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# How IAEA Safeguards Work

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IGA-232, Controlling the World's Most Dangerous Weapons

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# What safeguards do, and don't do

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- ◆ Safeguards intended to provide “timely detection” of undeclared diversion or production of nuclear material
  - Like an alarm bell -- what the international community chooses to do in response to the alarm is not up to the IAEA
  - *If* states fear the consequences of detection, chance of timely detection may deter illicit activities
  - Inspectors cannot physically *prevent* states from using material, facilities for weapons purposes
  - Allows civilian nuclear energy to proceed with some confidence it will not be used for weapons
- ◆ Despite the name, safeguards do *not* provide:
  - Safety
  - Guarding

# Some provocative bottom lines

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- ◆ The NPT has been highly successful *even though* its verification system has been weak for much of its existence
  - Must be something going on besides solving the rational-actor collective action problem
- ◆ Traditional safeguards offer reasonable – though imperfect – performance for most types of *declared* facilities (where inspectors know where to look)
  - Most states would probably consider risk of being caught diverting from declared facility too high for that to be the favored route
- ◆ New safeguards approaches, combined with national intelligence, offer a significant chance, but not high confidence, of detecting *covert* nuclear material production
- ◆ Can only detect weaponization if the world gets lucky

# IAEA safeguards – a sense of scale

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- ◆ 1,314 facilities or other locations in 179 states, ~150,000 tons of nuclear material (>183,000 significant quantities) under safeguards (as of end of 2012)
- ◆ ≈10,000 person-days of inspection/yr, €146.7M IAEA safeguards budget in 2012 (~same as Vienna police department)
- ◆ Primarily implemented in non-nuclear-weapon states; a few facilities in weapon states under “voluntary offer”; some facilities in non-NPT states safeguarded when supplier required it
- ◆ NPT member states have repeatedly expressed confidence that IAEA safeguards verify states are complying

# 5 paths past safeguards to the bomb

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- ◆ No non-weapons obligation, material produced in dedicated military facilities with no safeguards
  - All 5 NPT weapon states, India, Pakistan, Israel (though some non-verified peaceful use assurances in latter cases)
- ◆ Join NPT, accept safeguards, build needed facilities, then withdraw and expel inspectors
  - N. Korea (sort of -- never had full safeguards) -- Iran in the future?
- ◆ Join NPT, accept safeguards, divert material from declared, safeguarded facility
  - This is *only* path traditional IAEA safeguards designed to detect
- ◆ Join NPT, accept safeguards, build covert facilities
  - Iraq, N. Korea (U program), Libya, Syria -- Iran???
  - Additional Protocol designed to help detect
- ◆ Purchase or steal weapon or weapon material

# 2 paths are focus of safeguards

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- ◆ *Divert nuclear material from declared facility*
  - Focus of traditional safeguards
  - Additional Protocol measures (e.g., complementary access, environmental sampling) also help
- ◆ *Produce nuclear material at covert facility*
  - Not addressed effectively by traditional safeguards
  - Additional Protocol measures offer *some* potential (especially combined with information supplied by national intelligence agencies)
  - Not high confidence – but overall, no state has ever come close to nuclear weapons capability without detection (yet)
  - IAEA: without Additional Protocol, “the Agency does not have sufficient tools to offer credible assurance regarding the absence of undeclared nuclear material”

# Traditional safeguards

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- ◆ Traditional safeguards use “material accountancy” and “containment and surveillance” to provide *timely detection* of diversion of *significant quantities* of nuclear material, and to *deter* such diversion by the *risk of detection*
- ◆ Significant quantities:
  - Pu or U233: 8 kg
  - HEU: 25 kg contained U-235
  - *Bombs can be made with less -- a key issue*
- ◆ Timeliness goal:
  - 1 month for unirradiated Pu or HEU (incl. MOX)
  - *Longer than estimated conversion time – another key issue*

# Traditional safeguards (II)

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- ◆ INFCIRC/153 -- traditional safeguards agreement -- negotiated at a time when nuclear energy expected to be crucial to national economies, non-nuclear-weapon states concerned to prevent safeguards from interfering, or offering commercial advantage to weapon states
- ◆ INFCIRC/153 limits IAEA to “minimum” info “consistent with carrying out its responsibilities” -- verification mainly limited to few “strategic points” in declared facilities
- ◆ Result: IAEA inspectors’ culture of not asking too many questions, not being aggressive investigators (over-generalization -- contrary cases exist, such as Taiwan)



# Material accountancy

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*MUF* (*M*aterial *U*naccounted *F*or) =

Beginning inventory + Additions to inventory - Ending inventory - Removals from inventory

- ◆ Because of measurement uncertainties, all bulk facilities have some MUF – but does it mean a real loss?
  - $\sigma\text{MUF}$  -- standard deviation of MUF -- is measurement precision
  - If  $\text{MUF} >$  than some threshold level -- usually  $3 \sigma\text{MUF}$  -- IAEA rejects the hypothesis that real MUF is zero, investigates possibility that diversion has occurred
- ◆ For item facility (e.g., LWR),  $\text{MUF}=0$  unless something is missing

*These days MUF sometimes called “inventory difference” or ID*

# International accountancy standards

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Facility Type	<u>Relative STD (%)</u>
Uranium enrichment	0.2
Uranium fabrication	0.3
Plutonium reprocessing	1.0
Plutonium fabrication	0.5
Scrap store	4.0
Waste store	25.0

*Source: IAEA Inspector Training Course*

# Containment and surveillance

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- ◆ Containment and surveillance complements material accountancy by (a) detecting unusual activities, (b) confirming there has been no removal of material from measured, sealed containers
- ◆ Typical measures include:
  - Surveillance cameras
  - Tamper-resistant seals (which will be broken if sealed item is opened)
  - Tamper-resistant tags (uniquely identify particular measured items)
- ◆ What happens when cameras go out, seals break? Often, re-inspection required
- ◆ Clearly, containment and surveillance contribute to safeguards confidence – but no one has come up with a way to measure how much better accountancy is with containment and surveillance added

# Accountancy and inspection

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- ◆ Like bank auditor, inspectors don't actually count all the money (measure all the material). Instead:
  - *examine records* provided by operator
  - inspect *statistical samples* of total quantity of material (based on the risk of the diversion they are attempting to detect) to build confidence records are accurate
  - in modern, automated facilities, often rely on in-line measurement equipment built by the operator -- premium on validating that measurements are accurate and unbiased
  - inspector must be able to make *independent judgment* -- not simply believe what the operator says
- ◆ Difference between inspector's measurements and operator's measurements is *MUF-D*

# 4 diversion paths

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- ◆ Diversion into MUF: “Gee, we can’t figure out where that missing material went” (no attempt to falsify records)
- ◆ Diversion into MUF-D: “Gee, I don’t know why your measurements show less than mine do” (typically would require falsifying operators accountancy records)
- ◆ Diversion with faking/tampering: “Gee, I hope they don’t notice that we added more plutonium to their solution samples to make our Pu concentrations look higher”
- ◆ Diversion with safeguards plausibly disrupted: “Gee, when we had that fire, our records were destroyed, and the firefighters threw out a bunch of contaminated material -- that must be where that plutonium went.”

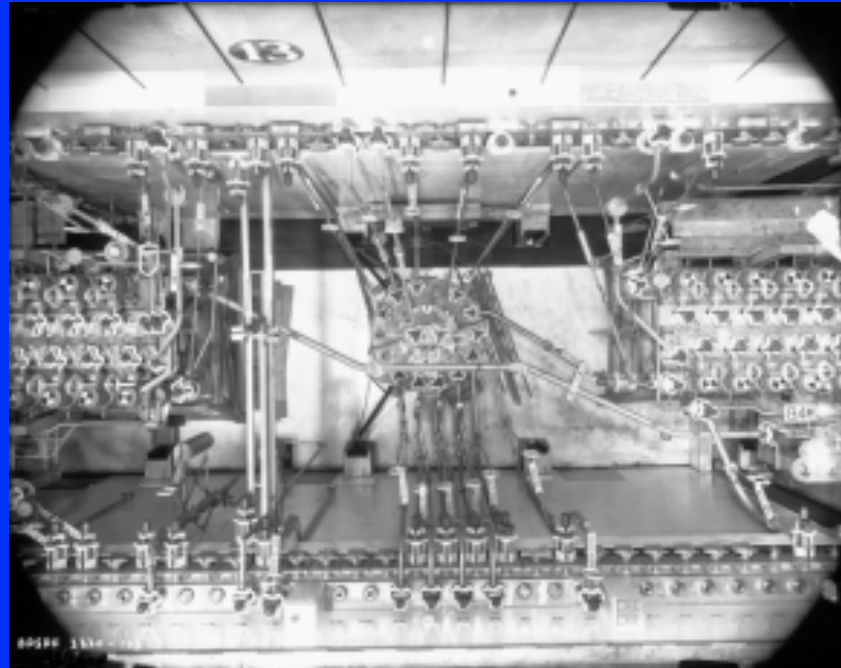
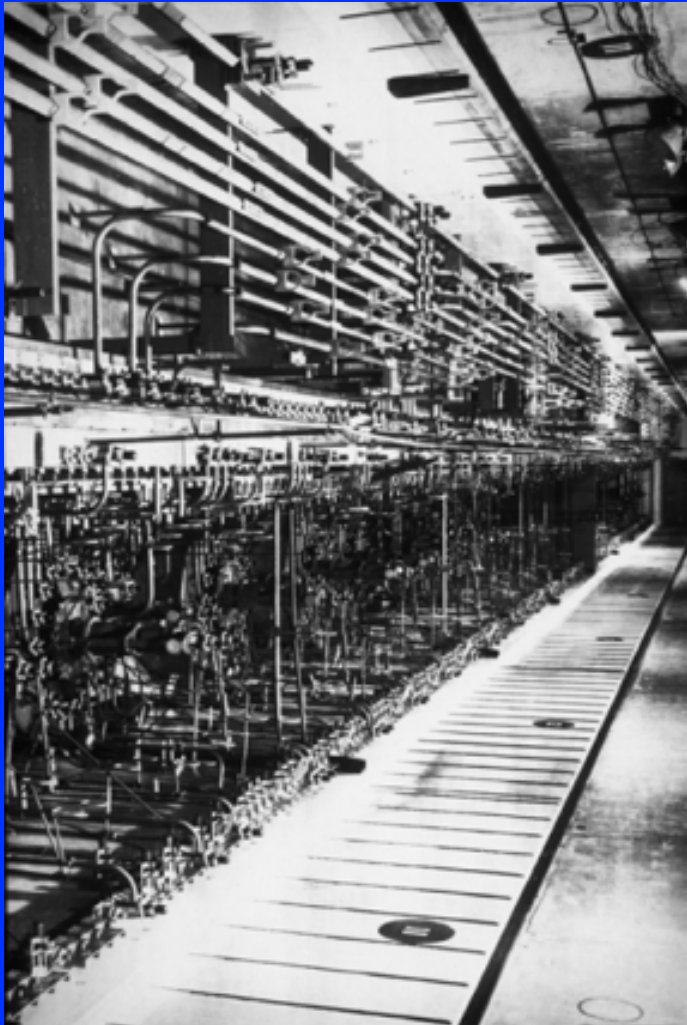
# Safeguarding a reprocessing plant

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- ◆ Large commercial plant: 800 MTHM/yr, ~8 tPu/yr
- ◆ 1 close-out for measured inventory/yr
- ◆ 1% uncertainty  $\approx$  80 kg Pu
- ◆ If only challenge if  $MUF > 3 \sigma_{MUF} \rightarrow$  240 kg Pu
- ◆ Also, can't meet timeliness goal with 1 inventory/yr
- ◆ Partial solutions:
  - Comprehensive transparency and containment and surveillance throughout plant – monitor all flows, detect all unusual activity
  - Near-real-time accountancy – much more frequent partial measurements of material in process, with statistical models designed to detect both abrupt and protracted diversions

# Reprocessing plant piping

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*Sources: DOE*

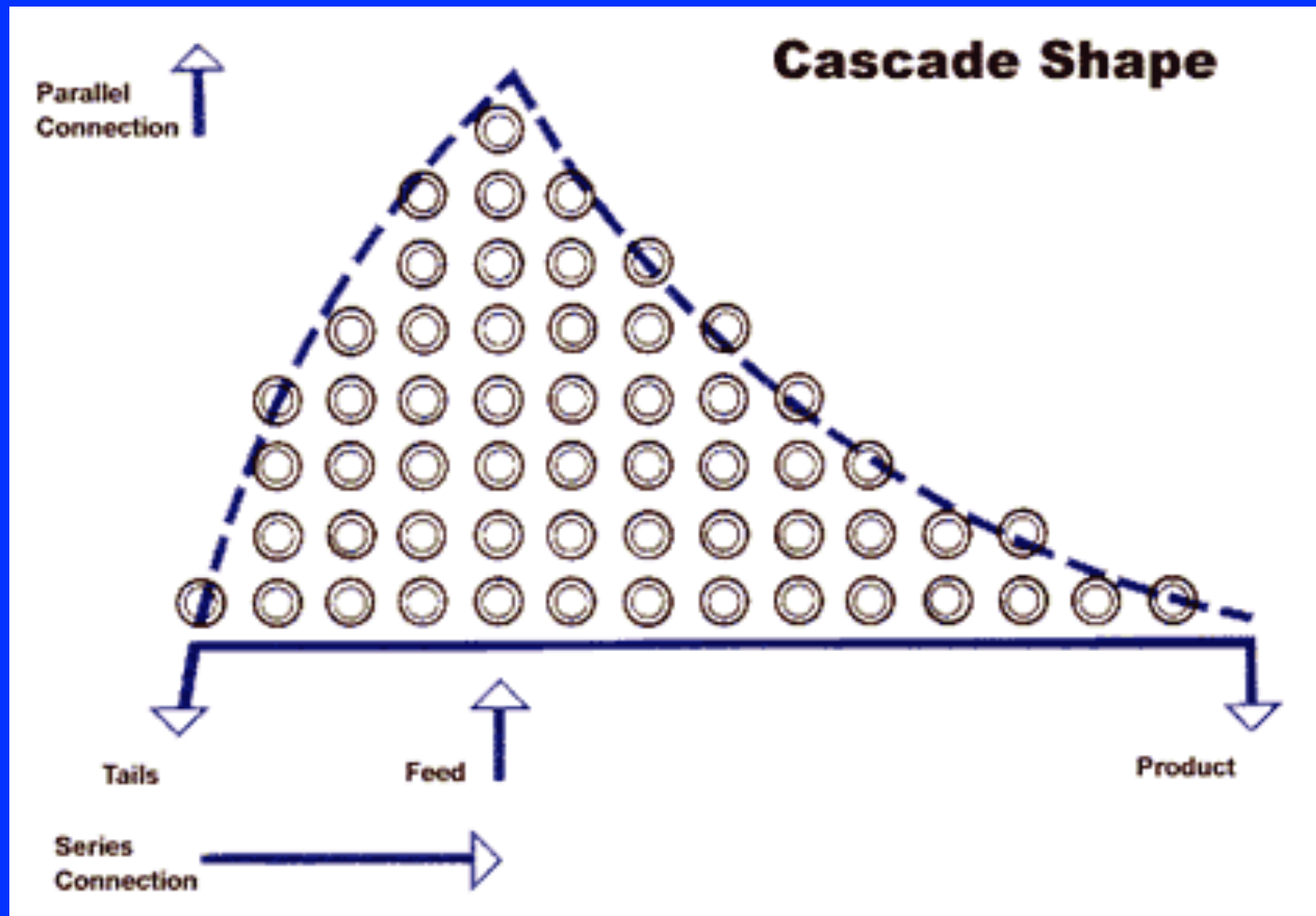
# Example: some failures in Iran

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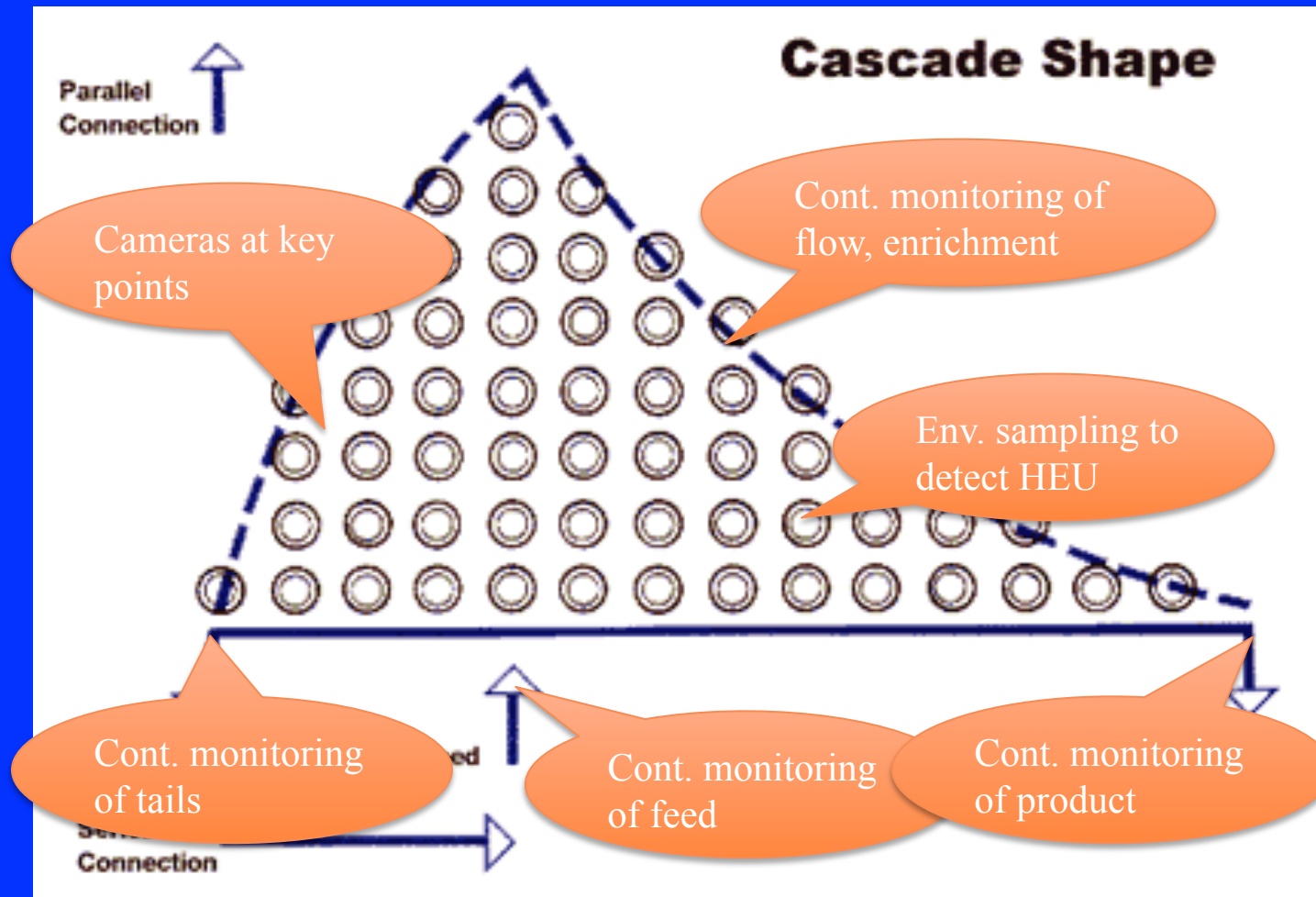
- ◆ 18-year centrifuge program undeclared, undetected by traditional safeguards
- ◆ Iran imported 100s of kgs of U from China without reporting it – no detection for > a decade
- ◆ Iran converted 100s of kgs of U to metal – no reporting, no detection, for years
- ◆ Iran conducted centrifuge tests with UF<sub>6</sub>, lied to the IAEA in saying it had not done so, was detected years later
- ◆ Traditional safeguards only designed to monitor *declared* activities – little capability to address *secret* activities
- ◆ *However*, once *other* sources informed IAEA of what was happening, IAEA has done a very professional job at peeling back successive layers of Iranian lies



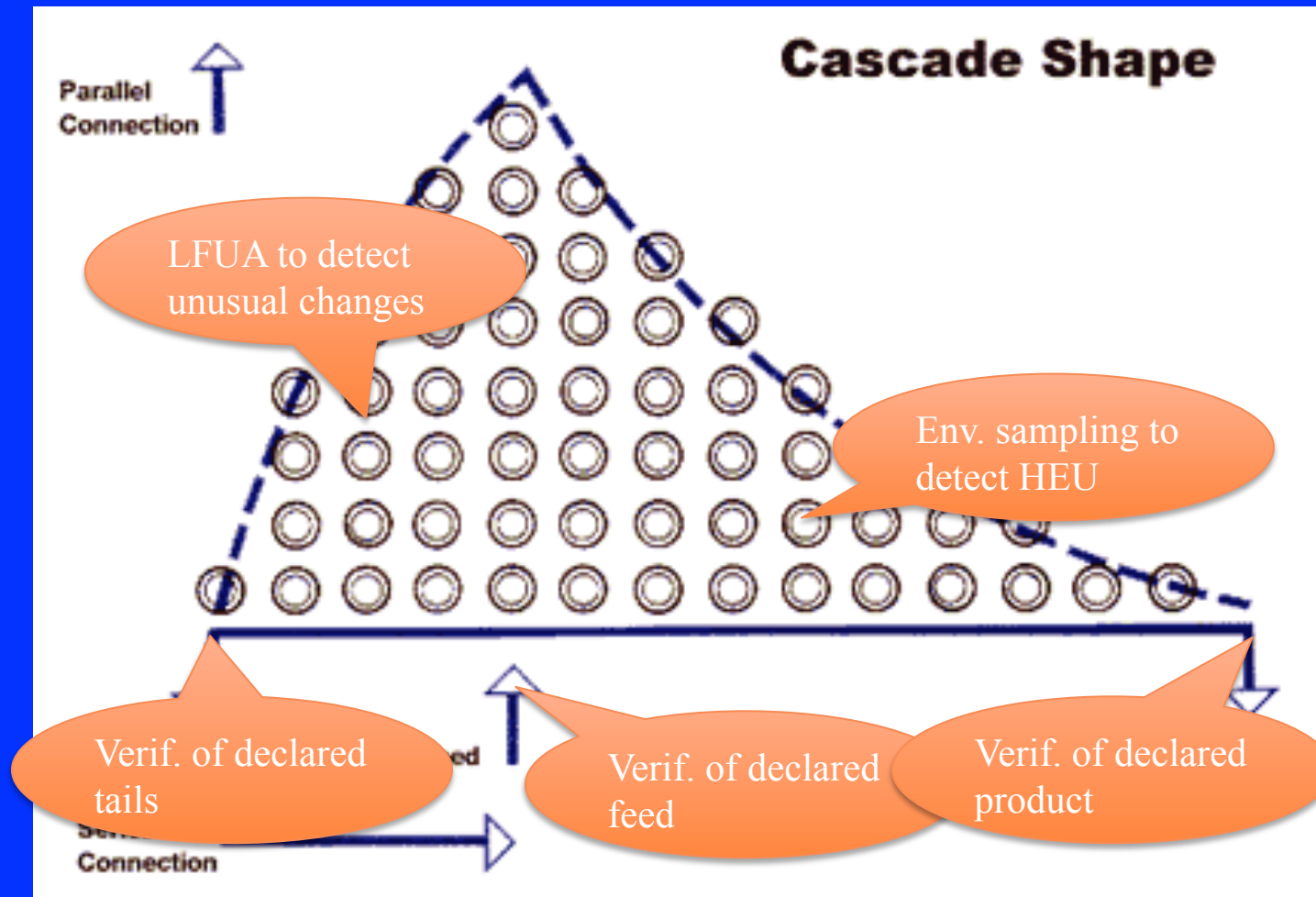
# Safeguards for a centrifuge plant



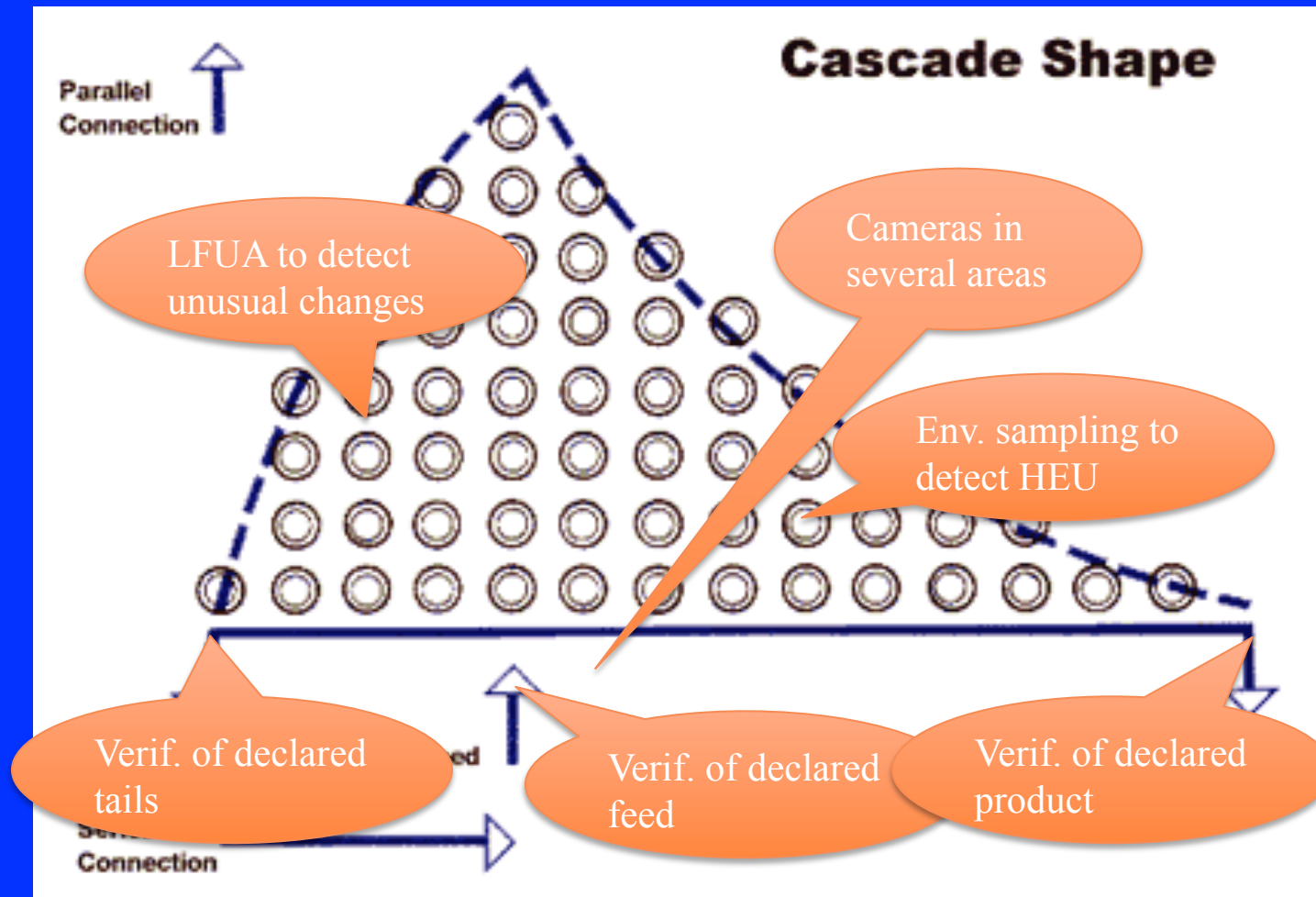
# Safeguards for a centrifuge plant: What you might like to have



# Safeguards for a centrifuge plant: What you actually have



# Safeguards for a centrifuge plant: What you actually have (Natanz)



# Example: safeguards at Natanz

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- ◆ Iran reports on feed to the enrichment cascade, product, tails
- ◆ IAEA has “containment and surveillance” measures – including cameras at the feed input point and the product withdrawal point – to ensure that material is neither added nor removed without detection (material under seal)
- ◆ “Unannounced” inspections (inspectors travel from Isfahan) roughly once/month
  - Check no rearrangement of piping to produce HEU
  - Swipe samples could detect particles of HEU (but takes weeks)
- ◆ Actual measurement of all material on-hand (Physical Inventory Verification) only once/year
  - In late ‘08, found more product, less tails, than Iran had *estimated* – but this was *Iran’s measurement*, verified by the IAEA

# Safeguards at Natanz: some issues

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- ◆ Would the IAEA detect HEU production?
  - Almost certainly yes. Would show up in environmental samples (weeks), repiping would be noticed in  $\approx$  monthly inspections, batch processing would be noticed by cameras
  - *But*, could take weeks to detect, debate, explain, confirm
  - As Iran adds more centrifuges, time required to produce significant amounts of HEU declines, IAEA demanding additional measures to improve timeliness
- ◆ Would the IAEA detect additional LEU production?
  - Probably. Removal of some product made from declared feed might be disguised as losses to waste; undeclared product could be made from undeclared feed; but cameras might detect additional feed or removals
  - Availability of unsafeguarded LEU UF<sub>6</sub> could greatly ease HEU production in covert facility

# Safeguards implementation realities

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From the 2002 *Safeguards Implementation Report* (courtesy of Iranian ambassador to the IAEA Salehi):

- ◆ 357 facilities under safeguards worldwide with at least 1 significant quantity (SQ) of nuclear material
- ◆ Of these, 34 facilities in 15 states failed to fully attain quantity goal (that is, safeguards would not have been able to detect diversion of an SQ with desired confidence)
- ◆ 32 facilities in 15 states failed to fully attain the timeliness goal (that is, detection might not have occurred fast enough)
- ◆ At 6 facilities, quantity goal hasn't been met for years, "because the measures foreseen in safeguards approaches could not be implemented"
- ◆ At 6-7 LWRs, inspections messed up by SF having already been loaded into casks before inspection

# New safeguards measures

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- ◆ How to confirm not just that there is no diversion from *declared* facilities, but that there are no secret, *undeclared* facilities? (State's declarations not only *accurate* but also *complete*.)
  - Traditional safeguards agreements already give the IAEA the authority and the *obligation* to confirm completeness – but the IAEA did not do much work on that until 1991 Iraq discoveries
- ◆ Key is integration of information from many sources
  - “Open source” information – newspapers, visitor's accounts, etc.
  - Intelligence information provided by IAEA member states – if you can get it reliably (validity challenged by Iraq experience)
  - New requirements for declarations of all relevant imports and exports, fuel-cycle R&D, etc.
  - Expanded access to more locations, including for *environmental monitoring*



# New safeguards measures

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- ◆ After 1991 Gulf war, inspectors found that Iraq had had large nuclear weapons program – undetected by traditional safeguards (and only partly detected by U.S. intelligence)
  - Major undeclared facilities
  - Some secret activities even at declared sites
  - UNSC council imposed unprecedented inspection regime – gave the IAEA a chance to test out new approaches
- ◆ Even in traditional safeguards, IAEA had the right and the obligation to check not only “correctness” (declared totals are as the state reported) but “completeness” (there aren’t any secret, hidden stocks) – but few effective tools to do so
- ◆ IAEA member states negotiated 2-part approach:
  - A set of measures the IAEA could carry out under *existing* legal authorities – applicable to all NPT non-nuclear-weapon-states
  - An “Additional Protocol” providing new legal authorities

# The Additional Protocol (AP)

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- ◆ AP is a new agreement the IAEA has to reach with each state
  - Effort to make this the new standard for verification worldwide
- ◆ The AP includes
  - More access to *information* (states required to provide more information about their nuclear activities, including R&D on technologies that could be used to produce HEU or Pu)
  - More access to *locations* (both additional locations at declared sites and at undeclared sites)
  - Better procedures for inspections (e.g., can get inspectors in with less advance warning to the state)
- ◆ Most (but not all) states with significant nuclear activities now participating
  - 114 states with APs in force (out of 179 under safeguards)
  - Outliers include: Iran, Syria, Israel, Pakistan, Egypt, Brazil, Argentina...

# The state-level concept and the “broader conclusion”

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- ◆ With the AP, the IAEA seeks to understand the total picture of a state’s nuclear activities, how they fit together
  - Is there a coherent overall picture, with no gaps?
  - Or are there mysteries, apparent contradictions?
    - » Example: Are there exports to the state that other countries have reported that the state has not reported?
    - » Example: Are there mysterious gaps in the record of what certain facilities have been doing?
    - » Example: Are there purchases of potentially nuclear-related equipment that do not appear to be at any of the declared facilities?
  - If there are mysteries, is the state helpful in resolving them?
- ◆ Based on this state-level analysis, IAEA draws the “broader conclusion” that “all nuclear material remains in peaceful activities” (conclusion drawn for 60 states so far)
  - But can they really draw this conclusion – as opposed to the simpler conclusion that there’s no *evidence* of secret material?

# Open source and intelligence information

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- ◆ The IAEA now has a major effort to collect information on states' nuclear programs from open sources
  - Commercial satellite photographs (increasingly important)
  - News stories
  - Journal articles, conference papers, other scientific literature
  - Trade data (legal and illegal, including marketing brochures)
  - Social media
  - But how to find the important points in this torrent of information?
- ◆ The IAEA also receives information from intelligence agencies of member states
  - Sometimes controversial – some member states oppose
  - IAEA uses this as pointers to collect confirming information – typically does not base an inspection request only on intelligence

# “Open source” collection effectiveness: an Iranian perspective

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It also became evident that the IAEA knew about some secret tests we had conducted a number of years earlier. For instance, we had conducted a test in Tehran. The person in charge of that project was a university professor. One of his students that year had written a dissertation, and several copies were made of that dissertation. The IAEA had accidentally taken possession of a copy of that dissertation, and we did not know anything about it. It was only sometime later that the IAEA produced a copy of that dissertation and said: You have conducted that test. Or, for example, in another case that we thought nobody knew anything about, one of the scholars who participated in that project wrote a scientific paper about it and had it published in an international journal. The IAEA had a copy of that paper. Therefore, the IAEA was fully informed about most of the cases we thought were unknown to them.

*-- Hassan Rouhani, then chief Iranian nuclear negotiator until 2005, speech to the Supreme Cultural Revolution Council, printed in Rahbord (Strategy), Tehran, September 2005*

# Environmental monitoring

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- ◆ All nuclear facilities, no matter how well-contained, release some atoms of Pu and U – can be detected, *in principle*
- ◆ Swipes taken from walls and floors of a building can reveal in detail what isotopic mix of plutonium was separated when, what enrichments of U was produced in that building
- ◆ Samples from as much as a kilometer away – pine needles, soil, etc. – can detect tell-tale traces of Pu or HEU
- ◆ Centrifuge plants harder to find than reprocessing:
  - OTA: “A small, carefully designed, constructed and maintained plant producing only enough HEU for one or two bombs per year, if equipped with a ventilation system using high efficiency filters, could be quite difficult to detect.”

# Finding a covert centrifuge plant

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- ◆ Heat? -- more or less negligible, not a likely signature
- ◆ Electricity supply? -- maybe, but modest ( $\sim 50$  kW-hr/SWU,  $\sim 7000$  SWU/yr for 2 bombs/yr,  $< 100$  kW continuous power) -- could be supplied by ordinary power lines, buried lines (e.g., Iraq at Tarmiya, not detected), diesel...
- ◆ Size? -- maybe, but 1-2,000 centrifuges could fit in this building
- ◆ UF<sub>6</sub> deliveries? -- Not likely, year's deliveries ( $\sim 7$  tons UF<sub>6</sub>) could be done in 1 truck
- ◆ Uranium emissions? -- maybe, but good design can reduce (Tarmiya had triple filters), need to know where to look
- ◆ Procurement? -- crucial, but hard to find where plant is
- ◆ Acoustic/radio from spinning? -- only if you know *exactly* where to look

# Integrated safeguards

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- ◆ Key emphasis now on “integrating” traditional and new measures – with goal of reducing intensity and cost of traditional measures where new measures can compensate
- ◆ Non-nuclear-weapon states insisted, as part of the price for the Additional Protocol, on reduction in traditional measures -- goal is “cost neutrality” (that is, after initial spike, every dollar spent on new measures should be matched by a dollar subtracted from traditional measures)
- ◆ Will “integrated safeguards” mean “weakened safeguards”?
  - Example: abandoning cameras in SF pools, since Additional Protocol will help confirm there are no covert reprocessing plants -- but how much confidence do we have that these measures WILL confirm that?



# Example: safeguards at Isfahan, and for possible weaponization

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- ◆ IAEA only recently decided to implement full safeguards at conversion plants, and now has full safeguards at Isfahan – but would production of additional UF<sub>6</sub> (for enrichment at a covert facility) be detected? How soon? Would a covert conversion plant be detected?
- ◆ Extensive IAEA effort to probe into “alleged studies” – intelligence provided by member states that suggest weaponization activities
  - NPT commits Iran not to “manufacture or otherwise acquire” nuclear weapons
  - But traditional safeguards agreement focuses only on monitoring nuclear material, Additional Protocol adds only technology to produce nuclear material
  - IAEA emphasizes need to confirm “exclusively peaceful nature”
  - Iran-IAEA deadlock, no significant progress in years

# The Iran case: some lessons

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- ◆ Not just a safeguards issue – an issue of high politics and international security
- ◆ With the right access, resources, and political backing, the IAEA can be highly effective
- ◆ However, a determined state can ignore legal requirements
- ◆ There are two different nuclear issues with Iran
  - Safeguards violations
  - Actual capabilities represented by Natanz and Arak
- ◆ Military strikes would carry huge costs and risks – may only make Iran more determined
- ◆ Diplomatic solution likely to require tougher sanctions and stronger incentives – has to address Iran's concerns as well as ours – will be very difficult to achieve

# Safeguards effectiveness: the good news

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- ◆ Iraq: Though dismissed as ineffective by the U.S. government, international inspections *worked*. U.S. investigation after 2003 revealed that Saddam's nuclear program was essentially shut down because of fears inspectors would find any significant activity. Picture provided by IAEA was *far* more accurate than that provided by U.S. intelligence.
- ◆ Iran: IAEA inspectors have pushed through one cover story after another, forcing Iran to admit decades of lies and to provide unprecedented access and information
- ◆ North Korea: the North Koreans thought they had cleaned up their reprocessing plant before allowing inspectors in – but the IAEA detected samples that proved North Korean declarations on reprocessing were lies

# Safeguards effectiveness: the bad news

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- ◆ Iraq: pre-1991, traditional IAEA safeguards totally missed massive Iraqi illegal weapons program – this episode drove the negotiation of the Additional Protocol
- ◆ Iran: IAEA didn't ask the tough questions until forced by the revelation of Natanz enrichment facility, still modest ability to find covert work without being told about it by intelligence agencies
- ◆ Large bulk processing facilities: at large reprocessing plants, MOX fabrication plants, nearly impossible to achieve safeguards goals through material accountancy alone – need to rely on supplementary measures, including thorough-going transparency throughout the plant

# The budget problem

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- ◆ IAEA safeguards budget: <€150M/yr
- ◆ A few years ago received first increase in 15 years, despite huge increases in:
  - number of countries with safeguards agreements
  - number of facilities under safeguards
  - quantities of materials under safeguards
- ◆ Fat long since trimmed out of the system, now cutting into bone – even with increase, need for more resources is clear
- ◆ Key states on IAEA Board of Governors, having grudgingly gone along with U.S. on modest recent increases, unlikely to support large additional increases
  - This year even United States initially opposed any increase – slight increase (about 1% above projected inflation) eventually agreed to

# Some key issues

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- ◆ What to do about states that simply refuse to join, or comply with, the regime (e.g., Iraq, North Korea)?
- ◆ How to detect secret, hidden facilities? Even once Additional Protocol is in force everywhere, it's difficult
- ◆ How to ensure no diversion from complex facilities like reprocessing plants?
- ◆ Inadequate resources for safeguards – IAEA on near-flat budget since 1985, despite dramatic increase in number of states, quantities of material under safeguards
- ◆ “Non-discrimination” – still large investment of safeguards resources spent in Japan, Canada, and Germany, to meet similar technical goals for everyone
- ◆ How to address political disputes among member states over what the IAEA should and should not do?

# Some opportunities

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- ◆ Redoubled global effort to ensure that all weapons-usable nuclear material is secure and accounted for, to high, consistent, and demonstrable standards
- ◆ Provide new fuel cycle supply assurances (commercial, IAEA fuel bank) to convince states they don't need reprocessing, enrichment of their own
- ◆ Fissile cutoff – end production of Pu and HEU for weapons worldwide (requires 2-3x more inspections worldwide)
- ◆ Integrate traditional and new safeguards measures
- ◆ Strengthen, reduce cost of safeguards and security with new technologies (incl. commercial security and inventory-tracking technologies)

*The world needs a whole new generation of safeguards experts – an exciting and critically important job*

Extra slides if needed...

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# Material accountancy (II)

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## *Tools of Material Accountancy*

- ◆ *Destructive Analysis* – Take a chemical sample of the material to laboratory for analysis. Highly accurate, but expensive and long delays.
- ◆ *Non-Destructive Analysis (NDA)* – Measure content of nuclear material by measuring gamma and neutron spectra (or other properties) using portable or on-site equipment. Less accurate (typically), but far more convenient. DA can be used to calibrate and confirm the accuracy of NDA equipment.

# Designing inspections

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- ◆ First, envision ways material might be diverted from facility to be inspected -- including possibilities for faking/tampering
- ◆ Second, envision inspection approaches that might be able to detect those diversion scenarios
- ◆ Third, assess required detection probability, based on risk associated with the particular diversion scenario (e.g., low probability sufficient for detecting diversion of natural U, high probability needed for detecting Pu diversion)
- ◆ Fourth, design intensity of inspection (e.g., frequency, fraction of materials to be sampled, etc.) to provide detection capability commensurate with risk
- ◆ *In reality:* Large number of budget, practicality, political factors enter into picture

# Diversion scenarios: reprocessing plant

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- ◆ Remove fuel assemblies (or rods) from spent fuel pool
  - Not promising, still need a reprocessing plant to get the Pu
- ◆ Remove solution from early process stages
  - Not promising; Pu not yet separated from uranium and fission products, concentrations low (from dissolver tank, 4000 liters solution weighing 5 tons needed to get 8 kg Pu)
- ◆ Remove Pu solution after separation and concentration
  - Very promising: Only 40 liters solution weighing 50 kg needed for 8 kg Pu -- and thousands of pipes into process area make undetected removal plausible
  - Could cover up diversion by (a) falsifying records and tampering with inspector samples; (b) diverting slowly enough accountancy can't detect it; or (c) introducing undeclared material into plant
- ◆ Remove finished Pu oxide
  - Promising, but easier to detect (no 1000s of pipes in and out)

# Safeguards technologies:

## A wide range

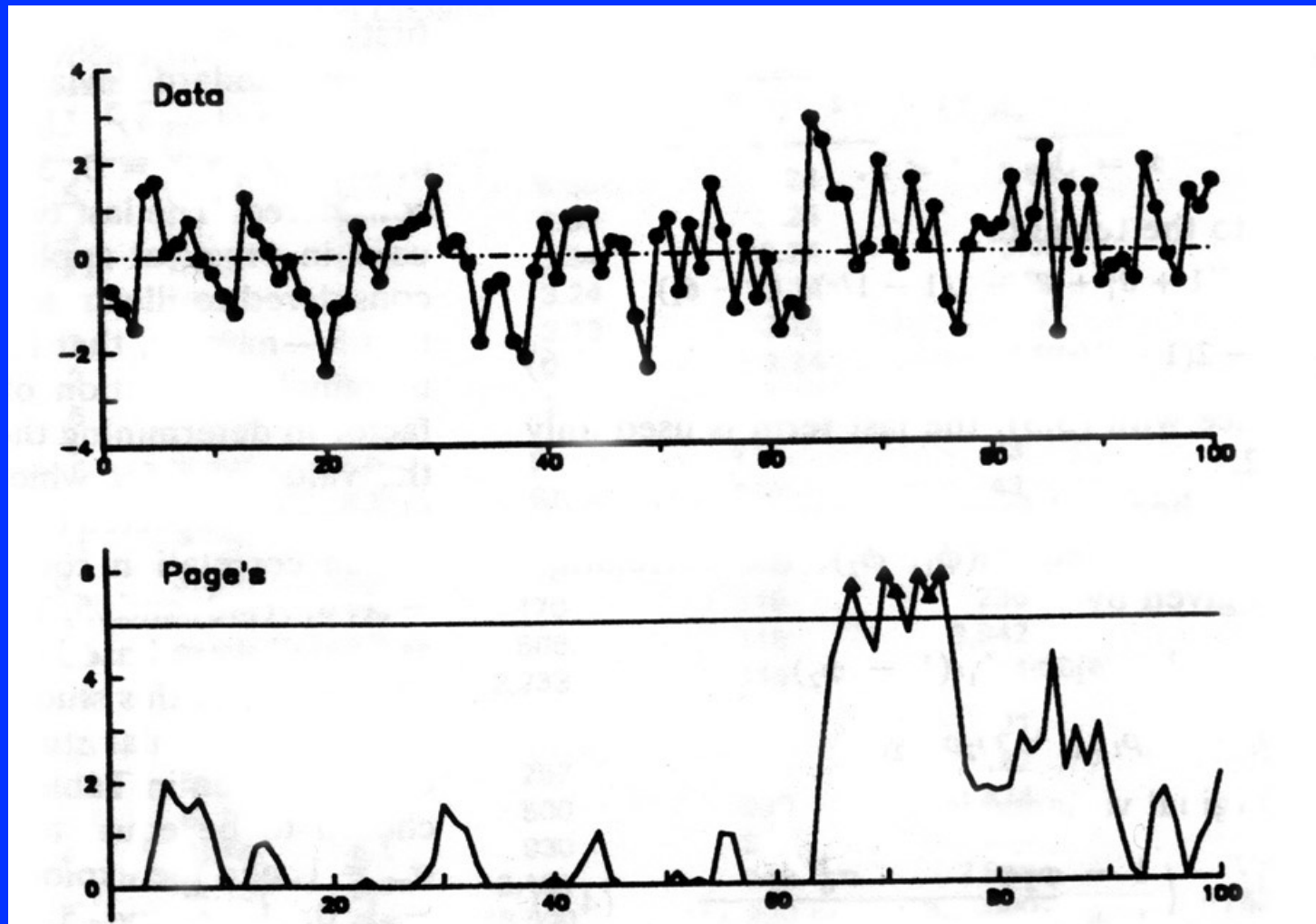
TABLE 7: VERIFICATION MEASUREMENT METHODS FOR ON-SITE IAEA ANALYTICAL LABORATORIES

PROCESS AREA	SAMPLING POINT	INSTRUMENT OR METHOD	CONCENTRATION MEASUREMENT	SAMPLE FRACTION	GOAL ACCURACY
HEAD END	INPUT TANK	HYBRID K-EDGE DENSITOMETER (HKEDG)	Pu U	100 % 50 %	≤ 1 % ≤ 0.5 %
SEPARATION	BUFFER/FEED TANKS	ISOTOPE DILUTION MASS SPECTROMETRY (IDMS)	Pu U	25 % 2 %	≤ 0.2 % 0.2 %
SEPARATION	SCRUB AND WASTE TANKS	Pu(VI) SPECTROPHOTOMETRY	Pu	< 20 %	≤ 25 %
Pu PURIFICATION	COLLECTION AND FEED TANKS	HKEDG IDMS	Pu Pu	50 % ≤ 10 %	1 % ≤ 0.2 %
	PuN TANKS	KEDG IDMS	Pu Pu	25 - 100 % 10 - 90 %	0.2 % 0.1 %
	WASTE TANKS	Pu(VI) SPECTROPHOTOMETRY	Pu	< 10 %	≤ 25 %
U PURIFICATION	UN TANKS	K-EDGE DENSITOMETER (KEDGG)	U	≤ 10 %	0.2 %
	UO <sub>3</sub> CANS	NDA (MEASUREMENTS MADE IN PLANT)	U	≤ 10 %	< 5 %
	UO <sub>3</sub> CANNING	KEDG	U	1 %	0.2 %
MOX CONVERSION	U, Pu N TANKS	KEDG	U Pu	< 10 % 50 %	0.2 % 0.2 %
		IDMS	Pu	20 %	≤ 0.2 %
	MOX CANISTERS	NDA (MEASUREMENTS MADE IN PLANT)	Pu	100 %	1 %
	MOX CANNING	KEDG	Pu	25 %	≤ 0.2 %
		KEDG			

Source: Shea et al., "Safeguarding Reprocessing Plants," JNMM, 1993

# Statistical tests:

## Can you find the diversion in the noise?



Source: E. Yashchin, "Performance of CUSUM Control Schemes," Technometrics, 1993

# Different steps, different safeguards

Fuel cycle step	Current safeguards	Future safeguards?
U mining and milling	Essentially none	Declarations +
U conversion	Covered; limited accountancy	Full accountancy
Enrichment	In-depth safeguards	Flow monitoring
LEU fuel fabrication	Covered; limited effort	Covered; limited effort
Power reactor operation	Covered; limited effort	Neutrino detection
Research reactors	Covered; limited effort	Increased effort
Spent fuel storage -- pool	Covered; limited effort	Remote monitoring
Spent fuel storage -- cask	Covered; v. limited effort	Remote monitoring
Reprocessing	In-depth safeguards--challenge	Still a challenge
Pu storage	In-depth safeguards	Remote monitoring
MOX fuel fabrication	In-depth safeguards--challenge	Still a challenge
Spent fuel disposal	Not operational	Unmanned monitors
HLW disposal	Termination of safeguards	Termination of safeguards

# Challenges to the safeguards regime

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- ◆ North Korea: first-ever case of complete withdrawal from NPT, then testing a nuclear bomb; now appears to be rejecting all talks, on confrontational course; possible military confrontation, possible “domino effect” causing proliferation elsewhere in East Asia, possible sale of nuclear material, possible “loose nukes” if regime collapses...
- ◆ Iran: Iran ignoring Security Council resolutions legally requiring it to suspend enrichment and reprocessing, enrichment capacity still growing, remaining questions about possible past weaponization activities...
- ◆ Iraq/U.S.: U.S. pre-war dismissal of inspections effectiveness could undermine credibility of regime – but post-war realization of high effectiveness could strengthen credibility.

# Challenges to the regime (II)

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- ◆ Providing confidence that covert facilities do not exist -- or finding them if they do -- will remain fundamental challenge
- ◆ Managing expectations -- int'l community expects IAEA to prevent proliferation, but safeguards can *only* detect, not prevent (and traditional safeguards *only* focused on 1 of five paths to the bomb)
- ◆ Managing the “discrimination” issue – is state-level concept just a way to focus on “suspicious” states?
- ◆ Ongoing need to reform, reinvigorate the system -- need culture focused on asking the hard questions, never being fooled



# Safeguards cases: MUF in Japan

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- ◆ In early 1990s, a safeguarded Japanese MOX fabrication facility began having a problem with “holdup” of MOX powder in a glovebox
- ◆ Eventually, there was >70 kg Pu in this one glovebox
- ◆ Special NDA equipment was being used to measure Pu from outside the glovebox – but with 10% uncertainty. Soon uncertainty became as large as an 8 kg “significant quantity”
- ◆ Problem was leaked to MOX opponents, who made a public splash pointing out there was no way to prove material was not missing
- ◆ Ultimately, IAEA required Japan to clean out and measure all the material in the glovebox (took months); Japan developed new process to prevent recurrence; and Japan and Los Alamos developed new, more accurate measurement equipment for measuring such materials
- ◆ Measurements demonstrated that no significant quantity of plutonium was diverted – but not within the IAEA’s timeliness goals

# Safeguards cases:

## Uncertainties at Japan's Tokai plant

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- ◆ Over many years, difference between estimated Pu in spent fuel introduced at Tokai reprocessing plant and measured Pu output built up to 206 kg (3% of throughput) by late '02
- ◆ This “shipper-receiver difference” began building up “from the beginning” in 1977 -- IAEA raised issue in 1987
- ◆ In 1996 (9 yrs later), Japan and IAEA reached agreement on IAEA sampling program for HLW -- showed higher Pu content than operator had assumed and declared
- ◆ Improved sampling approach developed during 1997-2000, while plant shut down -- implemented in 2002
- ◆ Latest Japanese figures: 72 kg of Pu in HLW; 105 kg in cladding hulls; 29 kg from neglecting Pu-241 decay (more likely: some significant part from misestimating Pu in SF in the first place)

# Safeguards cases: NUMEC

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- ◆ In the 1960s, a U.S. facility known as NUMEC, in Apollo, PA, had a huge MUF – enough HEU for many bombs
  - But accounting at the time was so poor that no one will ever know whether material actually went missing
- ◆ The facility manager, though holding U.S. security clearances, had close ties (and multiple unexplained secret meetings) with senior Israeli nuclear officials – and was a strong Zionist
  - Senior Israeli intelligence and procurement officials visited the plant before the loss
- ◆ Result: Widespread suspicion, and even public accusations, that the material had been stolen and provided to Israel.
- ◆ Case contributed to major strengthening of accounting requirements in the United States.

# Safeguards cases: Iraq Pre-1991

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- ◆ Iraq is a party to the NPT required to have all of civilian nuclear activities under safeguards
- ◆ Before the Gulf War, IAEA inspections (focused, as member states had agreed they should be, only on agreed “strategic points” of declared facilities) did not detect any illegal activity in Iraq – inspector suspicions were never followed through
- ◆ Iraq had massive nuclear weapons program involving many facilities – huge undeclared facilities, some illegal activity at declared facilities, plan to remove research reactor HEU from safeguards and use it for a quick bomb
- ◆ U.S. and other intelligence agencies knew Iraq had a nuclear weapons program, but were clueless as to its size and scope

# Safeguards cases: Iraq 1991-1998

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- ◆ After the Gulf War, UN Security Council resolutions gave the IAEA and UNSCOM unprecedented inspection authority, and massive scope of Iraqi program was revealed
- ◆ Provided testing ground for new safeguards measures, such as environmental monitoring. (Dust on clothes of “human shield” hostages revealed Iraqi uranium enrichment.)
- ◆ Nevertheless, even with this unprecedented (and unlikely to be repeated) access, there are still questions over whether there might still be secret facilities and bomb components
- ◆ Iraq remains determined to maintain its WMD
- ◆ Development of new “Additional Protocol” was in substantial part a reaction to the Iraqi case

# Safeguards cases: Iraq 2002-2004

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- ◆ Starting late 2002, IAEA began inspections in Iraq with unprecedented powers and access, following up where inspectors had left off in 1998
- ◆ IAEA found no evidence of renewed nuclear program – despite televised Saddam meetings with nuclear scientists he called his “nuclear mujahedeen”
- ◆ IAEA showed conclusively that charges related to purchases of uranium from Niger and purchases of aluminum tubes for centrifuges were false
- ◆ Bush administration dismissed value of IAEA inspections, warned they were being fooled, invaded Iraq
- ◆ Post-war inspections made clear (a) inspections and sanctions effectively stopped Saddam’s nuclear program; (b) IAEA picture far more accurate than U.S. picture

# Safeguards cases: North Korea

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- ◆ North Korea joined the NPT and signed a safeguards agreement with the IAEA in the early 1990s
- ◆ During inspection of the Yongbyon reprocessing plant, which the North Koreans thought they had cleaned up adequately, swipes taken from the walls of process areas revealed that plutonium had been separated at times *other than* those declared (ratio of Pu and Am isotopes) – clear evidence the North Koreans were lying
- ◆ North Koreans kicked IAEA out, threatened to withdraw from the NPT, unloaded the fuel from their reactor without monitoring, provoked international crisis ultimately resolved (temporarily) by 1994 Agreed Framework
- ◆ Full safeguards have never been implemented since then, now no IAEA inspectors in North Korea

# Safeguards cases: Libya

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- ◆ Libya was a member of the NPT – one safeguarded facility, a Soviet-supplied, HEU-fueled research reactor
- ◆ Libya has very little indigenous technology base
- ◆ AQ Khan network provided complete centrifuge designs, centrifuge parts, complete centrifuges, even atom bomb design, was planning construction of complete plant
- ◆ Libya was still far from the bomb – no centrifuge cascade, even a small one, up and running
- ◆ IAEA had only traditional safeguards agreement with Libya (focused on declared facilities), had no inkling of secret program – western intelligence also knew little
- ◆ Qaddafi decides to “come in from the cold”, abandon WMD programs – U.S., U.K., IAEA cooperated to dismantle, verify elimination