ASU Complex Adaptive Systems Initiative
Arizona State University

Biotechnology and Biosecurity: Enhancing Security in an Increasingly Unsecure World

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Guest Lecture
BCH462, General Biochemistry
Arizona State University
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Purposeful Use of the Term Biosecurity Rather Than Biodefense

Broader Term to Address the Full Spectrum of 'Biological' Threats Whether of Natural or Nefarious Origin

Natural Epidemics and Bioterrorism Share Same Features in Terms of Potential to Disrupt Society and Preparedness Capabilities are Similar Irrespective of the Origin of the Biothreat

Biosecurity and Global Health: Understanding the Implications of Major Economic Disparities and Environmental Dislocations











Seeking Security in an Unsecure World: The Military and National Security Calculus

Expanding Conflict Zones, Political Instabilities and Terrorism

WMD Proliferation

New Power Centers

US Retrenchment: Geopolitical/Fiscal

The VUCA World

- **V**olatility
- **U**ncertainty
- **C**omplexity
- **A**mbiguity

One More C to VUCA

- connectivity!
- understanding the global biosecurity implications of an increasingly inter-connected global system
- human health, animal health, plant health and environmental/ecological changes
- global transport and trade
- disease, food security, economic and social instabilities as triggers of political instabilities and military intervention (humanitarian, OOTW or confront exploitive terrorism)

The Biosecurity Triad

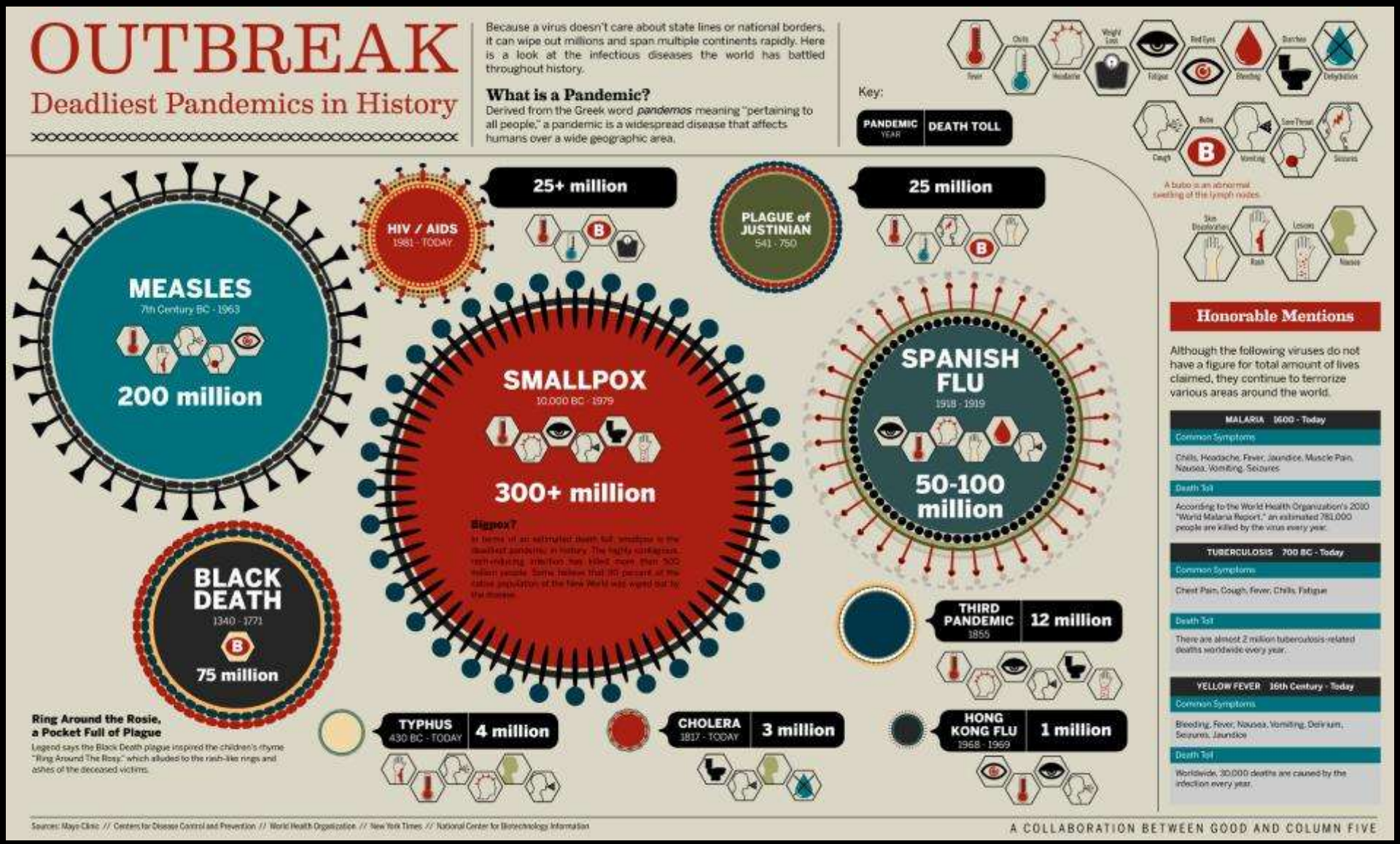
Infectious Diseases of Natural Origin

Urbanization, Environmental and Ecological Impacts on Disease Emergence

Bioterrorism and Dual-Use Technologies

Preparedness:
The “All Hazards” Challenge
and
Building Resilient Systems

OUTBREAK: Deadliest Pandemics in History



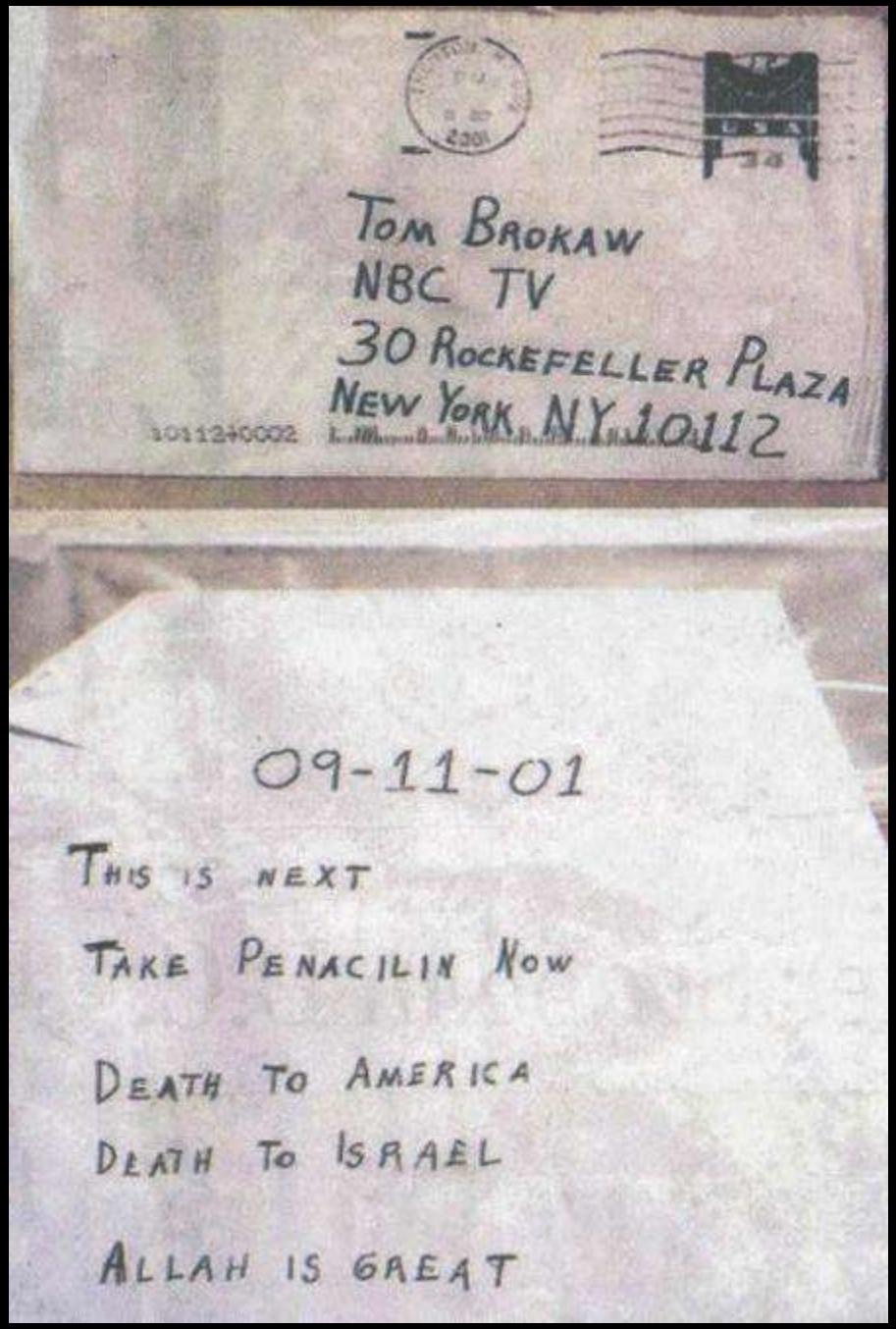
The Major Infectious Disease Pathogens

Today

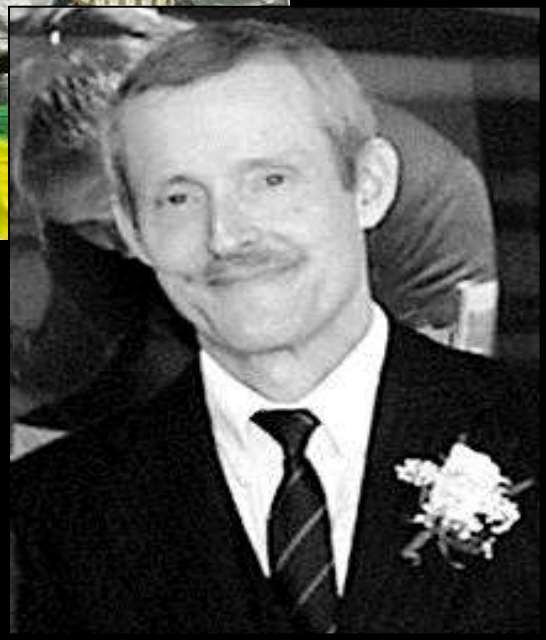
- malaria
- TB
- HIV/AIDs
- cholera
- enteric diarrhea pathogens
- Leishmaniasis

EIDs of Concern

- pandemic (avian) influenza
- dengue
- chikungunya
- Ebola, MERS
- Zika
- engineered agents (bioterrorism)
- antibiotic resistance and HAI



"I will show you fear in a handful of dust"
T.S. Elliot



The FSU Covert Biopreparat Program in Violation of 1972 BWC

Asymmetric Warfare and The Appeal of CBW to Extremists

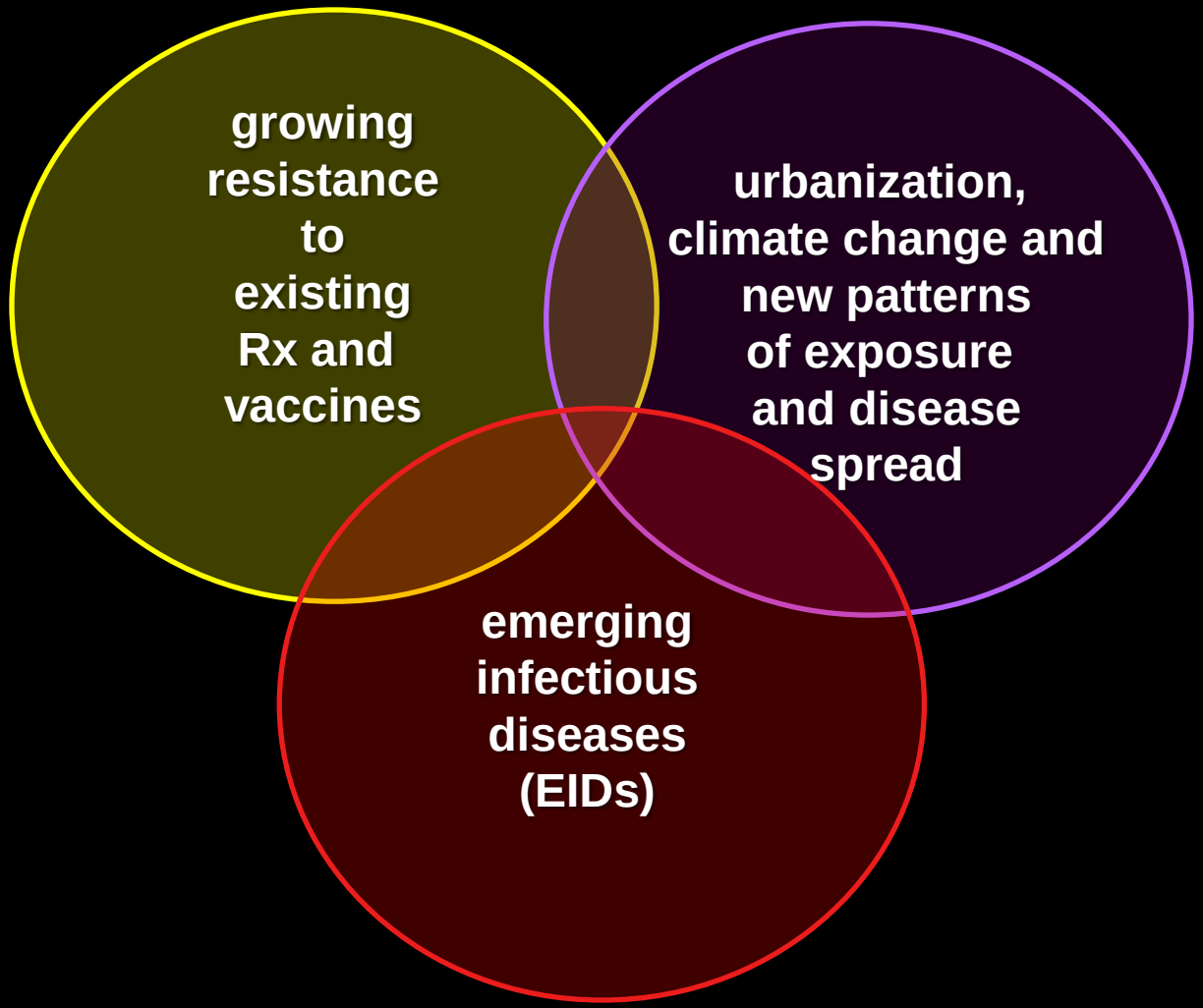
Synthetic Biology and the Potential of Dual-Risk Research and Bioterrorism

The Relentless Challenge of Natural Infectious (and Parasitic) Diseases

The Constantly Changing Dynamics of Global Infectious Diseases

Host-Pathogen Interactions as Classical Example of Evolutionary Dynamics (variation, adaptation, selection)

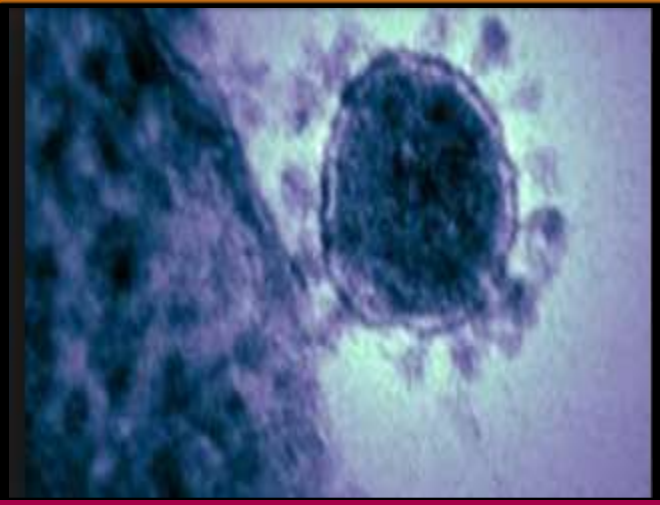
Outpacing Infectious Diseases



Human Coronaviruses

Emergence of SARS-CoV (PRC 2003)

Emergence of MERS-CoV (KSA 2012)



Pandemic Influenza: Still the Largest EID Threat?

- H1N1: high transmissibility - low virulence/mortality
- H5N1: low transmissibility – high virulence/mortality
- H5N1 x (H1N1) or (X): potential for devastating pandemic

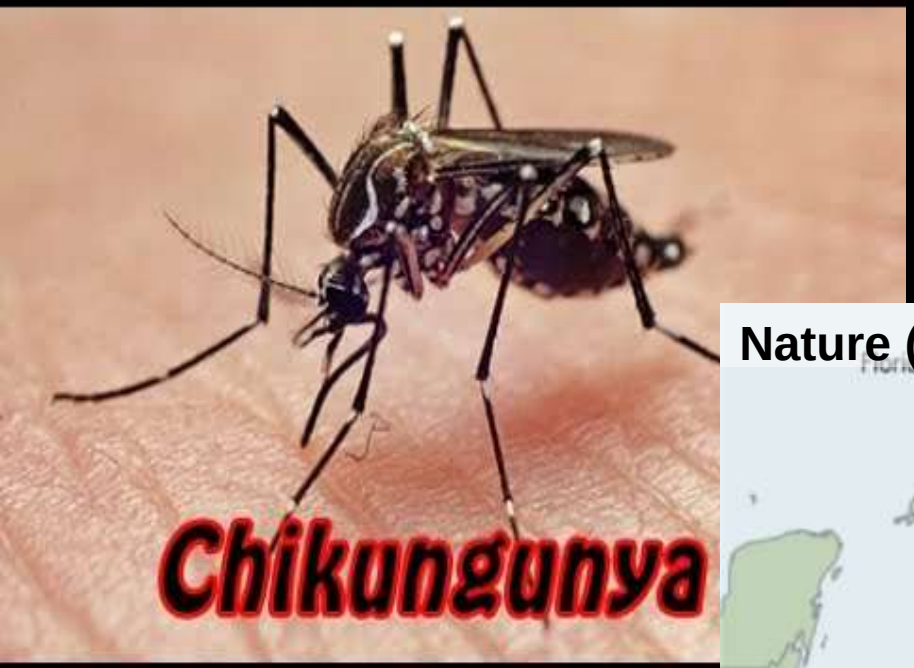
The Shifting Geographic Range of Pathogens and Their Vectors

Global Trade and Travel

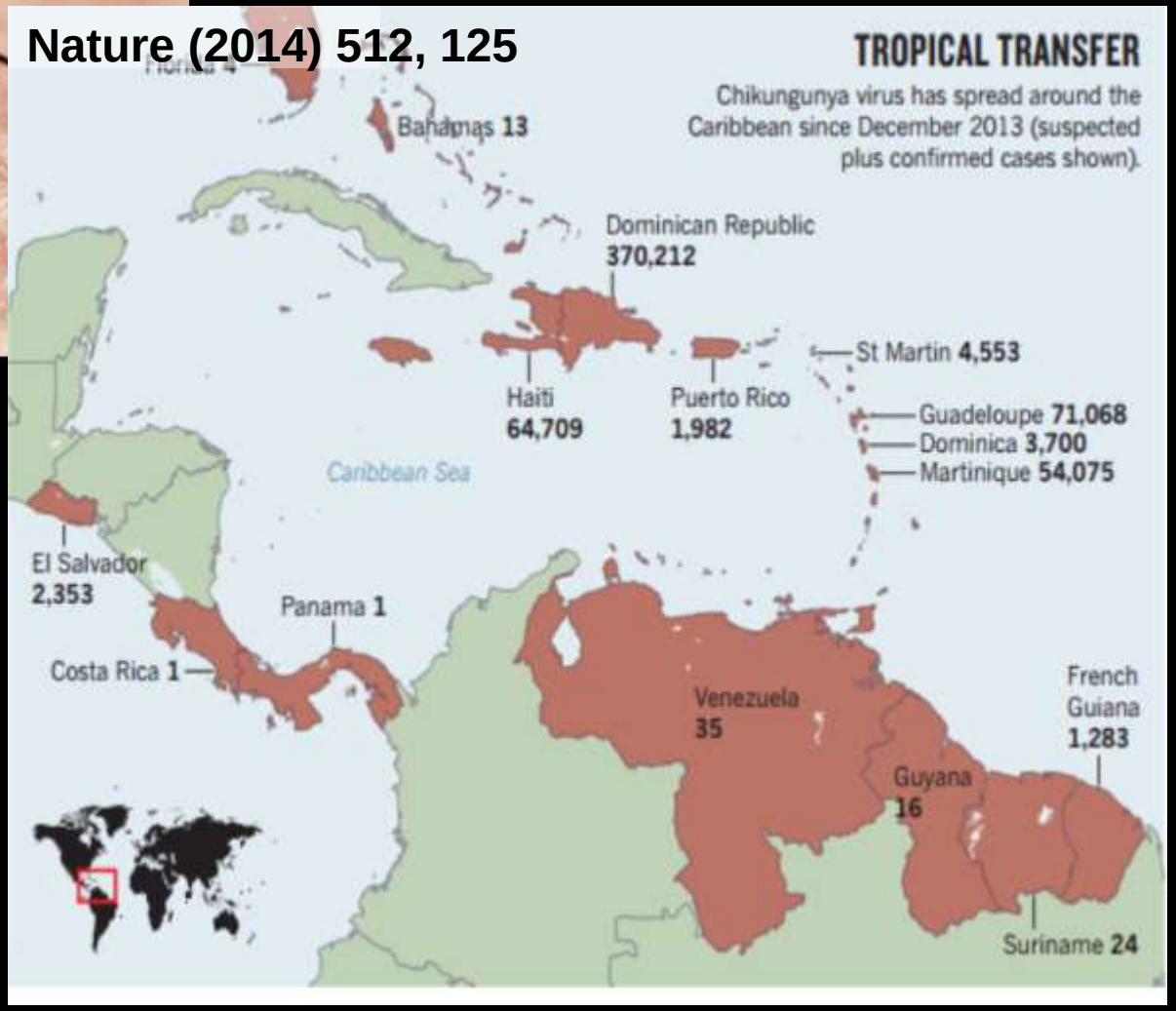
Ecosystem and Climate-Shifts

The Most Lethal Animal Species (Except Humans): Major Mosquito Classes for Vector-Borne Disease

Anopheles gambiae	Aedes albopictus	Culex pipiens
		



Nature (2014) 512, 125



The Global Public Health Challenge Posed by Rapid Urbanization in Developing Countries

High Disease Transmission

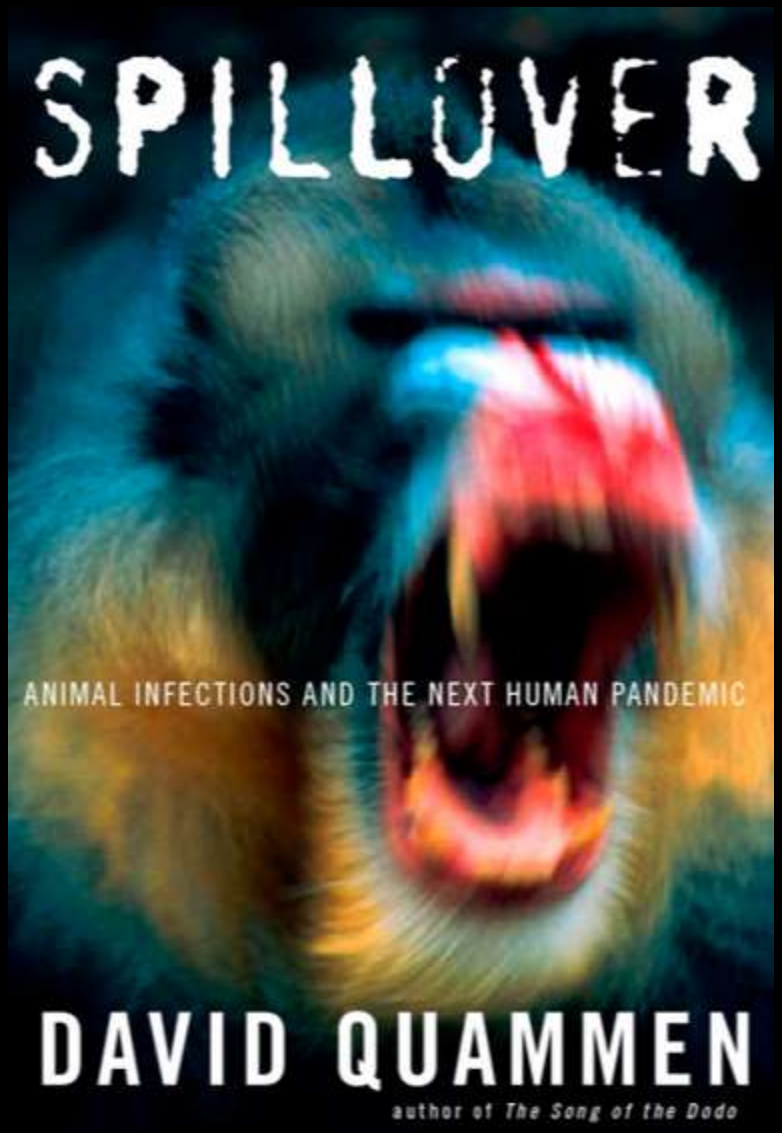
Lack of Safe Water

Bush Meat Food Chain

Major Deficits in Health Infrastructure

Expanded Eco-niches and Increased Zoonotic Risks

The Dominant Role of Zoonoses in Emerging Infectious Diseases



Megacities and New Biosecurity Challenges

- urban population projected to triple by 2030 with 70% occuring in developing countries (DCs)
- most growth will occur in resource-poor, highly fragile and often politically unstable regions
- many situated in low-lying coastal areas and vulnerable to flooding and sea level changes

Ebola in West Africa (2014)

Ebola

- both a biological plaque and a psychological one
- not nearly as contagious as many viruses but high lethality generates fear and irrational behavior
- fear spreads faster than the disease
- myth and misinformation (local) and media sensationalism (USA) fuel fear and stigmatization

Ebola Virus Disease: West Africa 2014

- first outbreak outside East and Central Africa
- simultaneous spread across multiple borders
- fragile health systems ill-equipped to implement surveillance and containment measures
- mistrust and violence against healthcare workers
- mistrust exacerbated by military enforcement of quarantine zones
- orphans, food shortages
- 28 million children already orphaned in region due to conflict and HIV/AIDS

Ebola in West Africa (2014)

- traditional cultural beliefs in shamanic medicine
- fear of sending loved ones to treatment centers to die alone
- rumors and hostility to role of health workers (particularly westerners) in disease spread
- denials about existence and cause of infection

Aliens in Our Midst!

Health workers in Liberia Push an Ebola Patient Who Escaped from Quarantine Into an Ambulance

Notice the Resemblance?
Hygiene and Quarantine as the Only Controls
Absent Drugs or Vaccines

Bubonic Plague
Physician 15th Century

Ebola, Liberia
21st Century

The Vital Importance of Biosurveillance

Early Detection Saves Lives!

Biosurveillance and Accurate Diagnosis: Early Detection Saves Lives!

- Ebola: West Africa
  - December 2013 to March 21 2014
  - IHE not declared until August 2014

http://www.darpa.mil/uploadedImages/Content/Our_Work/DSO/Programs/7-Day_Biodefense/Biodefense_a.jpg

Ebola in West Africa (2014)

- for reasons unknown hiccups are feature of Ebola
  - Medecins sans Frontiéres physician in Geneva sensed the clue in March 2014
- blood sample flown to Institut Pasteur March 20 tested positive for Ebola

Identification of Patient Zero and the Source of Infection

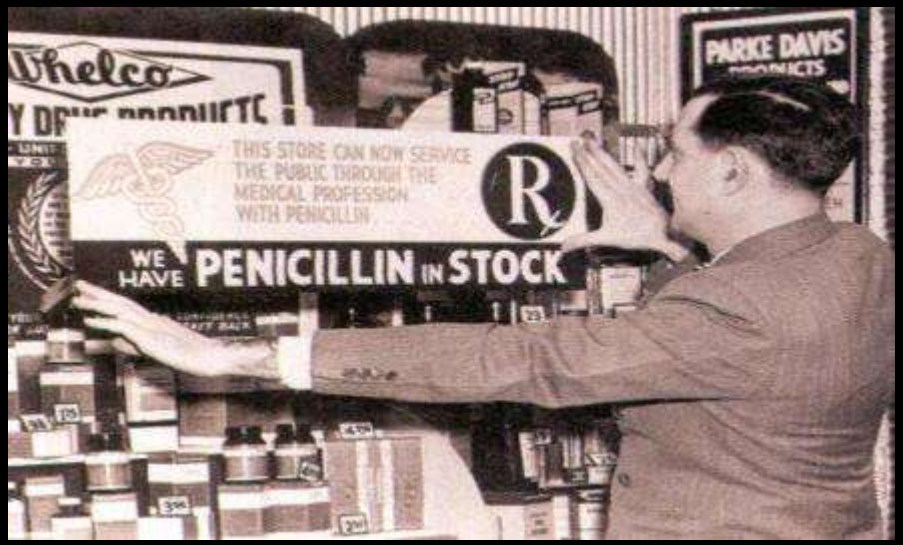
Bats as the Ebola Reservoir in W. Africa (2014)

Out of Sight: Out of Mind!

The Cocoon of Protection: How Quickly We Forget Past Epidemics and Their Toll

Reduced Investment in Public Health and Biosecurity: A False Economic Gain

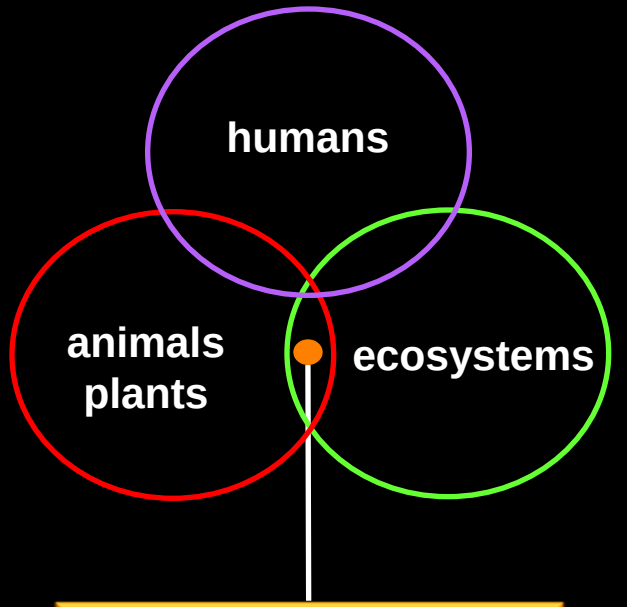
Comfort and Complacency: The Enemies of Vigilance and Preparedness



One Health

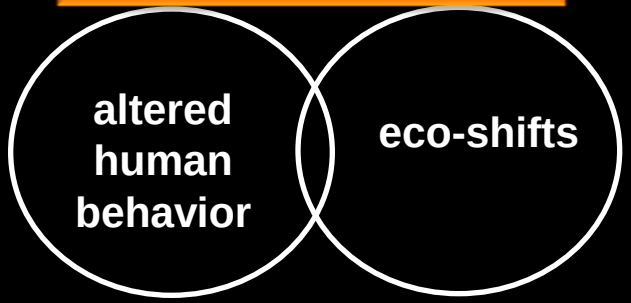
The Need for a Holistic View of Host-Pathogen Ecology

One Health: The Need for Holistic Approaches to Address the Complexity of Biosecurity Challenges



- urbanization
- travel
- trade
- intensive agriculture
- food security

Anthropogenic Effects



- conflict
- refugees

- climate change

- urbanization
- deforestation
- desertification
- water use
- water contamination
- invasive species
- weather

Detection and Management of a Major Bioincident

Trade and Transport Make Every ‘Local’ Event a Potential ‘Global’ Risk

Need for Similar Response Capabilities Irrespective of Whether Incident of Natural of Nefarious Origin (Terrorism)

Preparedness: Building Resilient Systems

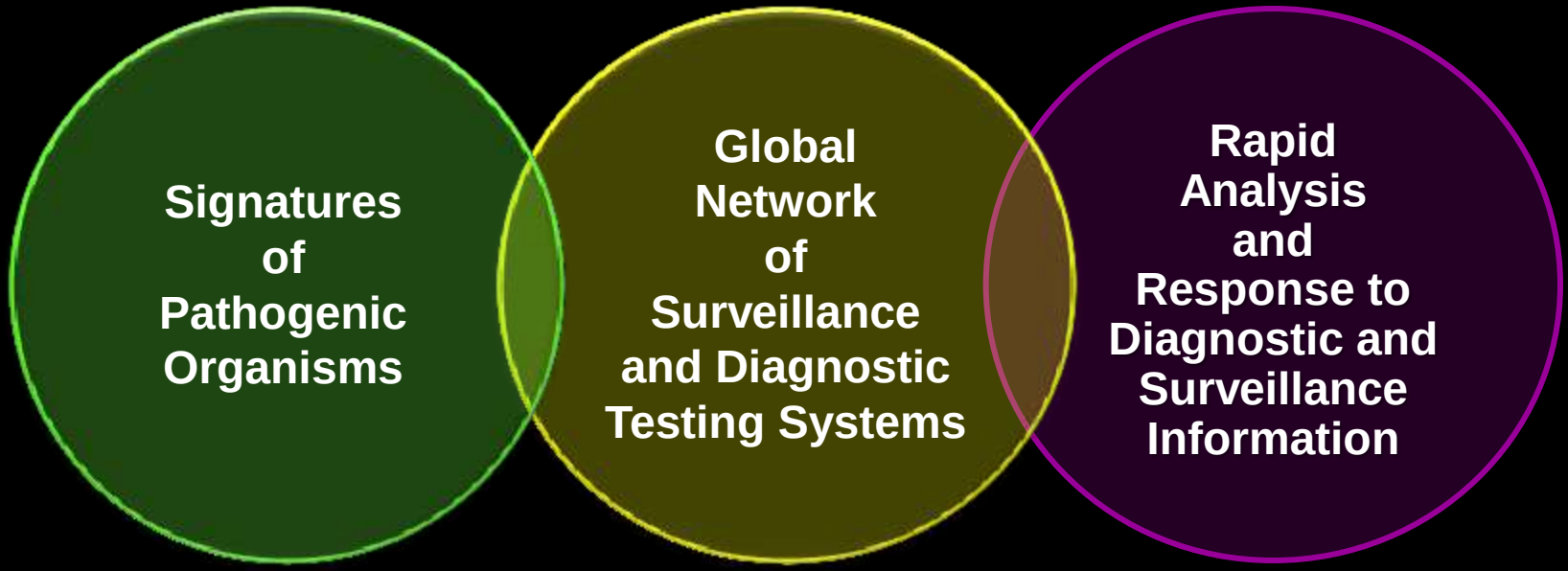
- are the risks known and analyzed?
- are there actions for meaningful intervention?
  - tractable, measurable
- if not, how can these be developed and implemented (resources, infrastructure, logistics, cost)?
- what are the principal risks and obstacles to success? (technical, economic, political, social, legal)
- how are these barriers being addressed and, if not, what is needed to reduce/eliminate them? (vulnerability assessment and mitigation)

Biosurveillance: the Value of Early Detection

Early Detection Saves Lives!

POC Diagnostic Tests, Population Triage and Managing the Worried Well

Surveillance Systems for the Rapid Detection and Control of Infectious and Parasitic Diseases



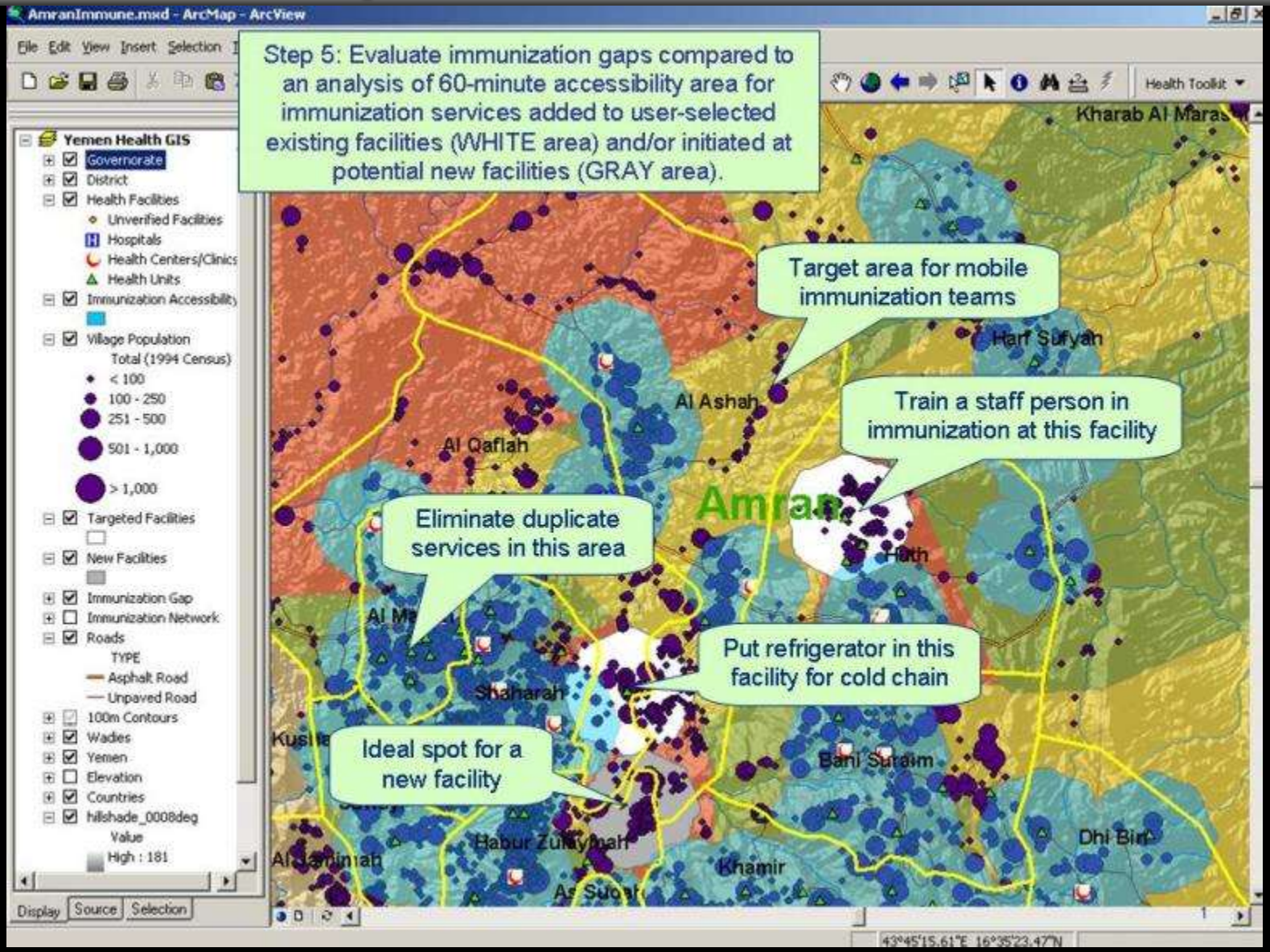
Profile

Sense

Act

Geodemographic Information Systems (GIS): Real-Time, Front Line, Ground Zero Data from Field Sampling and Sentinels

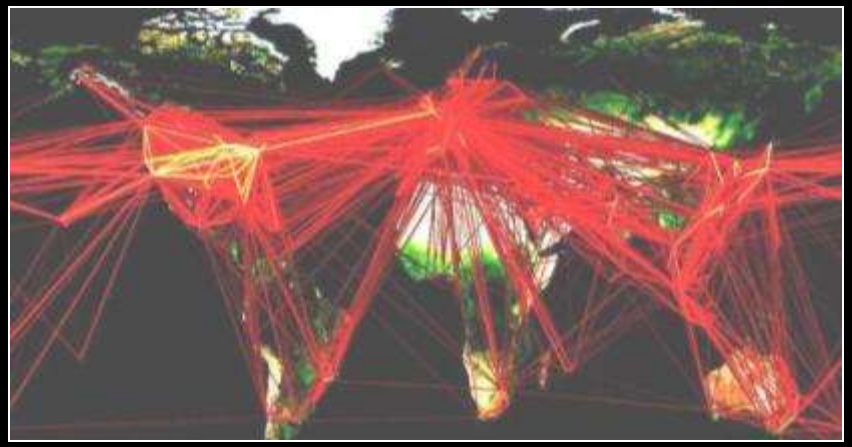
Mapping Epidemic Disease and Targeting Hot Spots for Immunization



Global Transport and Trade: New Interactions of People, Animals and Product Supply Chains

The Super Vector

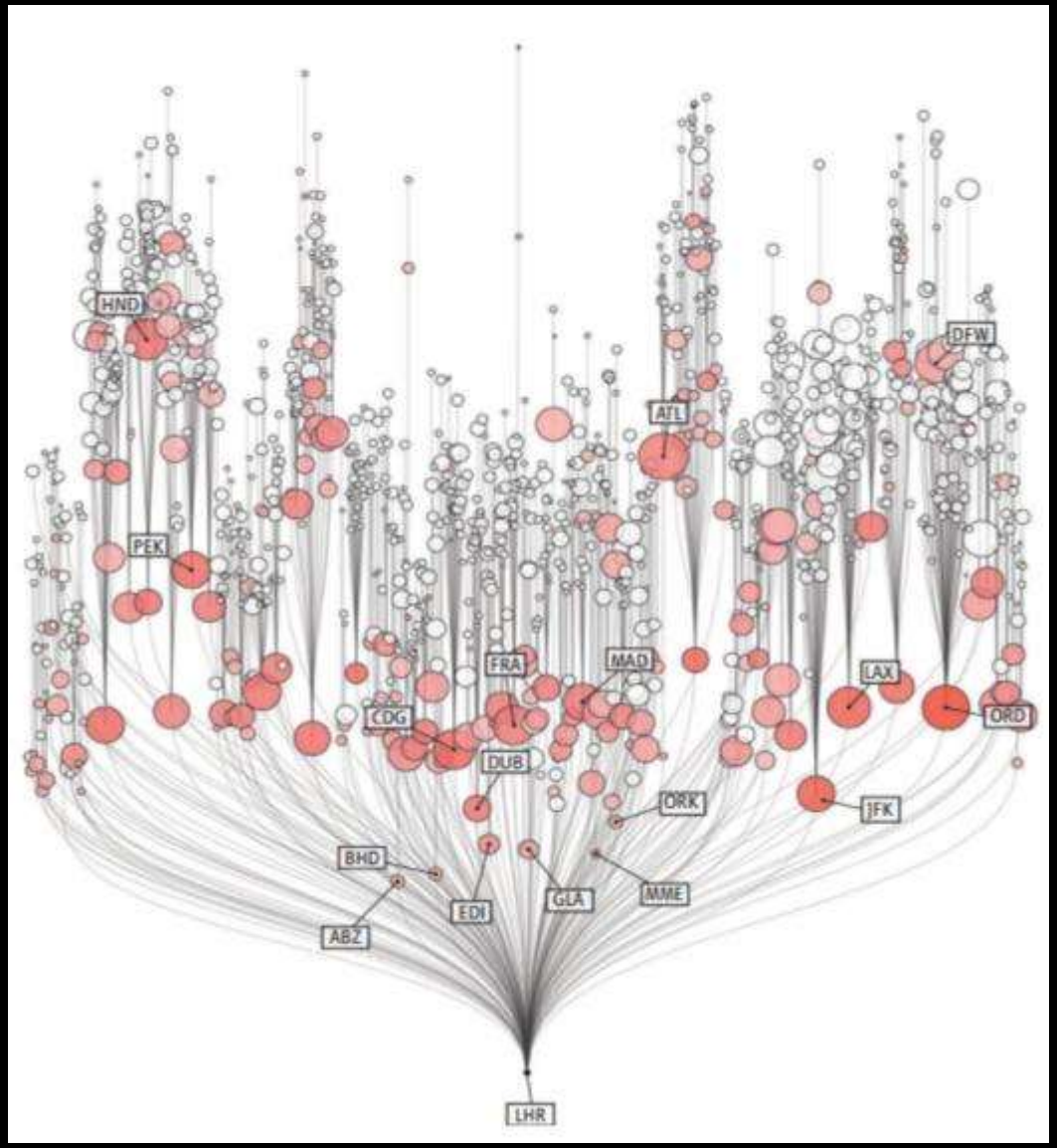
Billion Cross-Border Travelers



World Container Traffic Doubled Since 1997

Global Food Networks

Coming to an Airport Near You:



Modeling Airport Connectivities, Traffic and Distance Relationships and Implications for Epidemic Spread via the Global Aviation Network

From: A. R. McLean (2013) Science 342, 1330

Infectious Diseases (Natural) and Bioterrorism (Nefarious)

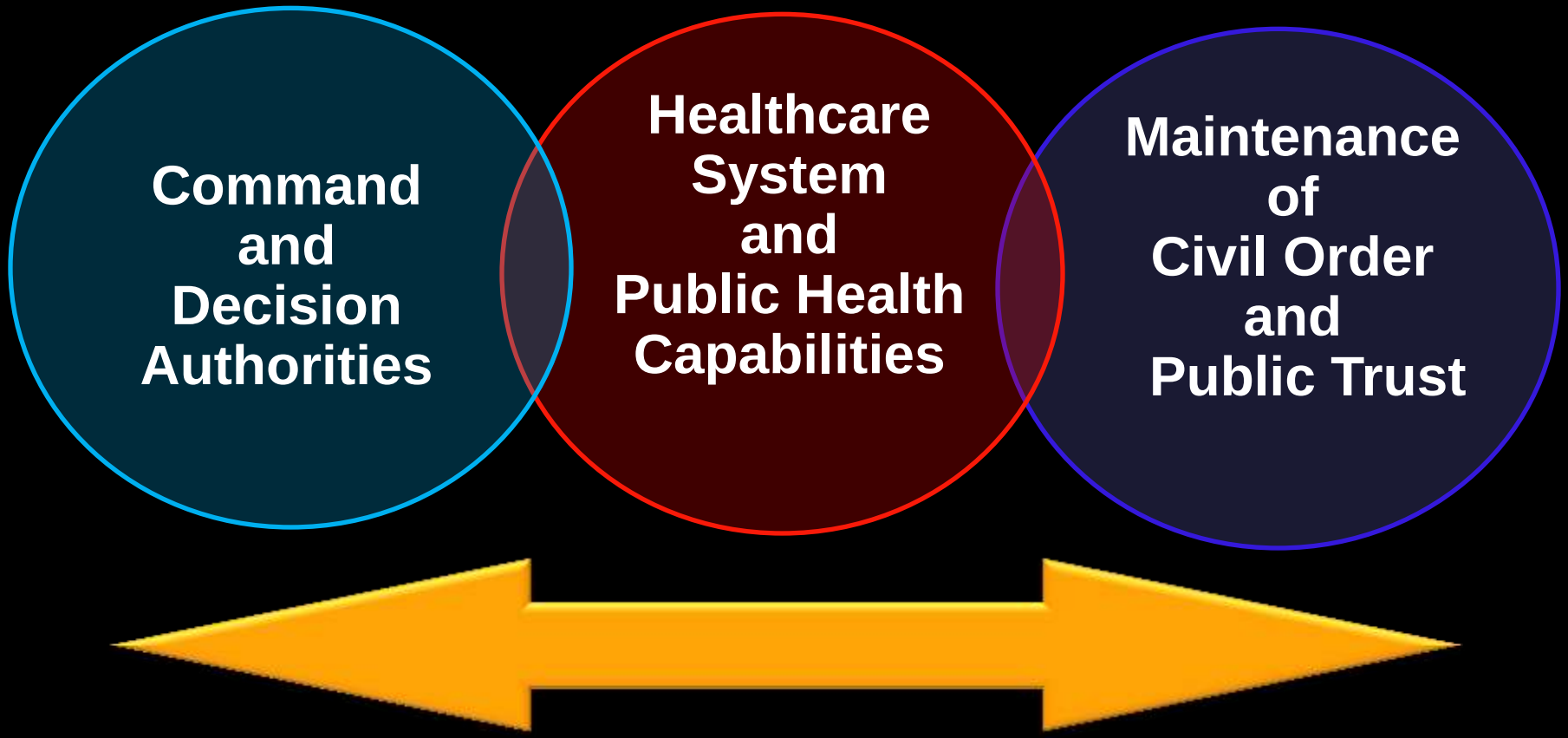
Shared Features: Stealth and Spread

Detection of Infectious Disease Threats:

Not A Hazmat or Wide Area Sensor Network Solution

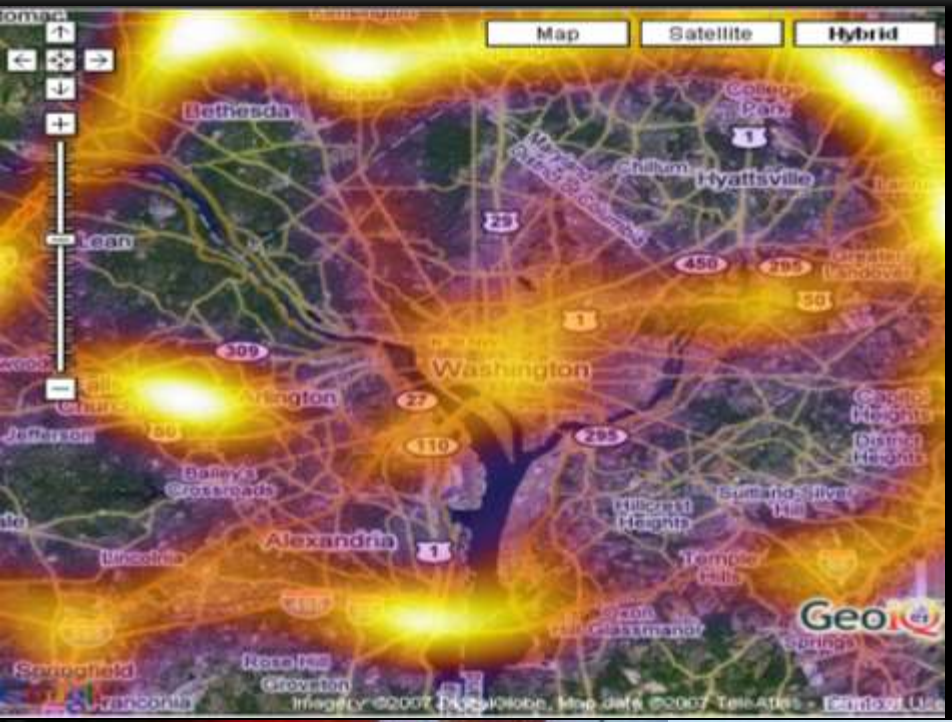
Emergency Rooms and Farms Will be the Front Line

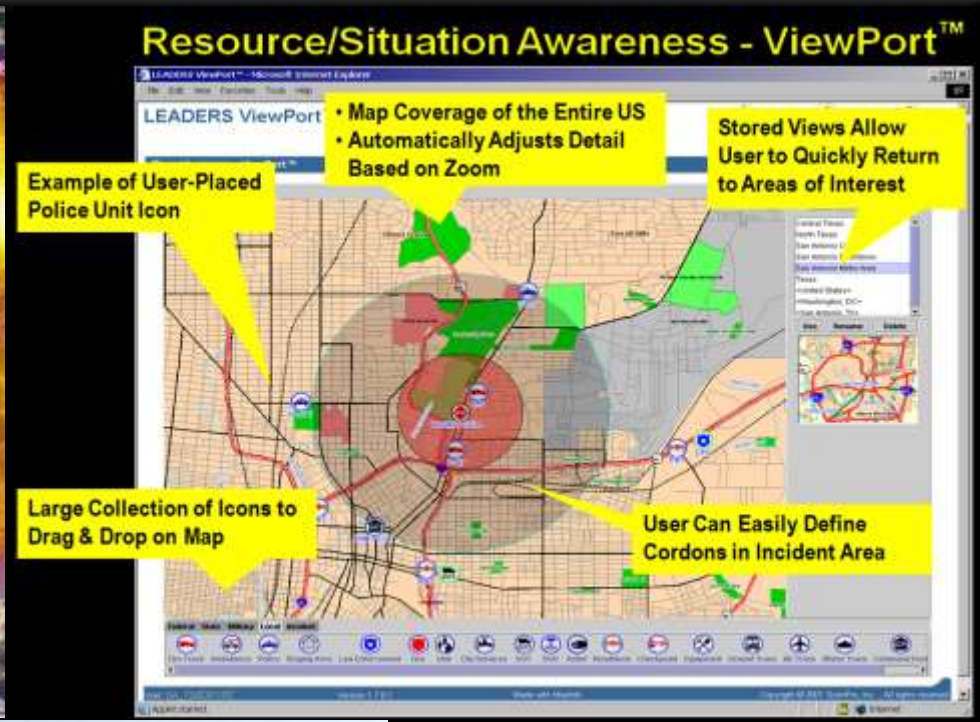
The Three Core Components of Bioincident Management

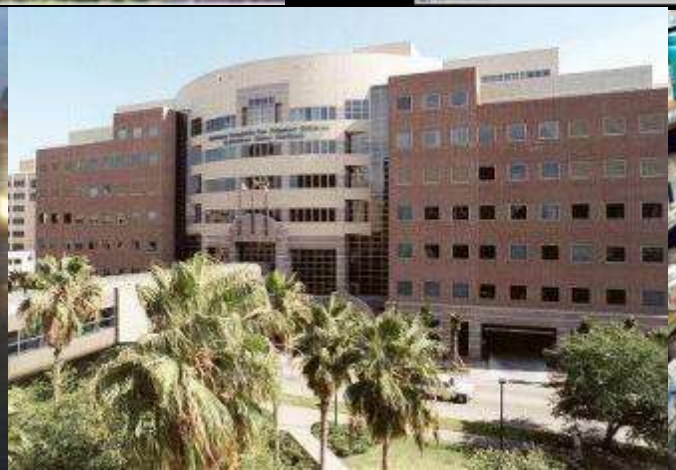


- robust inter-operable communication networks for real-time situational awareness and rapid actions
- managing the media and the ‘worried well’
- transparency, credibility and public trust

Use of GIS for Management of Population Movement, Healthcare Facilities and Supply Chains for Optimum Bioincident Control







Vulnerability of Global, National and Local Supply Chains in a Major Epidemic/Pandemic

Medicines

- "just-in-time" supply networks
  - major hospitals 2 or 3 deliveries per day
- out-patient prescription drugs
  - insurance company limits on prescription volume (USA)
- majority of drug intermediates, excipients and final products sourced off-shore
- 95% generic drugs used in US (64% of total Rx) are made off-shore, primarily in PRC and India
- no national stockpile for routine prescriptions

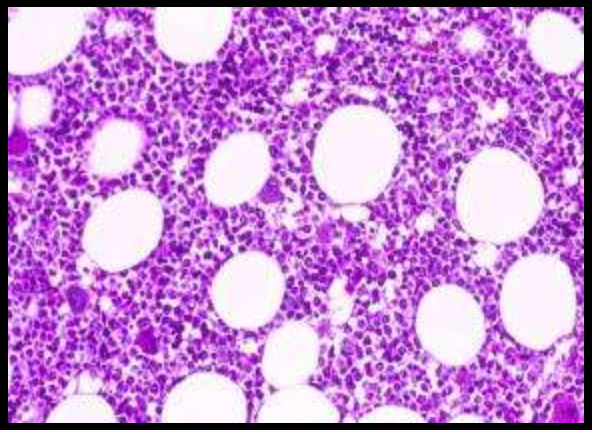
Medical Countermeasures (MCMs) for Special Populations: Emergency Use Authorization

Children

Pregnant

Aged

Immunosuppressed



Impaired Major Organ Function

ICU-Critical Care

“For most of us design is invisible until it fails”
Bruce Mau

The ‘Fog of Disaster’: Crisis Standards of Care and Proliferation of Unanticipated Events and Consequences

Failure of Power Generators in Major NYC Hospitals During Superstorm Sandy 1 November 2012

Control of Population Movement and Supply Chain Networks

Compromising Critical Systems

Bad Bugs
and
Few New Drugs

NO ESKAPE!: Resistant Bugs and Few New Drugs

- increasing resistance in G^+ and G^- pathogens in hospital and community settings

- the **ESKAPE** pathogens
  - ***E**nterococcus faecium*
  - ***S**taphylococcus aureus*
  - ***K**lebsiella pneumoniae*
  - ***A**cinetobacter baumanii*
  - ***P**seudomonas aeruginosa*
  - ***E**nterobacter species*

Antibiotic Resistance (Rx^r)

- adds estimated $35 billion in healthcare costs
- 8 million additional hospital days per year
- Relentless rise in lethal Rx^r
- major gaps in new Rx pipeline

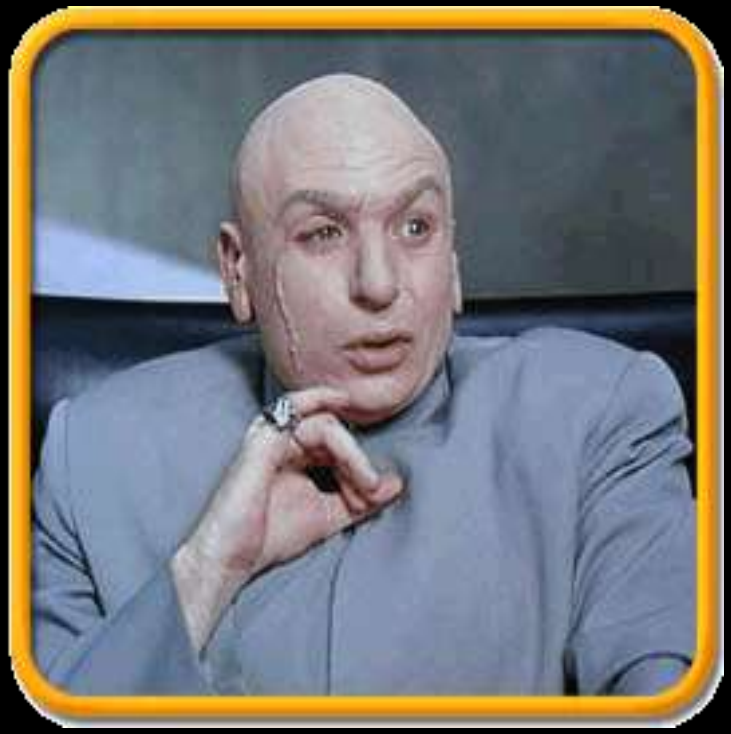
Drug Discovery and Development: One of the Most Complex Intellectual and Logistical Exercises Undertaken by Modern Industry

- $750 million to $2 billion R&D cost/drug
- 9-15 year R&D cycle

"Fewer countries have discovered,
developed and registered drugs
to an international standard,
than have developed atomic bombs"

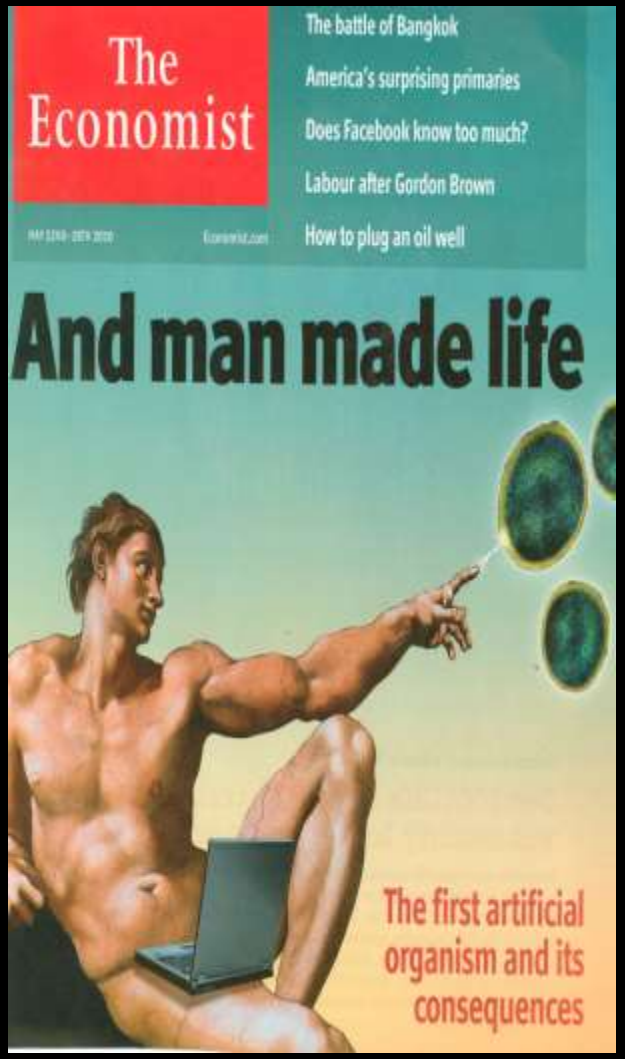
Chris Hentshel
Medicines for Malaria Venture: Lancet (2004) 363, 2198

Future Trajectory Trends and Threat Expansion

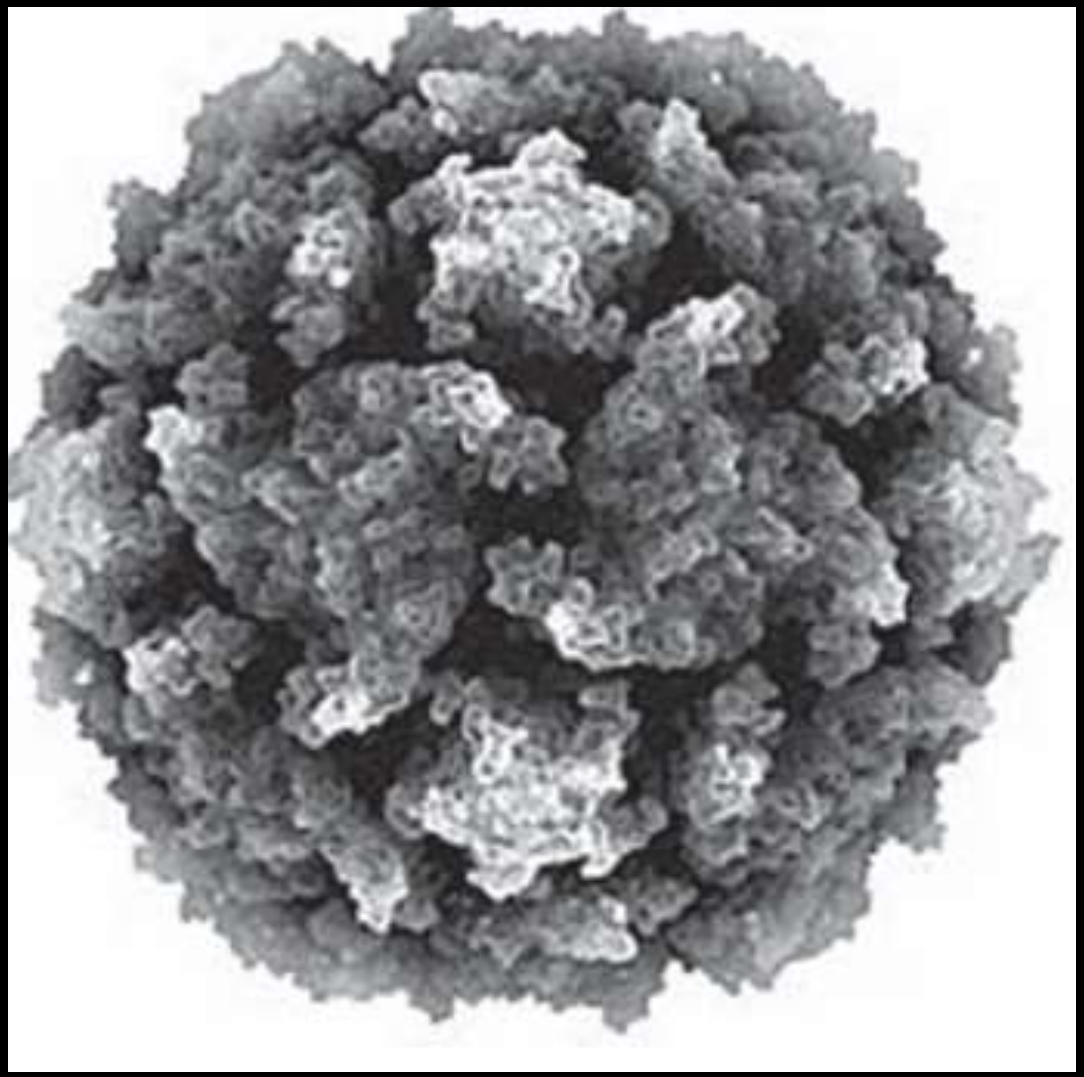


New ‘Dual-Use’ Technologies and Engineered Biothreats

Synthetic Biology

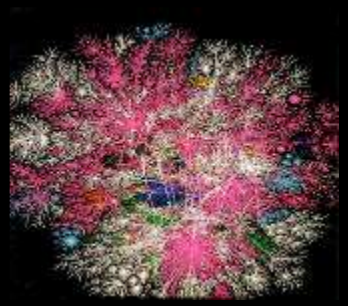


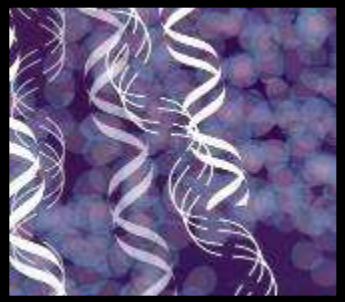
C332,652; H492, 388; N98, 245; O131, 196 P7, 501; S2,340 (a.k.a. poliovirus)



ATTGACTGCAA ……(design specifications)

The Expanded Dimension of the ‘Bio’ Challenge





- thinking beyond ‘bio’ as just infectious agents
- systems biology
  - targeted disruption of ANY body function
  - novel C and B threats
- synthetic biology
  - exploring biospace: designing new life forms
  - designer organisms to attack materials/infrastructure

Dual-Use Research of Concern (DURC)

Nature (2012) 482, 153

COMMENT

INFLUENZA Further explanation of the NSABB recommendations p.158

PRIMATES Imitation and social learning in apes p.159

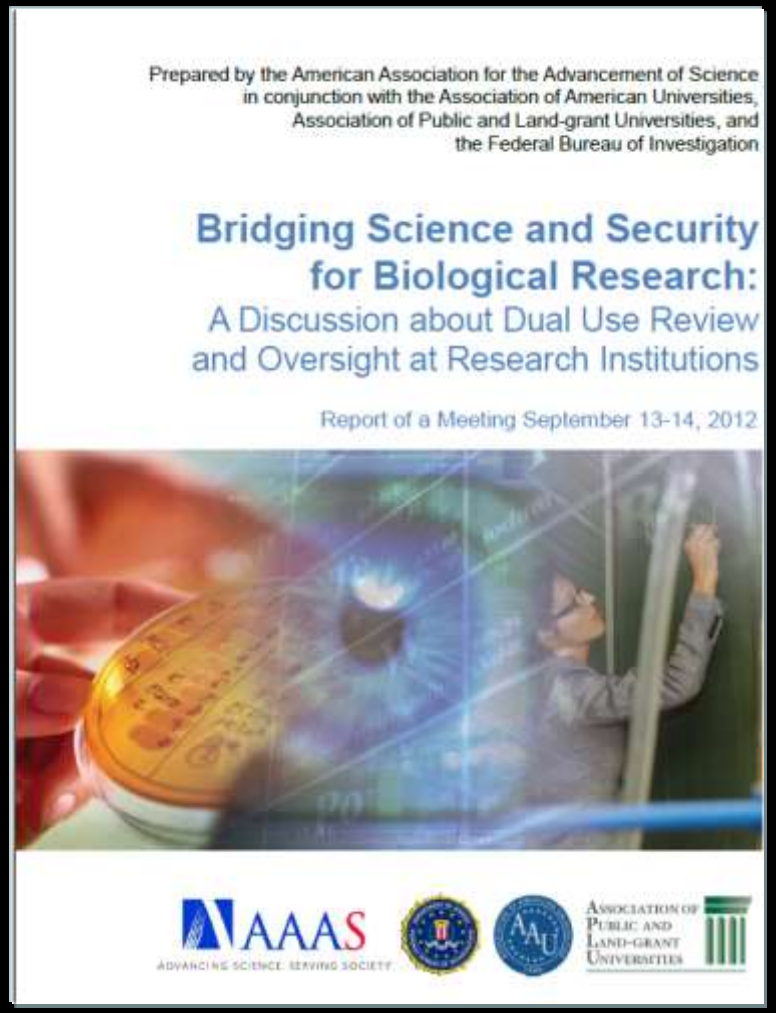
HISTORY John Dee's sweaving of scientific magic in the Elizabethan court p.160

CONSERVATION Trade in whale 'quotas' may be insufficient protection p.162

Pathogenic H5N1 avian influenza has led to the culling of hundreds of millions of birds. A human-transmissible form could have much worse consequences.

Adaptations of avian flu virus are a cause for concern

Members of the US National Science Advisory Board for Biosecurity explain its recommendations on the communication of experimental work on H5N1 influenza.



Prepared by the American Association for the Advancement of Science in conjunction with the Association of American Universities, Association of Public and Land-grant Universities, and the Federal Bureau of Investigation

Bridging Science and Security for Biological Research:

A Discussion about Dual Use Review and Oversight at Research Institutions

Report of a Meeting September 13-14, 2012

AAAS

ADVANCING SCIENCE, SERVING SOCIETY

Association of Public and Land-grant Universities

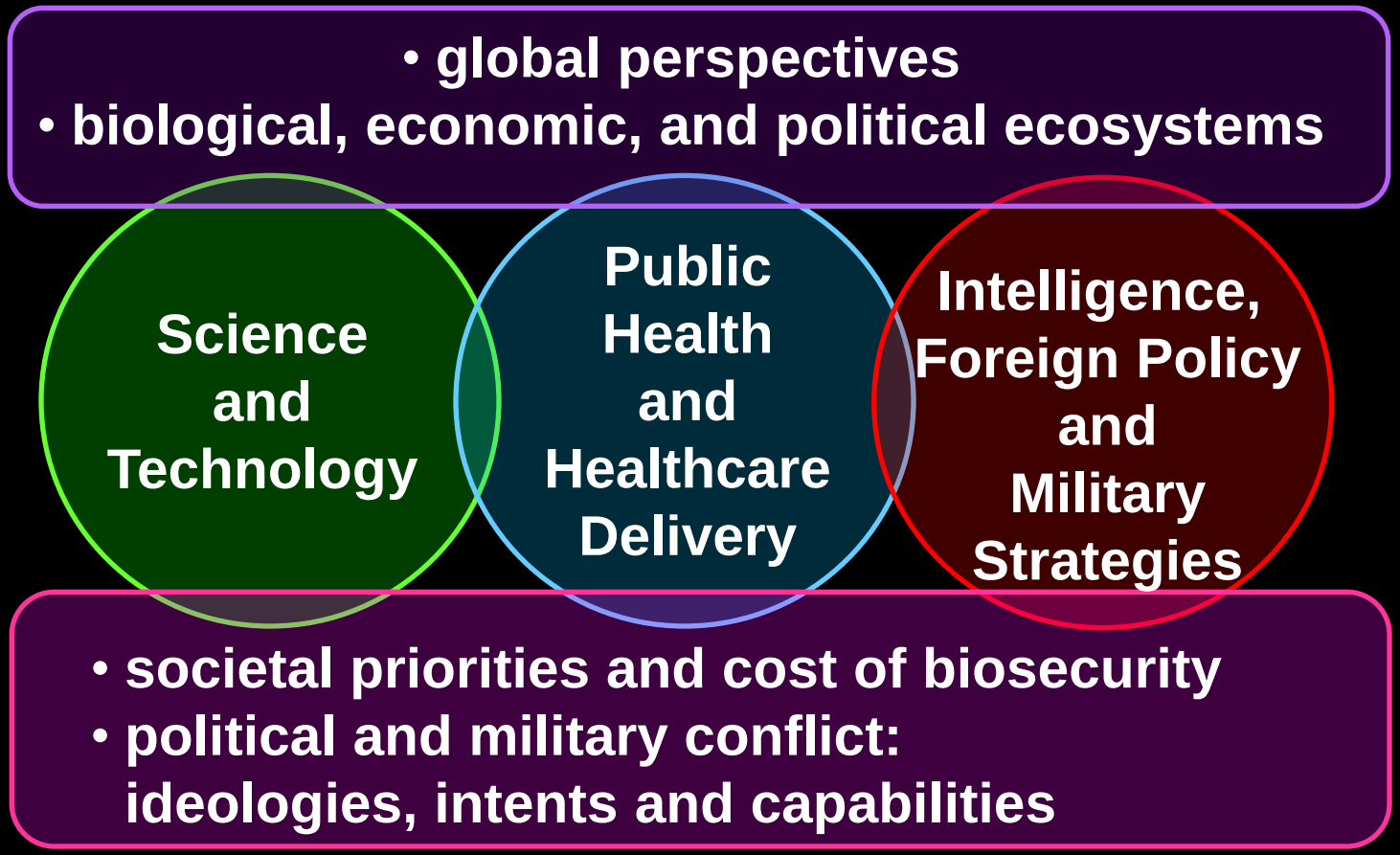
Biosecurity

- collective term embracing biodefense, public health and dual-use technologies
- fundamental but still politically neglected component in national security
- understanding how changes in biological systems threaten health and societal stability
  - directly and indirectly
  - infectious disease, food production
  - disruption of transportation and supply chains, economic loss and risk of civil disorder
  - ecosystem shifts and new patterns of disease
- chronic social and economic instabilities as triggers of political turmoil and military conflict

Biosecurity

- infectious diseases as dynamic foes
- relentless dynamic shifts in pathogen biology and geography (evolution at work!)
- reality: outpacing infectious diseases versus conquest
- preparedness: surveillance, infrastructure, personnel
- innovation and investment incentives: drugs, diagnostics and vaccines
- new (dual use) technologies and engineered threats
- risk assessment and proactive actions: public health and national security

Biosecurity:
A Classic Complex Systems Challenge



Biosecurity

one health:
humans
animals
ecosystems

urbanization,
environmental
sustainability
and
depletion of
non-renewable
resources

economic
and
political
instabilities
and
escalating
conflict risk

terrorism
and
international
security

**International Engagement,
Commitment and Political Resolve**

Building Robust Defenses for Biosecurity

- governments must accord higher priority to ‘biosecurity’ as a integral component of national security and foreign policy

- (re)building a national and international infrastructure for the surveillance, diagnosis and containment of infectious diseases is fundamental to future protection against major instabilities triggered by infectious agents, whether of natural or malevolent origins

“Politics is the art of the possible,
the calculated science of survival”

Prince Otto von Bismarck

“Survival owes little to the art of politics,
but everything to the calculated application
of science”.

Professor Rudolph Virchow
(in reply)

Slides available @ http://casi.asu.edu/