



# U.S. Nuclear Robotics: Yesterday, Today, Tomorrow

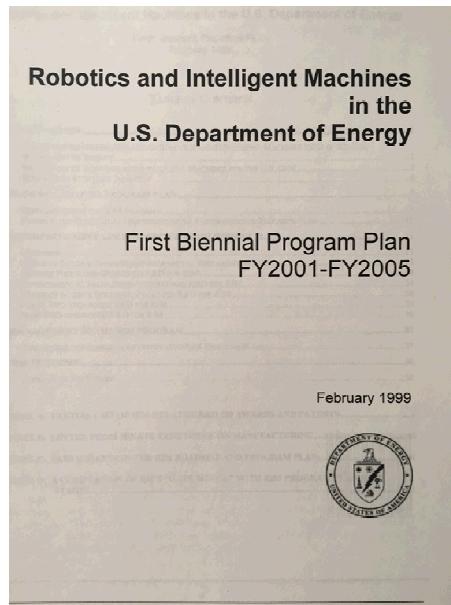
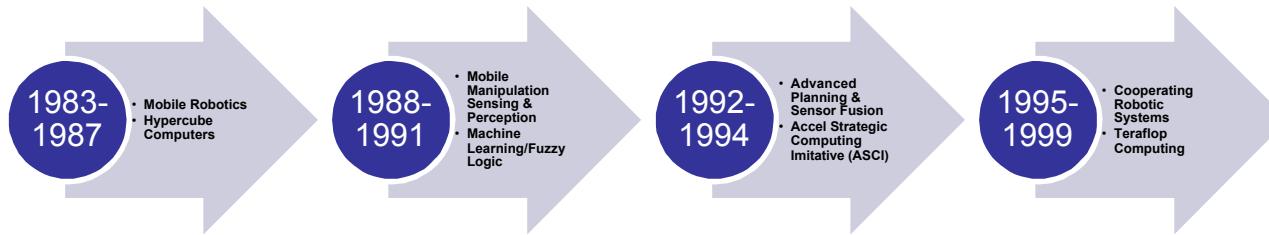
Perspectives on Tomorrow

**Philip Heermann, Ph.D.**  
**High Consequence Automation and Robotics**  
**Sandia National Laboratories**

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# U.S. DEPARTMENT OF **ENERGY**

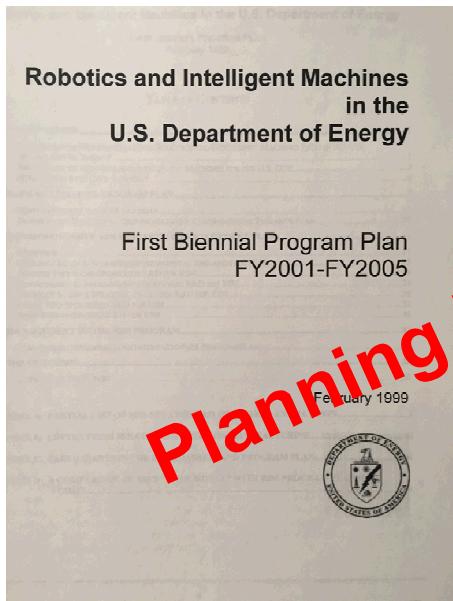
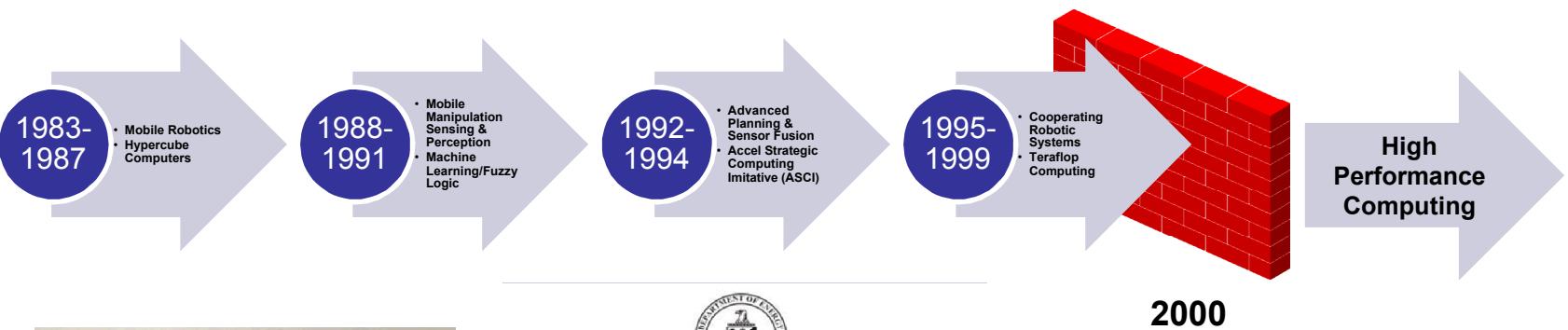


# DOE Robotics

## 1980's - 2000



# U.S. DEPARTMENT OF ENERGY

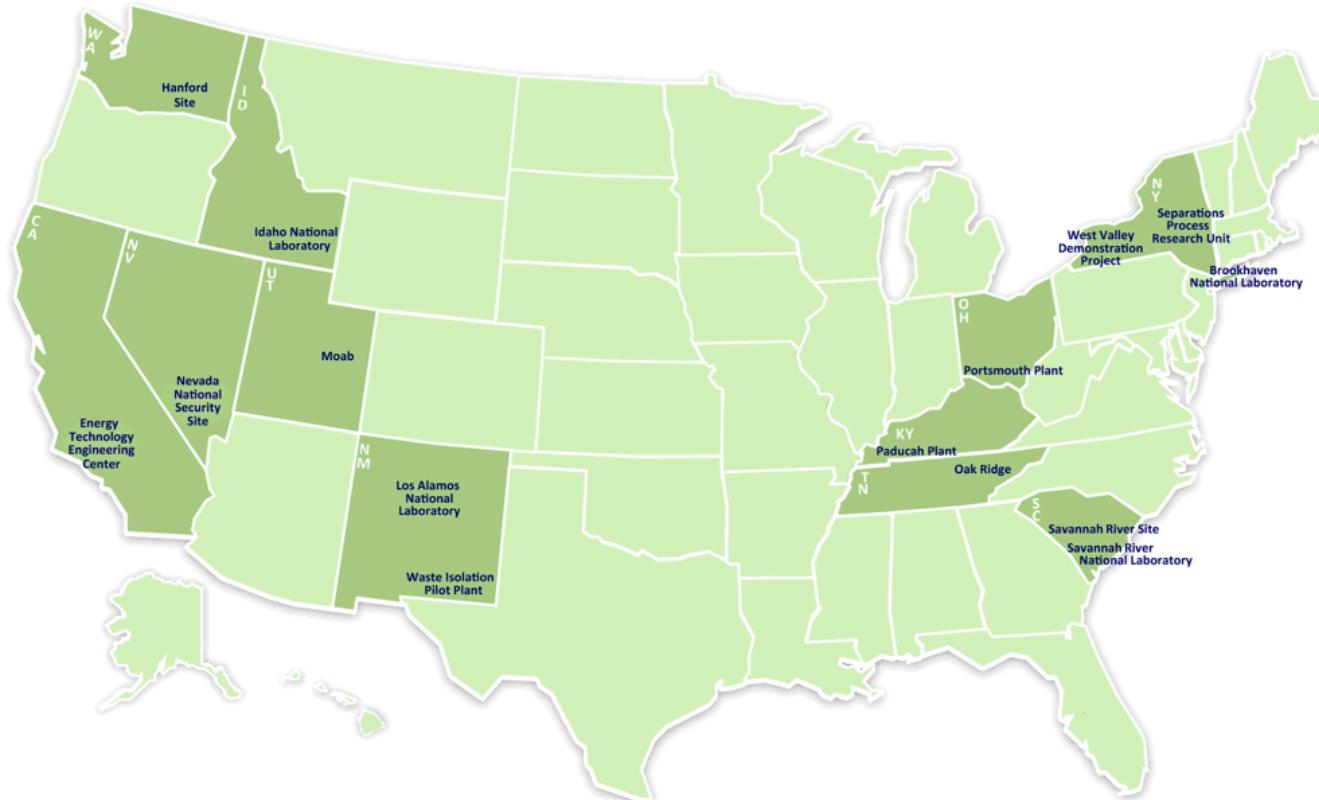


# Initial Scope of Legacy Cleanup



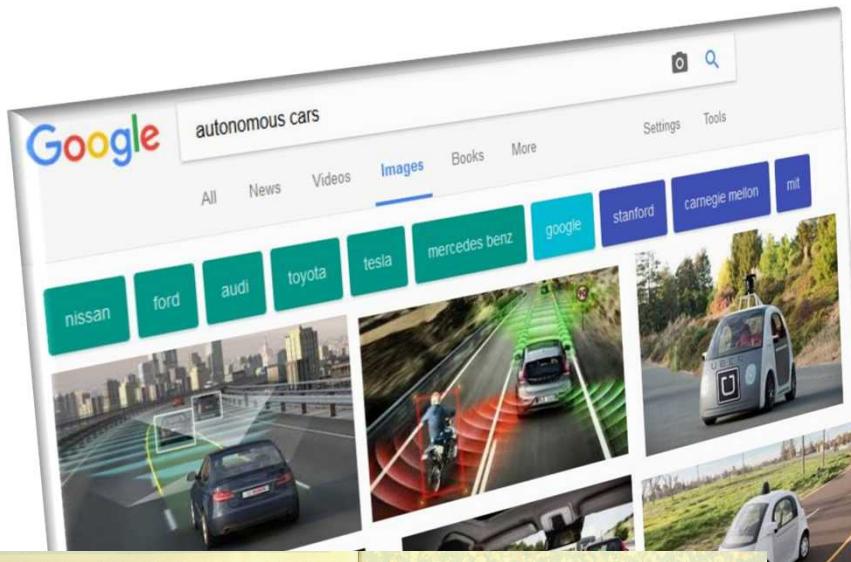
# Much completed... much more to go...

## Some of the most difficult challenges remain



- ❖ Completed legacy cleanup at 91 of the 107 major sites
- ❖ > \$152 billion spent
- ❖ Estimates of remaining cleanup
  - > \$250 billion
  - ≈ 2065 completion

## Meanwhile.....



“Apple supplier Foxconn expects robots to take over more factory work”

ComputerWorld Feb 27, 2015



"In three years, Foxconn will probably use automation to complete 70% of its assembly line work."

ComputerWorld Feb 27,  
2015



Popular Science March 2014



amazon

# Autonomy in Motion: Autonomous Vehicles Landscape

- Autonomy brings together multiple disciplines, market sectors, etc.
  - to create operational (and safe) systems

## AUTONOMOUS SOLUTIONS





# U.S. DEPARTMENT OF ENERGY

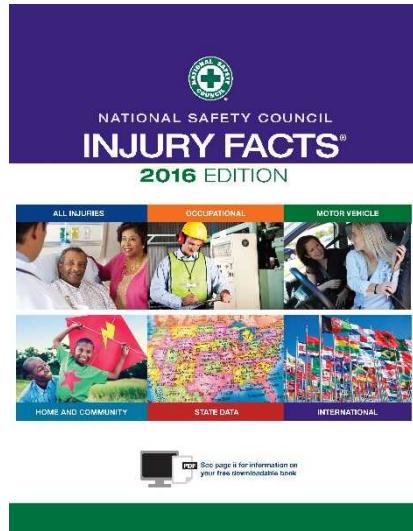
Robotics & Automation Spring  
2016 - present

# Current PPE protects from external hazards

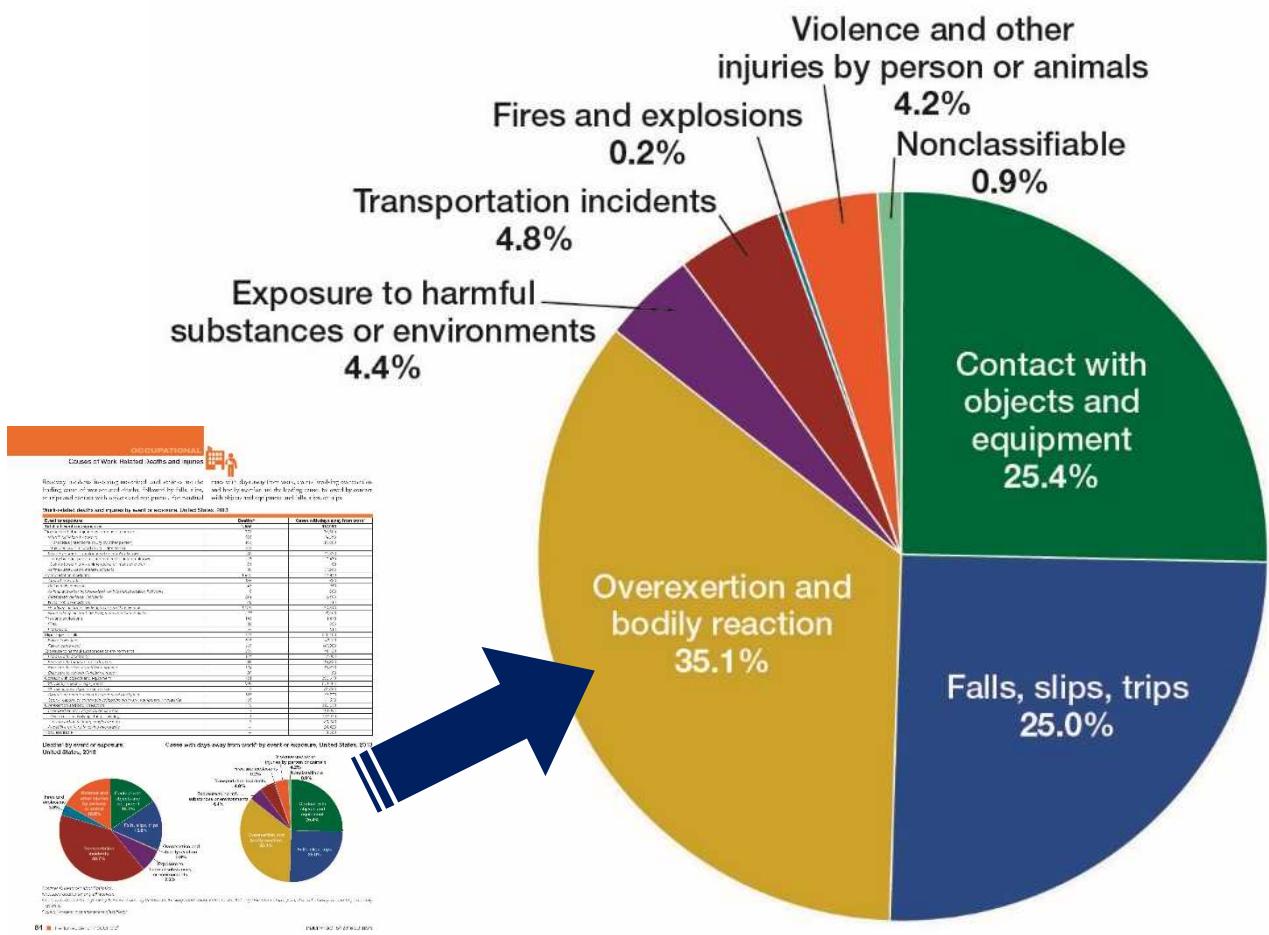
Current PPE protect workers from **external hazards** and exposures in the workplace



# Preventing Internal Injuries



Cases with days away from work by event or exposure. *United States, 2016*

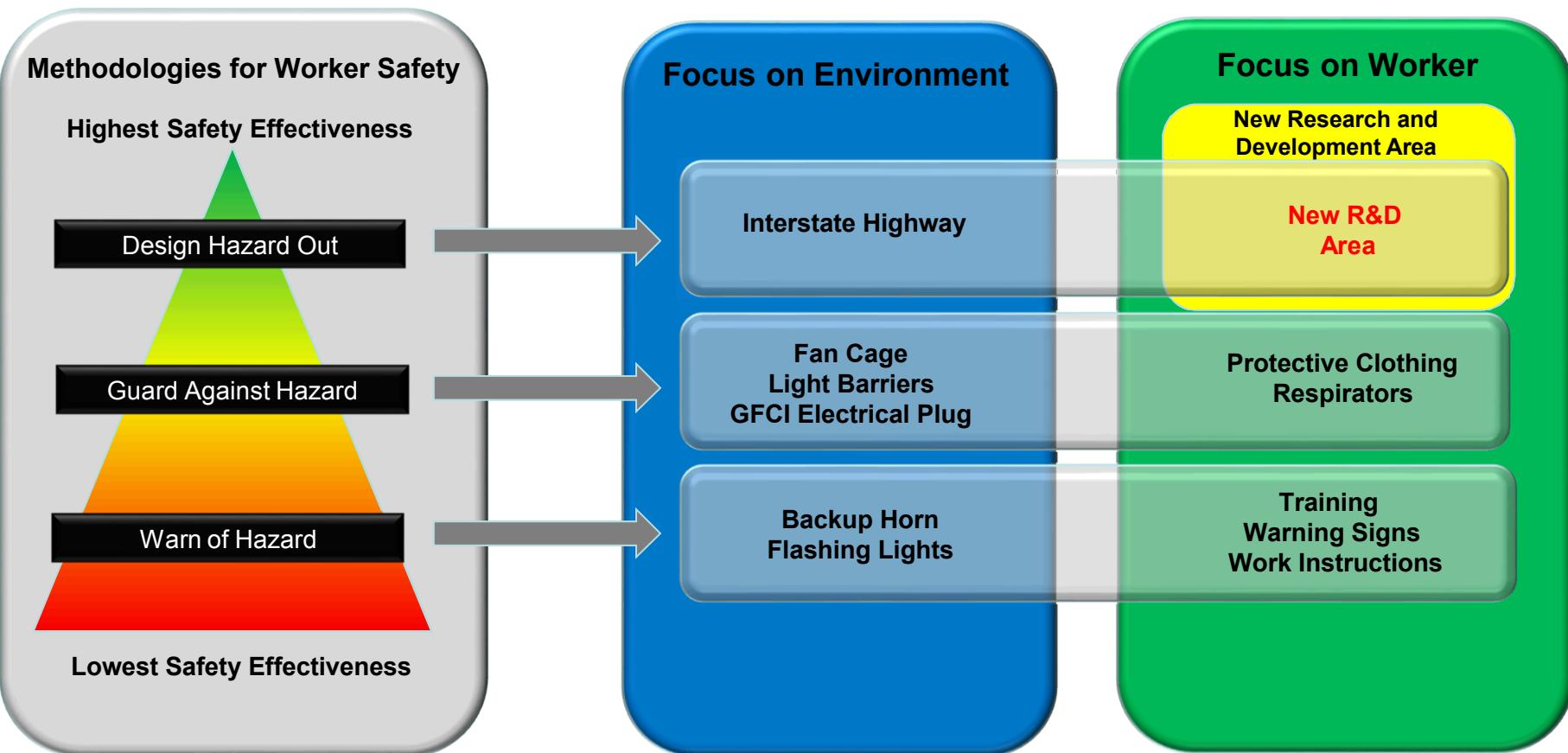


# Robotic PPE

**Robotic PPE** is intended to help protect workers from sustaining **internal injuries** due to forceful or over-exertion, fatigue, hyperextension, over-rotation, abrupt movements, repetitive motion or stress, repetitive or excessive vibration, awkward or prolonged postures, and possibly the latent effects of aging

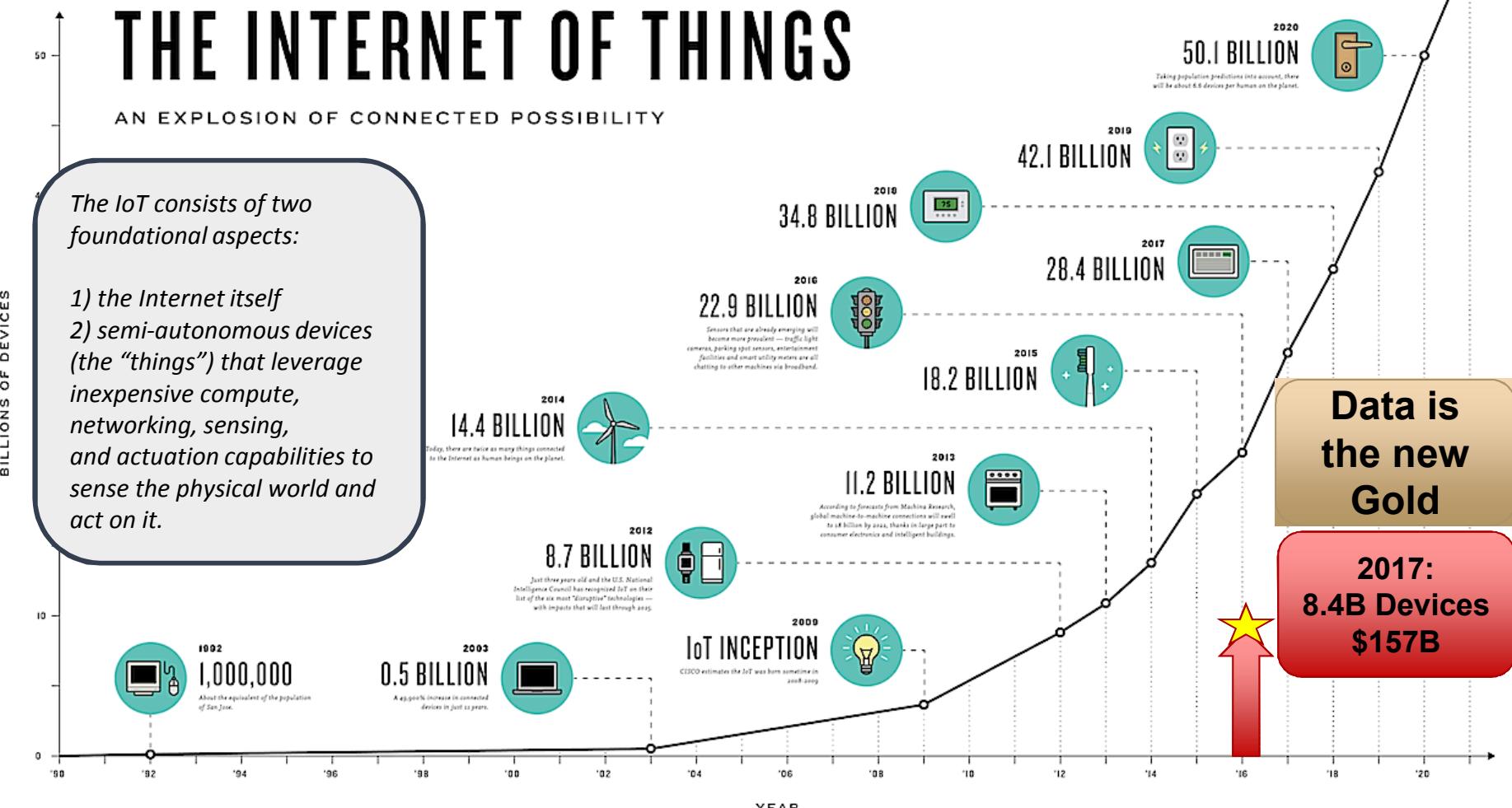


# New Area of R&D

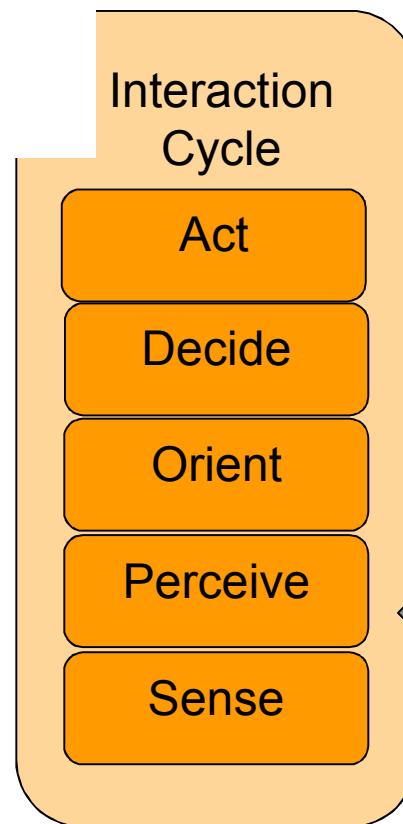
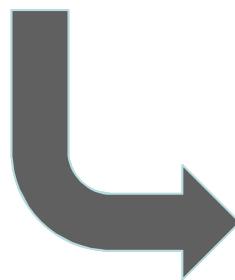
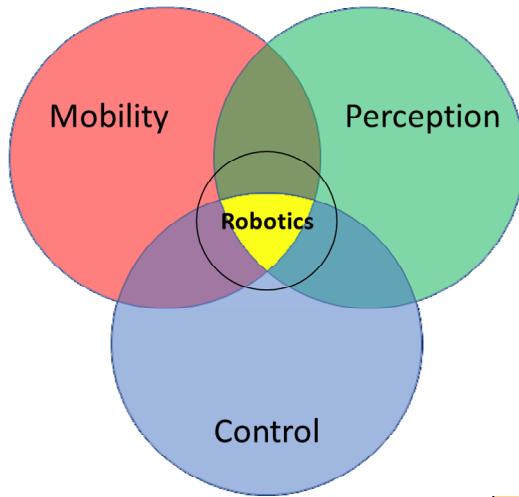


# Autonomy at Rest: *Internet of Things*

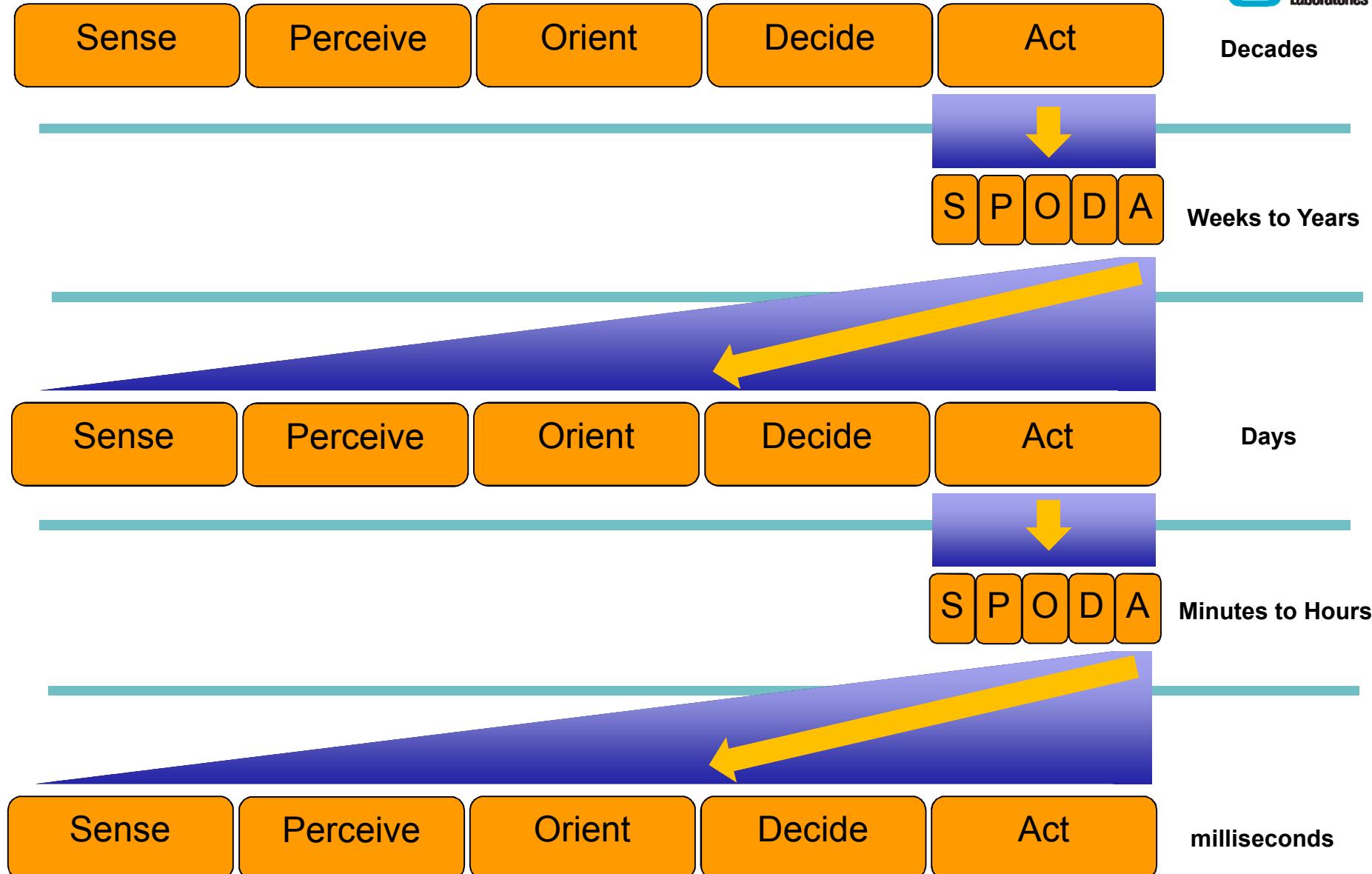
***The IoT will include 50 billion devices and each user of those gadgets will generate 1.5 gigabytes of data every day.***



# Three Classical Pillars of Robotics

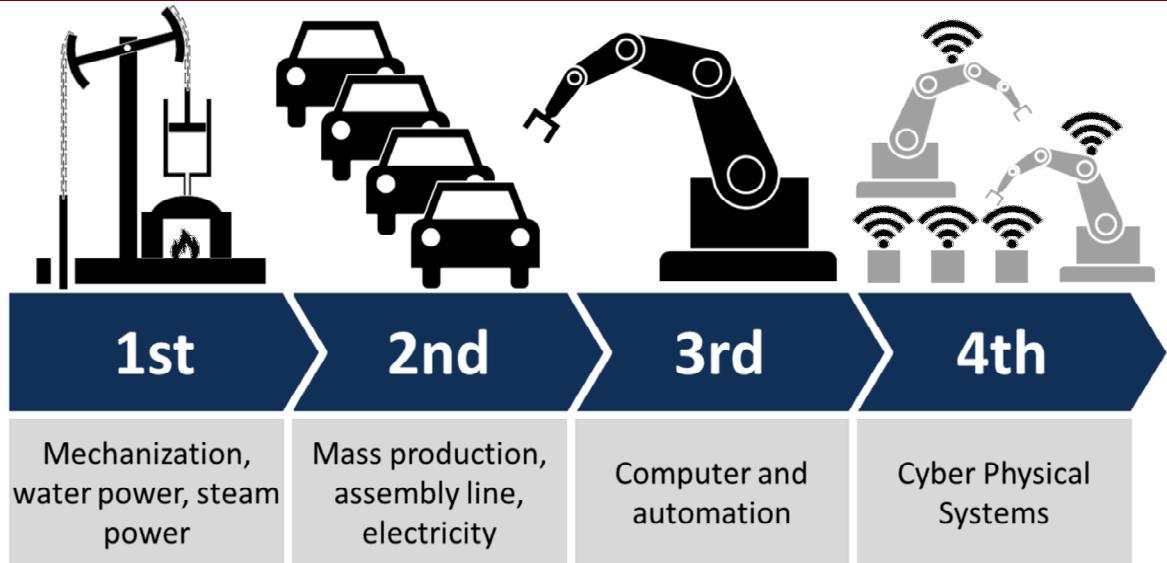


# Timescales



# Industry 4.0

**Industry 4.0** is the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the internet of things and cloud computing.



## Design Principles:

**Interoperability:** The ability of machines, devices, sensors, and people to connect and communicate with each other via the Internet of Things (IoT) or the Internet of People (IoP).

**Information transparency:** The ability of information systems to create a virtual copy of the physical world by enriching digital plant models with sensor data. This requires the aggregation of raw sensor data to higher-value context information.

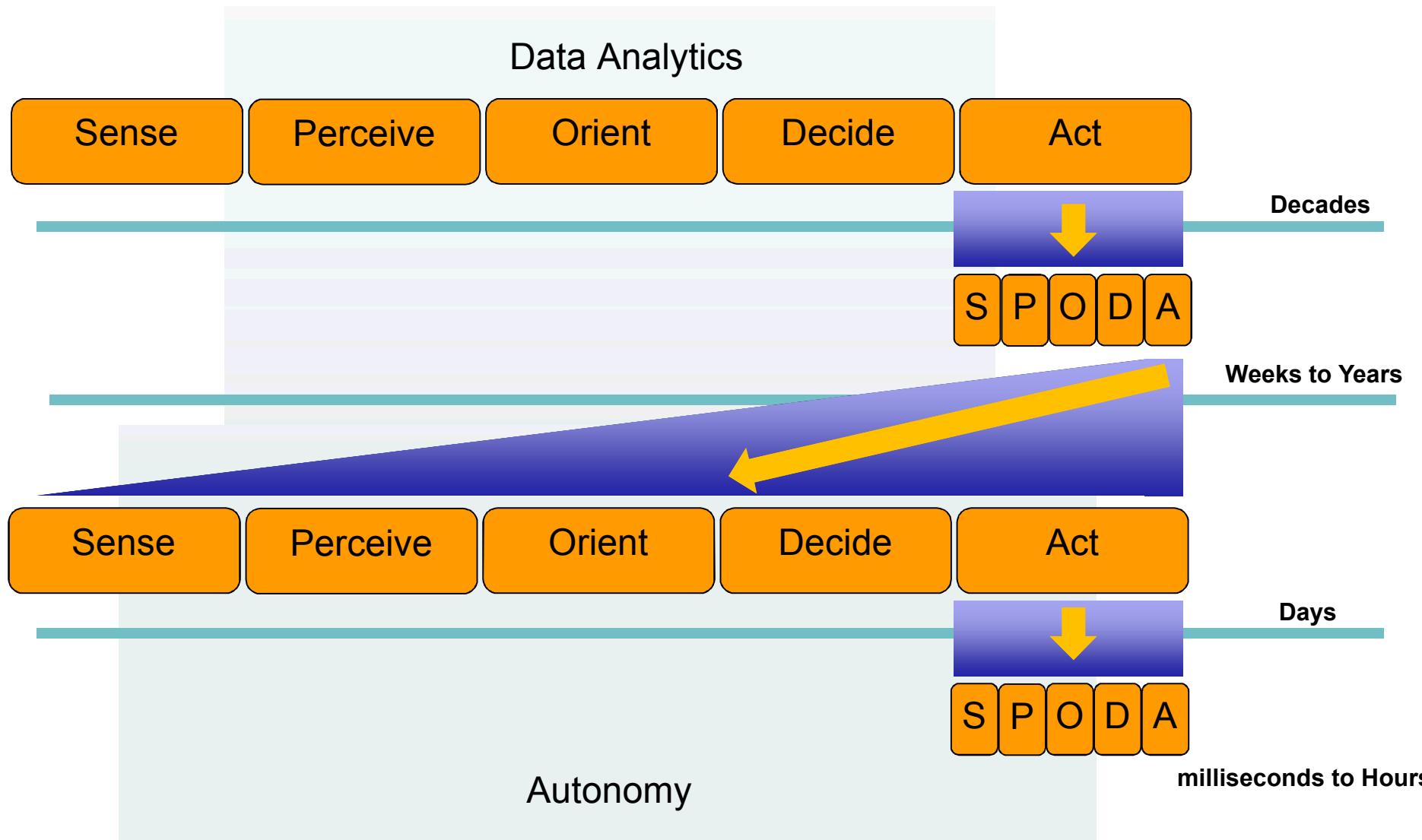
**Technical assistance:** First, the ability of assistance systems to support humans by aggregating and visualizing information comprehensibly for making informed decisions and solving urgent problems on short notice. Second, the ability of cyber physical systems to physically support humans by conducting a range of tasks that are unpleasant, too exhausting, or unsafe for their human co-workers.

**Decentralized decisions:** The ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of exceptions, interferences, or conflicting goals, are tasks delegated to a higher level.



# QUESTIONS?

# Data Analytics to Autonomy



# Roadmapping 1.0

1998-1999



**DOE offices contributing plans and guidance to the Roadmapping effort include:**

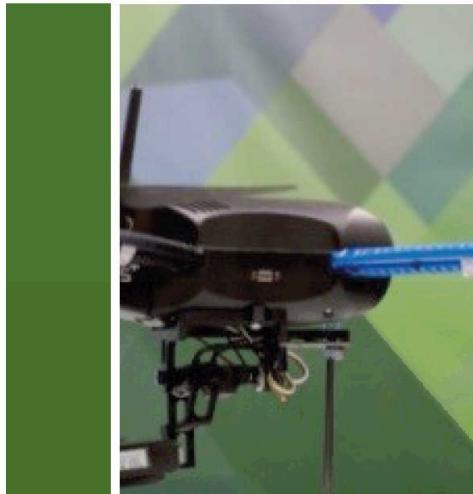
- **Defense Programs (DP)**
- **Fissile Materials Disposition (MD)**
- **Nuclear Energy Science and Technology (NE)**
- **Nonproliferation and National Security (NN)**
- **Environmental Management (EM)**
- **Energy Research (ER)**
- **Environment Safety and Health (EH)**
- **Energy Efficiency and Renewable Energy (EE)**
- **Fossil Energy (FE)**



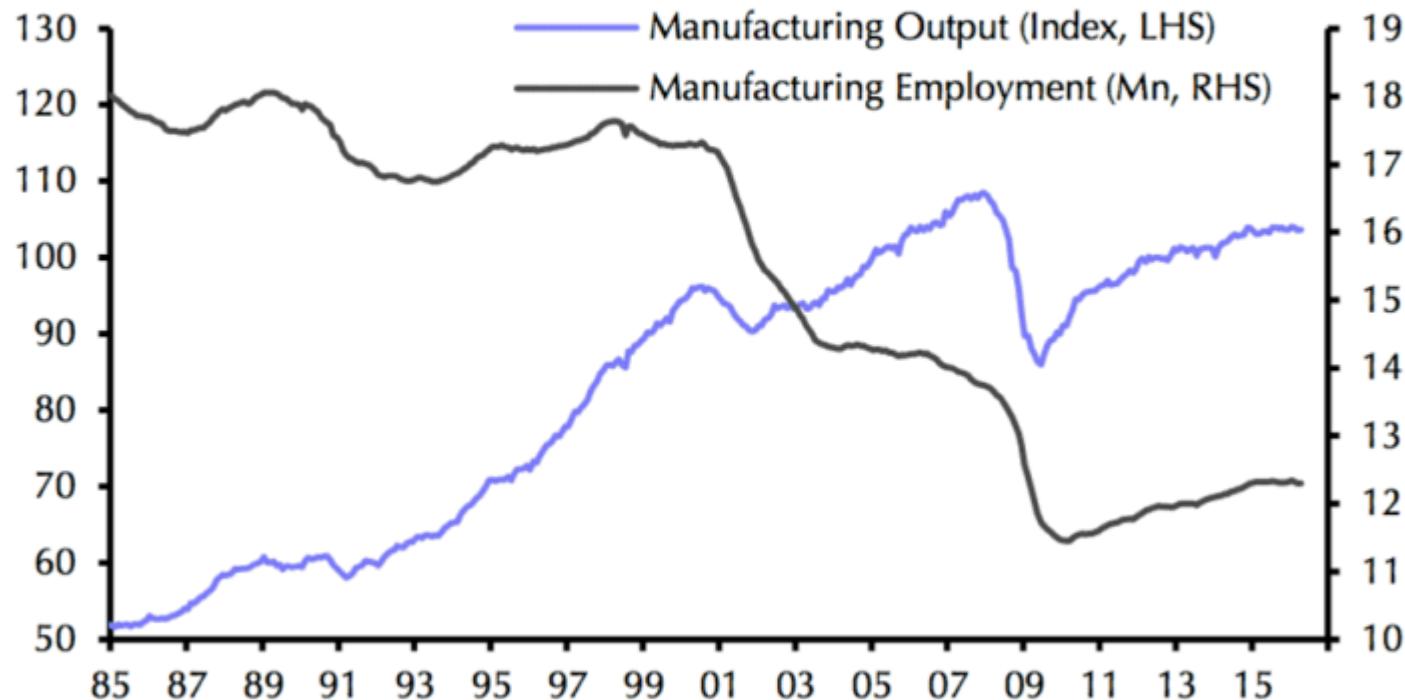
Robotics Program Included all Major  
DOE Program Offices

## DOE EM RESEARCH AND TECHNOLOGY ROADMAP

## ROBOTICS AND REMOTE SYSTEMS FOR NUCLEAR CLEANUP



2017

Markets  Chart of the Day**CHART 1: MANUFACTURING OUTPUT & EMPLOYMENT****Source – Thomson Datastream**

BUSINESS INSIDER

Source: <http://www.businessinsider.com/manufacturing-output-versus-employment-chart-2016-12>

# ATLAS Humanoid Robot Backflip



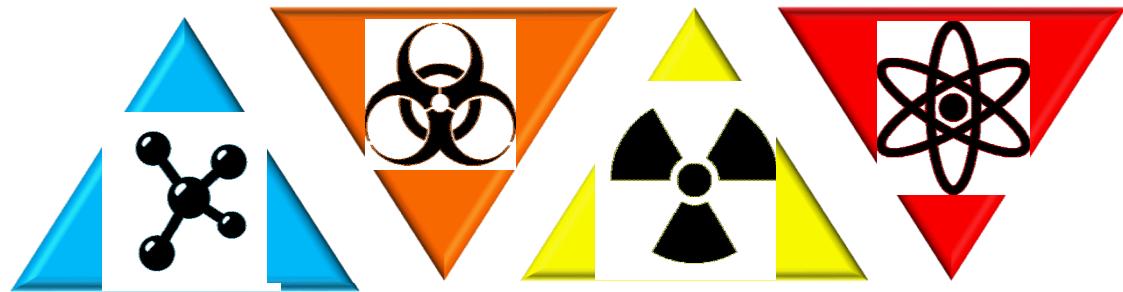
**Click Picture  
for link to  
Youtube video  
of Atlas  
Backflip**



# DOE Safety Perspective: ALARA

- Handling of high-hazard, high-consequence materials and waste

- Chemical
- Biological
- Radiological
- Nuclear



- Gaining remote access/entry to high-risk areas/spaces
  - Presence (potential) of CBRN materials
  - Unsafe, unstable, or unknown conditions
  - Configurations are hard to reach or beyond reach

# Future Workforce

**Infusing and integrating scientific and technological advancements into the routines of work planning and execution in a manner that**

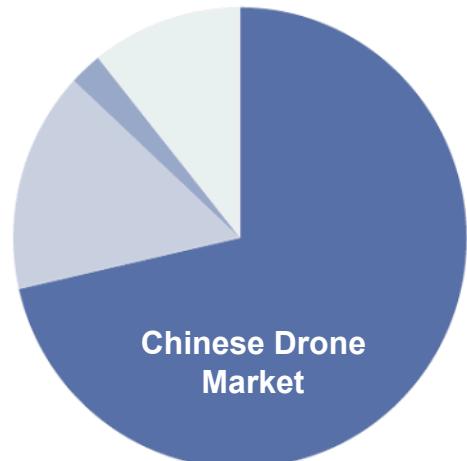
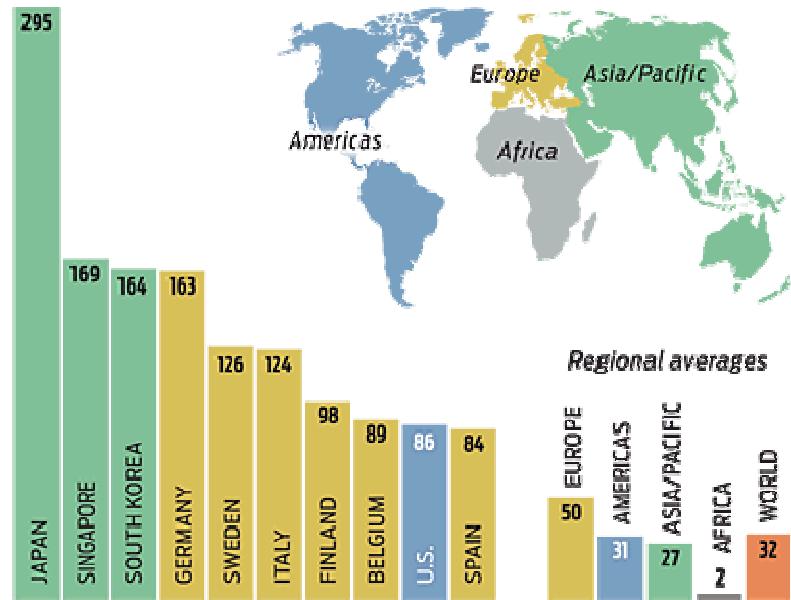
- 1) improves safety and quality and**
- 2) reduces the government's liability for cleanup**



# Competition in the World Robotic Market

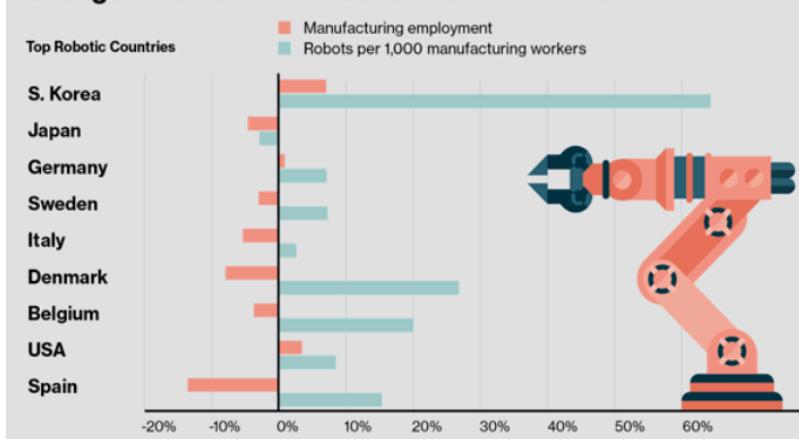
## TOP 10 COUNTRIES BY ROBOT DENSITY

(Industrial robots per 10 000 manufacturing workers)

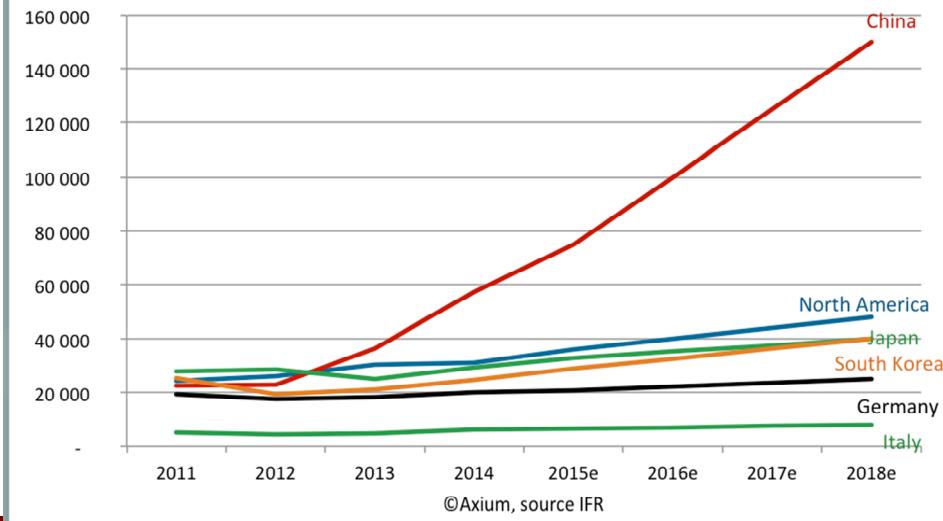


**Note: 3D Robotics has since gone out of the Drone Business**

## Change in Human Workers and Robots Since 2009



## Industrial robot yearly shipments



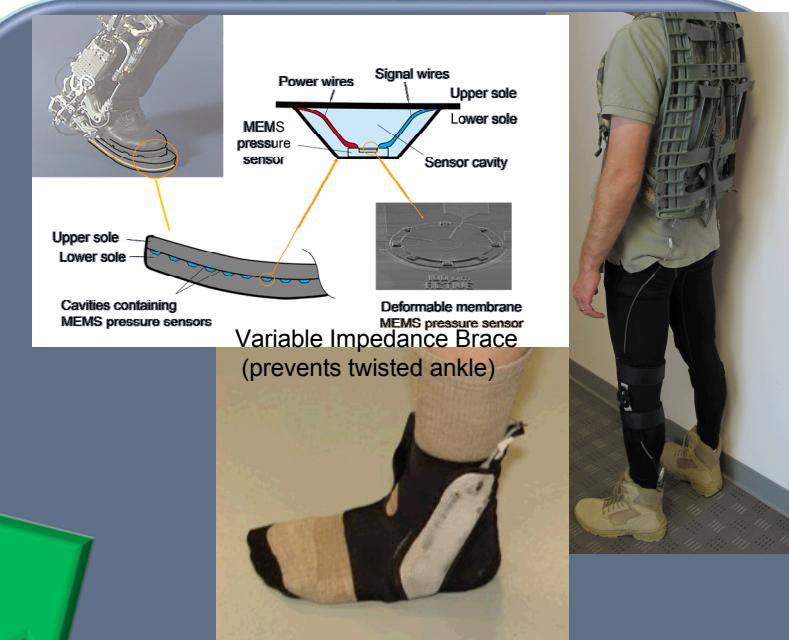
# Technology to Enhance Worker Safety and Performance

People Adapted to Enable Technology



Image in the Public Domain  
<https://www.awm.gov.au/collection/P03702.063>

Image in the Public Domain  
[https://commons.wikimedia.org/wiki/File:Ford\\_assembly\\_line\\_-\\_1913.jpg](https://commons.wikimedia.org/wiki/File:Ford_assembly_line_-_1913.jpg)



Technology to Enable People



TECHNOLOGY DEMONSTRATION	DEMONSTRATION LEADER
1. Machine Learning Pipe Crawler	1. Sandia National Laboratories
2. Modular Prosthetic Limb	2. John Hopkins University Applied Physics Lab
3. Virtual Reality Immersive Teleoperation	3. Open Source Robotics Foundation (A non-profit org)
4. Radiation Robotic Rabbit	4. Exelon/State University of New York (Oswego)
5. Serpentine and Modular Robotics	5. Carnegie Mellon University
6. Swabbing Unmanned Aerial Vehicles (UAVs)	6. Purdue University
7. Forklift Automated Safety System	7. Southwest Research Institute
8. Human-Centered Robot-Robot Teams	8. Texas A&M University and Endeavor Robotics
9. Mobile Systems for Inspection	9. University of Texas - Austin
10. RoboGlove	10. NASA Johnson Space Center
11. Virtual and Augmented Reality Modeling	11. Savannah River National Laboratory
12. Robotic Inspection of Cylinders	12. Sandia National Laboratories

# ROBOTICS DEMONSTRATIONS:

PORSCMOUTH GASEOUS DIFFUSION PLANT,  
AUGUST 2016