a sustained dialogue among those conducting the research and those using the end-state products.



Best Use of Collections: Now

- **Using existent and building new resource collections**
 - Biorepositories could provide baseline information for analysis of environmental changes linked to nuclear activity.

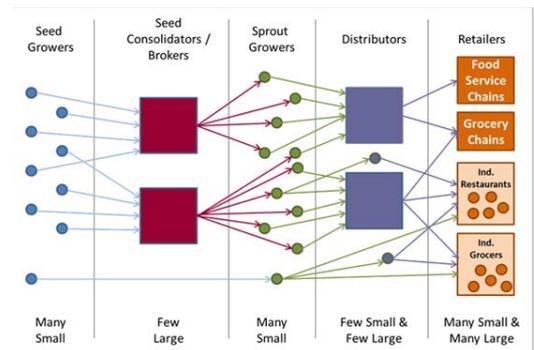


Biota leave traces of their DNA (“eDNA”) in the environments they inhabit. Longitudinal collection and analysis of eDNA could reveal changes to species diversity that can be related to presence of contamination. ~Stat et al. 2017. Sci Reports 7:12240

- **Agri-food supply chain**
 - Food radiation testing is common following radiation accidents and could be exploited for identifying suspected nuclear sites.



Foodstuffs from areas close to the sites of nuclear accidents are routinely tested for contamination, although finding the sources of contamination can be difficult.



http://www.sandia.gov/casosengineering/food_defense.html



Coming Down the Pipeline: Soon

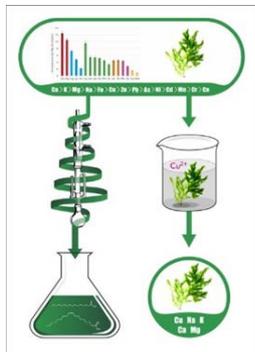
- **Novel detection motifs**
 - Enzyme-containing inks can be used for DIY sensor production.

Off-the-shelf ballpoint pens can be filled with high-tech bio-inks that react with chemicals. Sensors can be drawn directly onto substrates of interest.

~Bandodkar et al. 2015. Adv Healthcare Mater 4:1215-1224.



- **Biosorptive materials**
 - Biosorptive materials could be used for remote sampling of stream discharges from suspect sites.



Several commercial biosorbents can remove heavy metal ions from industrial or mining wastewaters and have been evaluated in pilot tests for metals like Fe, U, Co, Cd, Pb, and As.

~Das and Karthika. 2008. Indian Journal of Biotechnology 7:159-169

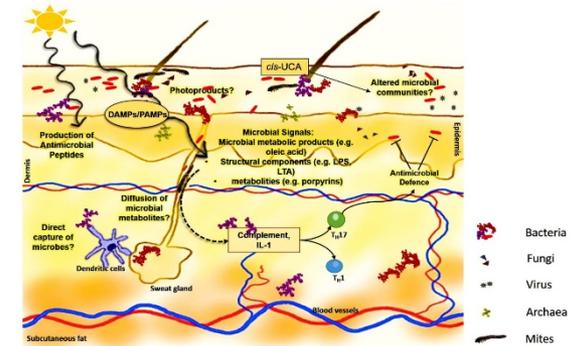


Coming Down the Pipeline: Soon

- **Human and non-human animal microbiome studies**
 - The skin microbiome may be the “first responder” to radiation.

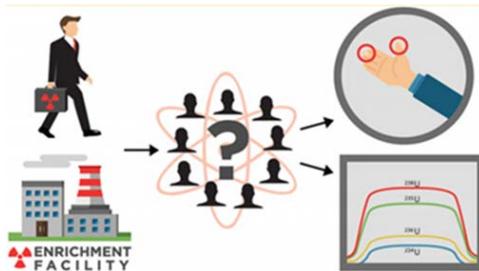
Propionibacterium acnes, a human skin commensal, decreases porphyrin production following irradiation, and decreases exhibit dose-dependencies.

~Shu, M. et al. 2013. *Curr Med Chem* 20:562-568.



- **Human indicators**

- People working in close proximity to special nuclear materials can retain materials in various tissue matrices and in specific ratios.



Uranium isotopes can be detected in hair and nail samples from nuclear workers, and ratios of those isotopes ($^{235}\text{U}/^{238}\text{U}$ and $^{236}\text{U}/^{238}\text{U}$) are sensitive indicators of exposure to materials not normally associated with occupational settings.

~Brockman. 2016. *Anal. Chem.* 88:8765-71

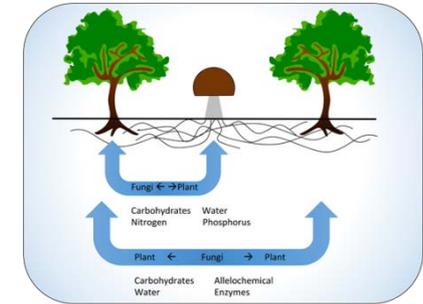


Something Really Different: Timeline Unknown

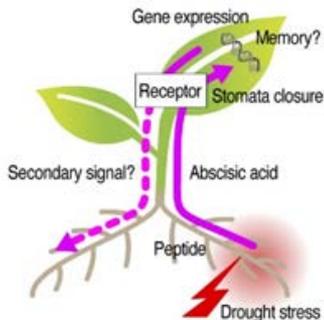
- **Detection powered by the Internet of things**
 - Multiple plant and fungal species develop “wood wide webs” that connect entire ecosystems through vast communication networks.

Neighboring, aphid-free bean plants connected to an aphid-infested plant by underground fungal networks will preemptively emit the same chemical response as attacked plants.

~Babikova et al. 2013. Commun Integr Biol 6:6



- **Plant memory as a detection motif**
 - Plants are sensitive to environmental stimuli and can “record” stressful events for later retrieval.



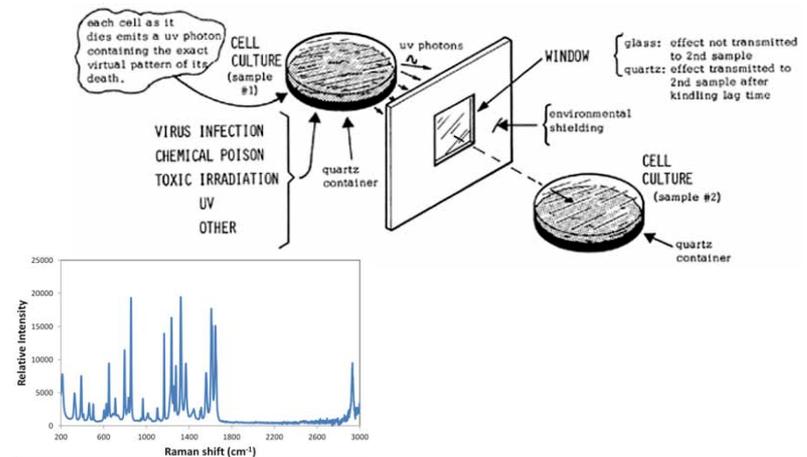
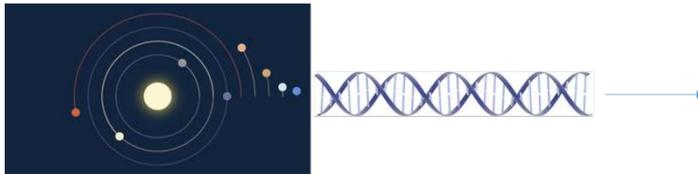
Stimulation like manipulation, drought, wind, cold shock, and radiation had no visible effect on flax seedlings. When calcium depletion treatments were applied a few days later, seedlings “recalled” the stimulation as shown by morphological changes. ~Tafforeau M. et al. 2012. Plant Signal Behav 1:9-14.



Something Really Different: Timeline Unknown

- **Biological responses to electromagnetic radiation**
 - Some studies demonstrate impairment of DNA integrity in response to electromagnetic fields created, e.g., by electronic devices. Double-stranded DNA and other cellular structures also appear to **EMIT** electromagnetic radiation which promotes communication within and among cells. Does exogenous perturbation result in changes to EM emissions and are such emissions measurable using available technology?

“Death transmission” appears to occur via emissions in the ultraviolet and infrared frequencies. ~V.P. Kaznacheyev et al. 1976. *Psychoenergetic Systems* 1:141-142.



Credit (can be a double-edged sword): R.P. Oates



Ex Nihilo Nihil Fit



Thanks to the Bionuclear Working Group