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Consequence Management for Radiological Incidents

Science and Technology Working Group
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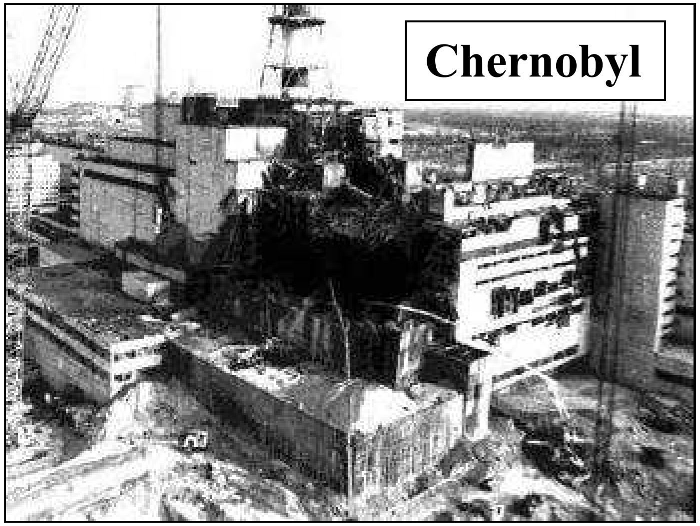
Sandia National Laboratories

Radiological Consequence Management Concerns

- Historical Accidental Examples:
  - Chernobyl, Ukraine
  - Goiania, Brazil
  - Three Mile Island, USA
  - Fukushima, Japan
- Potential Events:
  - Regional nuclear reactor accident
  - Lost control and release of radioactive materials
  - Terrorist Nuclear Explosive Device
  - Terrorist Act “Dirty Bomb”



Consequence Management (CM) Program

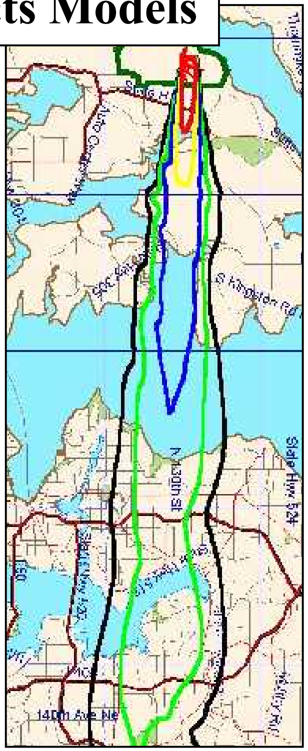
Mission:

- **Develop and maintain rapidly-deployable equipment and technical expertise for world-wide response to nuclear and radiological terrorism events as well as nuclear/radiological accidents or emergencies.**

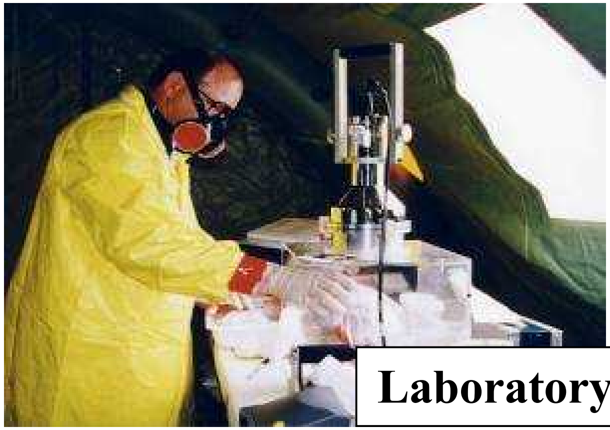
Consequence Management (CM) Assets

Data Analysis/ Management

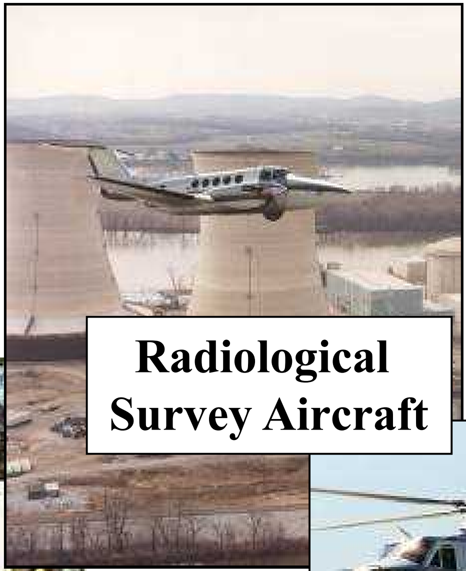
Field Personnel



Effects Models



Laboratory Personnel



Radiological Survey Aircraft

Mobile Laboratories

Example: How Does the US Respond?

Response Timeline
T = 0 to 1 Hour

- Local Authority and/or Nuclear Facility will implement its Emergency Response Plans
- State and Local Officials will be notified.
  - Local First Responders will be first to arrive on the scene.
  - First Responders will begin responding to the emergency and evacuation of local area based upon Emergency Response Plans.

CM Resource Response
Timeline T = 1 to 6 Hours

- NNSA's Radiological Assistance Program Teams (RAP Teams) begin to arrive.
- Department Of Energy activates National Consequence Management Assets upon request of state.
  - CM Home Team Activated and providing assessment within 2 hours of activation.
  - CM Response Team assets in route within 4-hours of activation.
- NNSA's Plume Dispersion Modeling underway.

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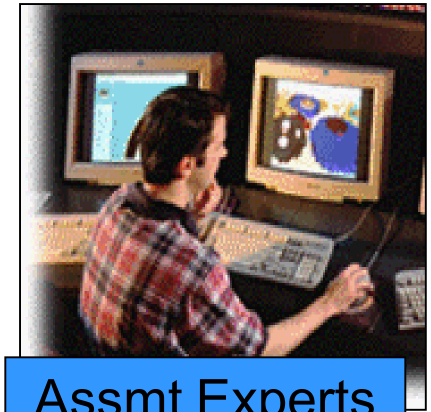
Radiological Assistance Program
Teams Arrive

CM Home Team Is Activated

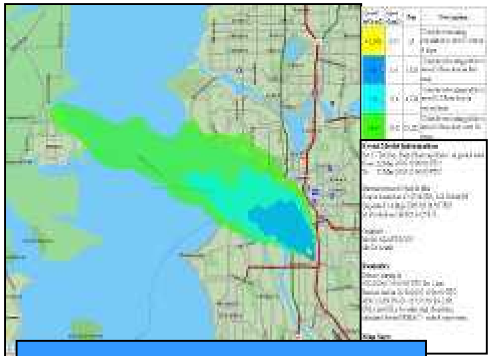
- Objectives:
  - Provide Technical Assessment and Plume Map support before CM response team assets arrive at the event site
  - Provide a resource for local authorities early in an event

- Resources
  - National Lab personnel
  - Assessment tools
  - Plume modeling

Field Team



Assmt Experts



Plume modeling

Emergency Operations Center

CM Response
Timeline T = 24 to 36 Hours

- CM Response Teams arrive (approximately 150 - 400 additional personnel in 3 teams).

- Provides experts to support the operations:
  - Sampling Experts
  - Lab Analysis Experts
  - Health and Safety Experts
  - Assessment Experts
  - Radiological Technicians

- All of these individuals take on specific roles as defined in pre-event planning/training.

Consequence Reports

- **Standardized report integrating effects predictions with Geographical Information System (GIS) provides consequence information in a format more directly useful to decision makers**

- **Reports are customized for different Weapons of Mass Destruction (WMD) scenarios or accident situations**

- **Different levels of detail can be selected**
  - **summary, full report, full report including background and reference information**

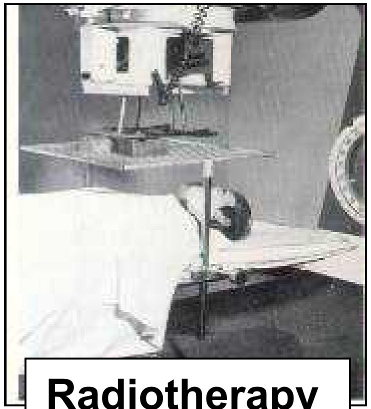
Discussion

- **Merits of a Middle East regionally based program for radiological consequence management**
- **Potential for an S&T working group to be established with this focus**
  - **Survey of existing capabilities**
  - **Mechanisms for sharing information and resources**
  - **Gap analysis to identify local and regional needs**

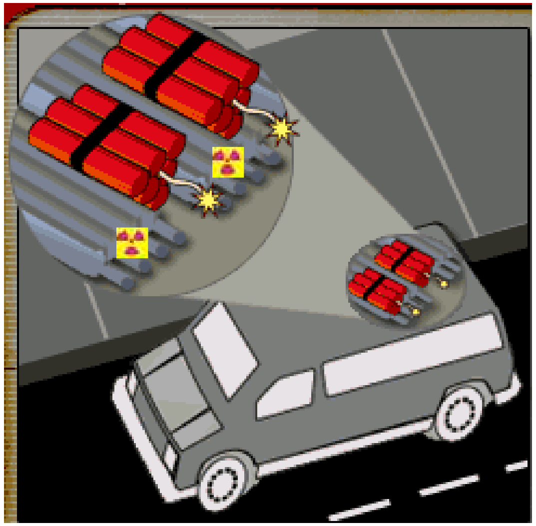
Backup Slides

Radiological Dispersion Device (RDD)

- Radioactive sources that are widely used in the civilian and military sectors could be employed in "dirty bombs" or radiological dispersal devices (RDDs).
- The conventional explosive is used as a means to spread radioactive contamination. It is not a nuclear explosive and does not involve a nuclear explosion.
- Passive device, or non-energetic devices, including sprayers and direct exposure devices.



Radiotherapy Unit



"Dirty Bomb"

RDD Impacts

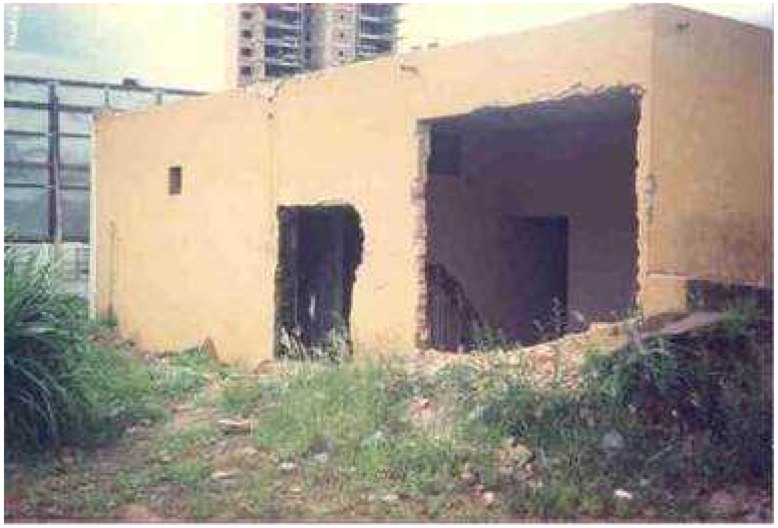
- Difficult to get enough material and not be detected (gamma/beta emitting vs. alpha emitting isotopes).
- Shielding limited to keep it mobile.
- Most injuries caused by the detonation of conventional explosives and not the radiation.
- A RDD could potentially have a significant environmental, economic, and psychological impact, by causing fear, panic and disruption.
- Clean-up costs can be massive.

Example of Failure to Control Radioactive Materials – Goiania, Brazil

- **The accident occurred in September 1987 in Goiania involving a Cs-137 medical teletherapy source**
- **Goiania had a population of about 800,000 at the time of the accident**
- **In 1985, the Goiania Institute of Radiotherapy moved to a new location leaving behind an obsolete Cesium-137 teletherapy unit in a partially demolished building**

How did it happen?

- Two young men learned that there was a heavy equipment at an abandoned hospital building in downtown Goiania (Sep. 13)
- They removed the shielding head of the teletherapy unit and sold it to a junk yard
- The two men, the owner of the junk yard and his two employees initiated attempts to dismantle the equipment
- A capsule containing about 1400 Curies of Cesium-137 (Cs-Chloride powder) was dismantled and ruptured (Sep. 18)
- Pieces of the source were distributed among the junk yard owner's relatives, neighbors and most close friends



Initial Symptoms

- The owner's wife observed the occurrence of the first symptoms of acute radiation syndrome among her relatives and decided to look for medical assistance at the Hospital for Tropical Diseases
- Pieces of the source were put in a bag that she took along with her by bus to the hospital
- On September 29, the Brazilian Nuclear Energy Commission was notified by a Goianian physicist about the occurrence of a serious radiological accident

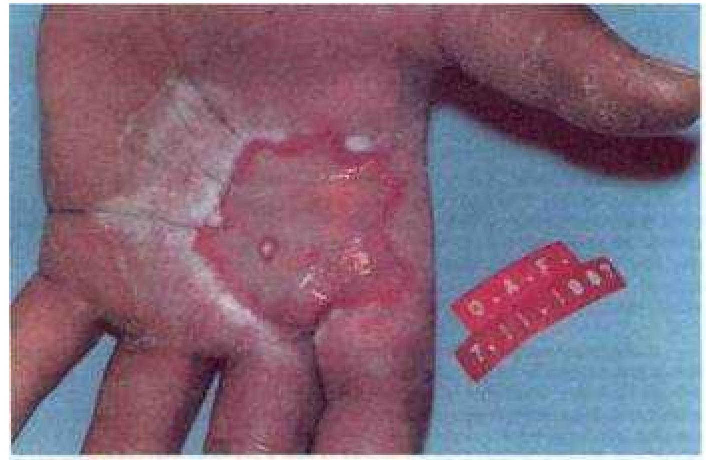


FIG. 9.3. 3–30 days after exposure. The skin was excised. A raw reddish surface is covered with a delicate layer of fibrinous exudate. Note the centripetal character of the healing process and the attempt of re-epithelialization.

source assembly that was removed from the shielding of the radiation head.
It was enveloped by a cloth bag and placed on a chair, which was taken to the corner of the Health Department courtyard. OSEGO

First countermeasures and contamination survey

- About 112000 people were monitored at the Olympic Stadium using survey meters
- 8% of the people screened exhibited signs and symptoms consistent with acute radiation sickness: skin reddening, vomiting, diarrhea, etc. although they had not been exposed
- 250 were identified as contaminated
- 50 contaminated people were isolated for more detailed screening
- 20 people were hospitalized
- Contamination survey in the residences was initiated

Early consequences of the accident

- Four fatalities (2 men, 1 woman and 1 child)
- Radiation induced skin injuries observed in 28 patients
- Widespread contamination of downtown Goiania
- External exposure to members of the public
- Four main foci of contamination identified: 3 junkyards and 1 residence
- 85 residences found to have significant levels of contamination (41 of these were evacuated and a few were completely or partially demolished)

Late consequences of the accident

- Intense psychological consequences amongst the population such as fear and depression.
- Discrimination against the victims and important products of local economy
- Large amounts of money spent during and after the recovering phases
- Need for the construction of a large repository to store the radioactive waste (5000 cubic meters)
- Complete revision of Brazilian regulations related to the storage and use of radiation sources

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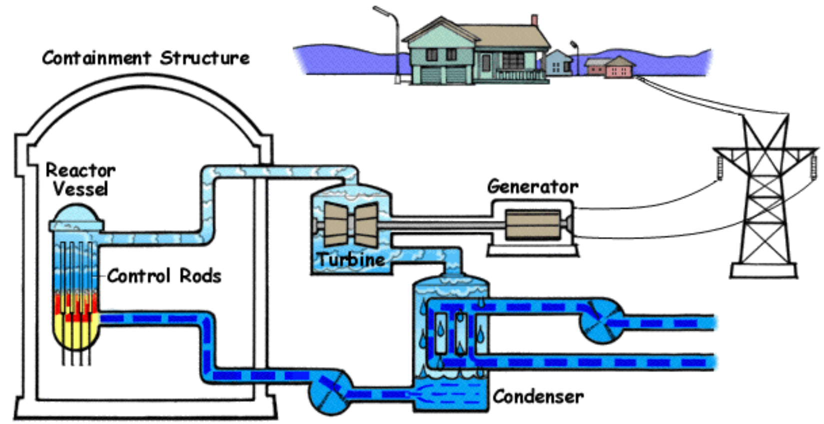
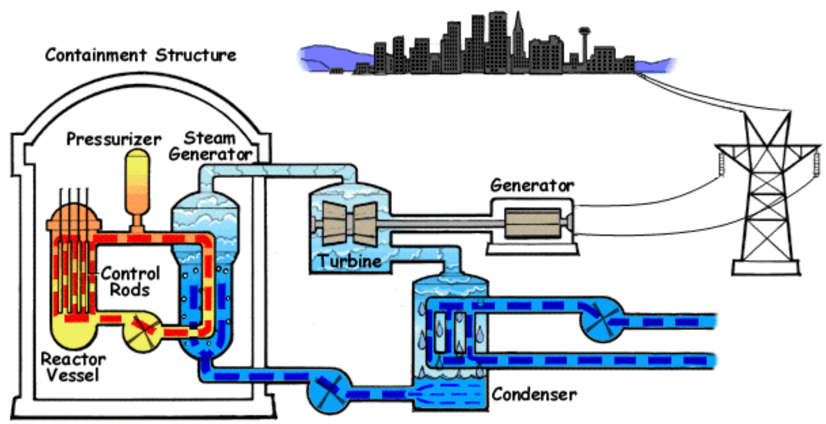
Types of Nuclear Reactors

There are two main types of commercial nuclear reactors used in power plants in the United States:

- Boiling Water Reactors (BWRs) [30]
- Pressurized Water Reactors (PWRs) [74]
- The VVER-1000 Reactors share the same basic design as the Western PWRs

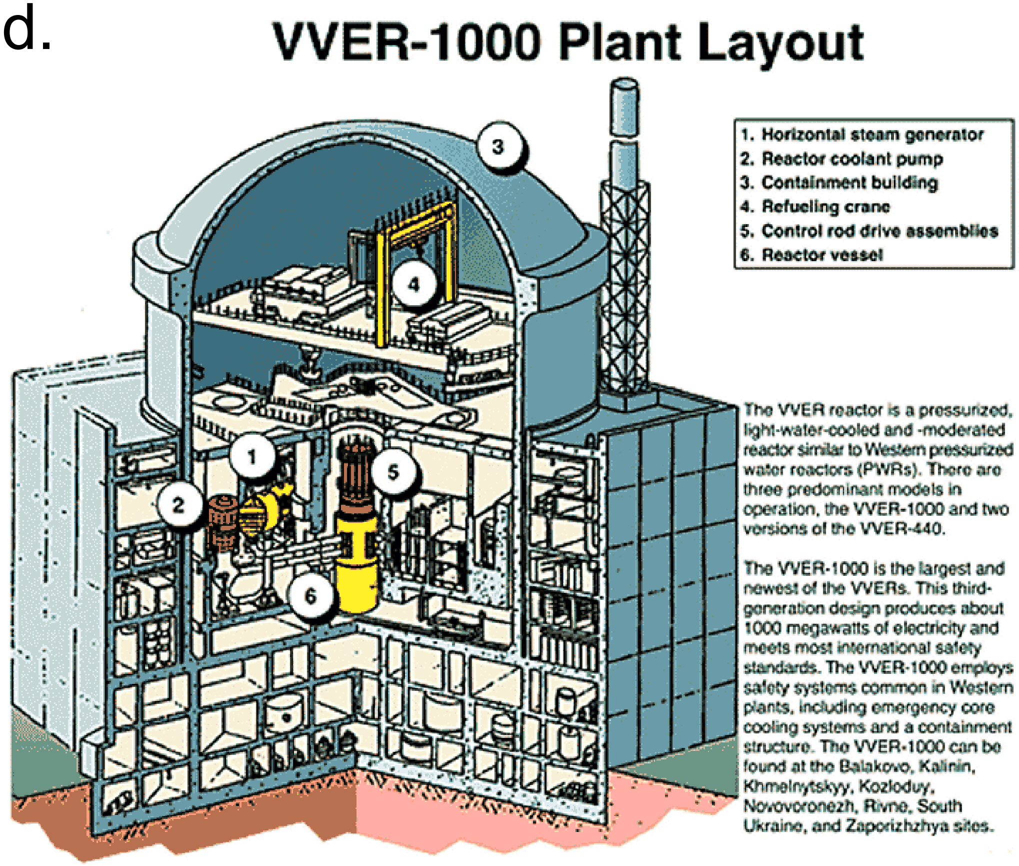




Nuclear Power Plants

Inside, the reactor building is divided into two containment areas, one formed by the steel containment and the other an outer containment shield.

Both are high-pressure parts of the nuclear steam supply system and the spent fuel storage pool and the new fuel store.



Power Plant Accidents

Nuclear power plants are designed with two principal safety objectives in mind:

- To contain fission products to prevent offsite health effects
- To ensure that heat generated by the reactor, including heat generated by the decay of fission products after reactor shutdown, is removed

If the decay heat is not continually removed from the reactor following shutdown, this heat could cause failures of the system designed to contain the fission products.

Power Plant Accidents – Three Mile Island

- Caused by equipment failures and human operator errors: the water level in the reactor core decreased to the point that the fuel was no longer submerged in water,
- Without the cooling normally provided by this water, the cladding and some of the fuel pellets melted,
- Large quantities of radioactive materials were released into the containment building,
- Radioactive releases to the atmosphere that occurred during the accident were very small,
- <u>**The containment worked**</u>: No fatalities, injuries, or large scale contamination.

Power Plant Accidents - Chernobyl

- Caused by a combination of human errors, deliberate failure to follow procedures, and poor reactor design,
- Design of the reactor resulted in a very rapid increase in power after the water used to cool the core was lost,
- Pressure increased to the point that the reactor was blown apart,
- Resulted in multiple fatalities, injuries, exposed public to long term radiation effects.

Note: Such an accident is impossible at PWRs or BWRs in the U.S. since such a loss of cooling water would have shut down the reactor.

Bushehr Reactor Location and History

-The Bushehr nuclear facility is located near Halileh which is about a dozen kilometers to the south of Bushehr proper, along the Gulf coast.

-1974: Siemens began construction of two 1200 MW PWR reactors

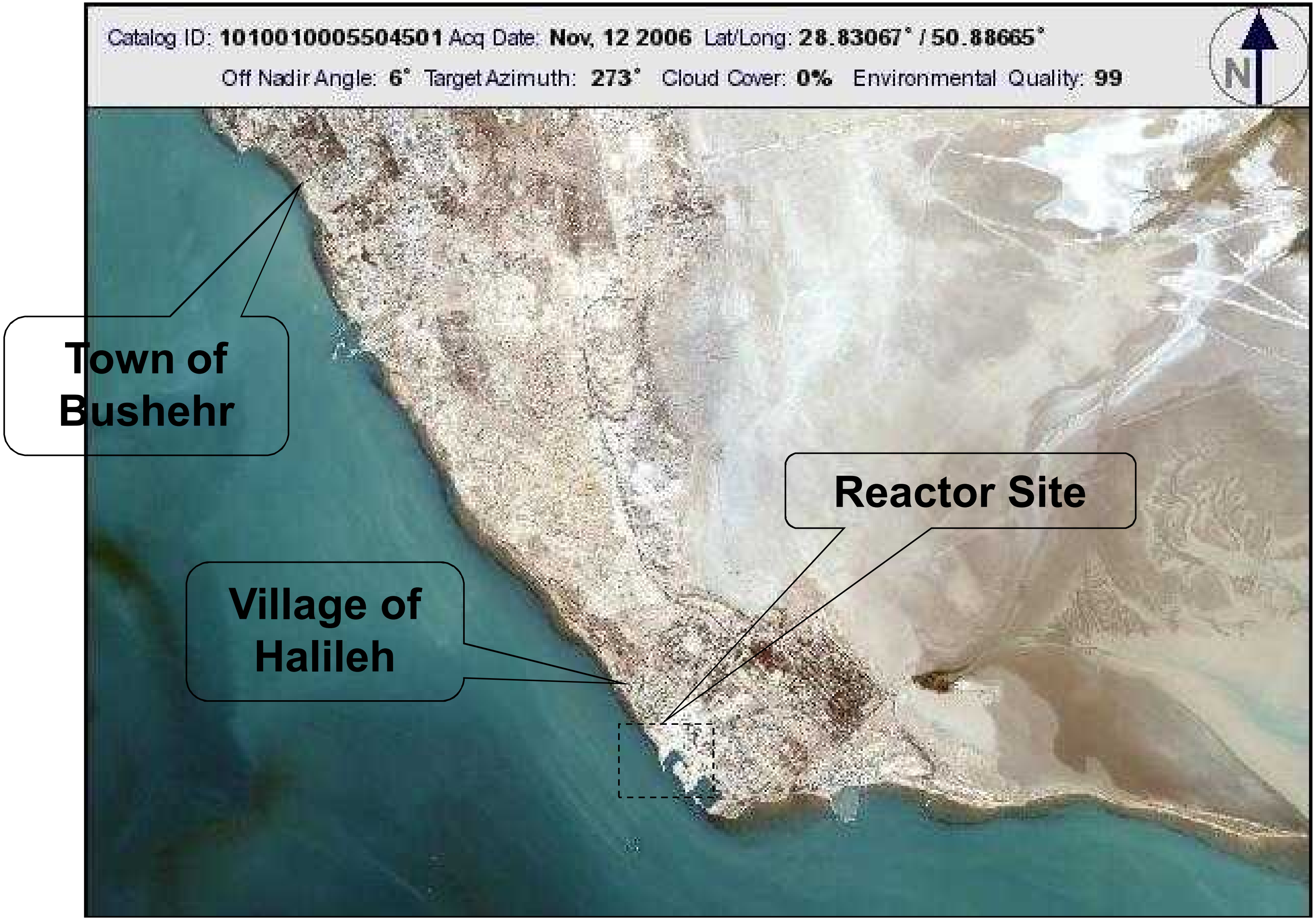
- 1979: Work stopped due to Iranian revolution and opposition by Ayatollah Khomeini

- 1995: Russia agrees to provide one VVER-1000 light water reactor

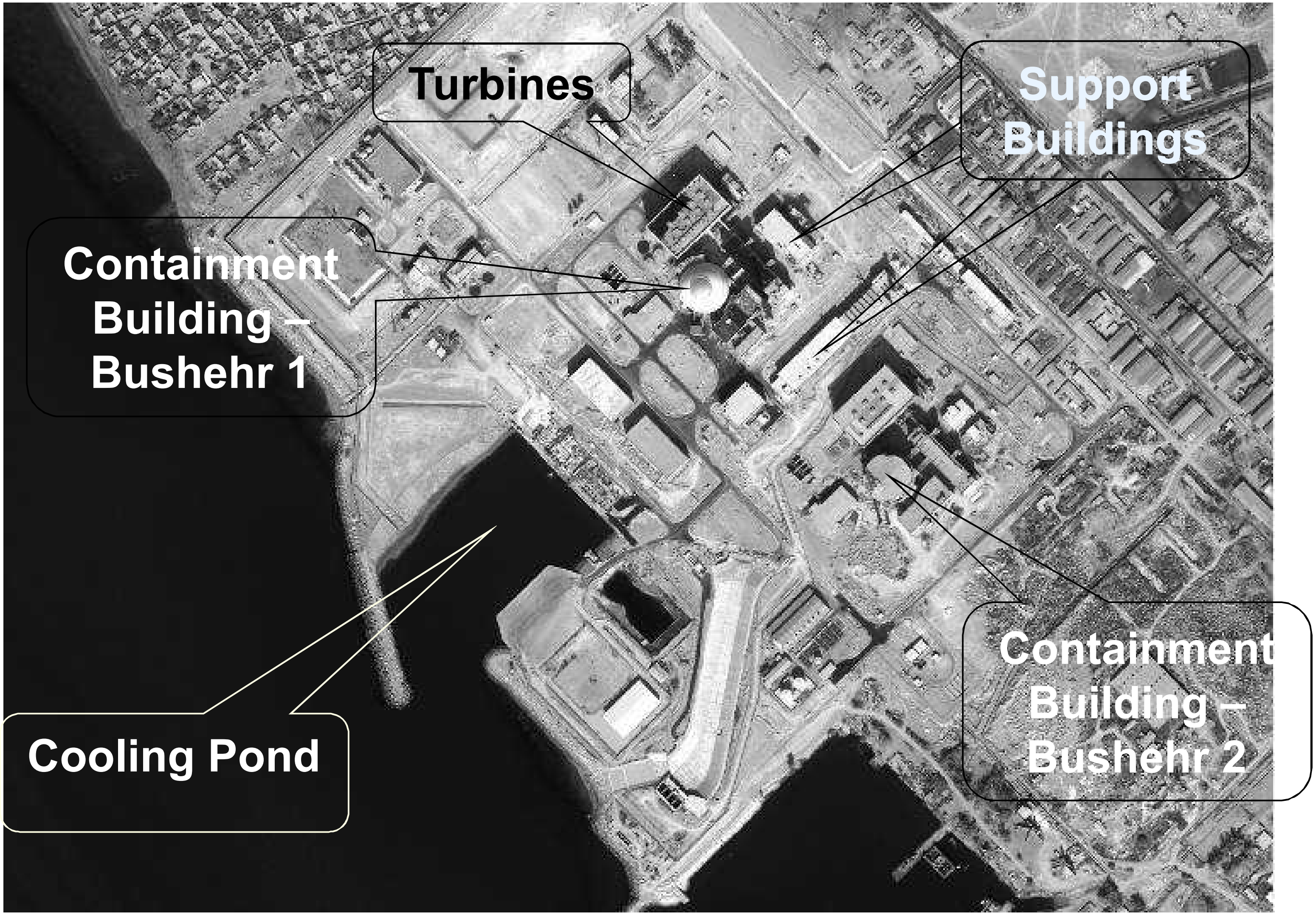
- Agreement includes supply of fresh fuel and take back of spent fuel

- Most work on Bushehr I completed, ready for fueling by late 2007

Bushehr Reactor Site



Bushehr Reactor Site, 16 November 2006, QuickBird Image, 0.62 Meter Resolution



Bushehr Reactor Site: June 2003

VVER 1000/V320 Main Features

- A pressurized reactor vessel containing 74 tons of enriched uranium dioxide,
- Four coolant loops at a temperature of 289°C at core inlet and 320°C at core outlet connected to a pressurizer at 15.7 MPa pressure,
- Four horizontal steam generators producing saturated steam at 6.4 MPa and 278°C,
- A type K-1000-60/3000 steam turbine rotating at 3000 rpm exhausting to a condenser and driving a 1000 MW generator at nominal voltage 24 kV,
- Nuclear auxiliary systems to maintain the water quality and inventory of the primary coolant circuit in all operating modes,
- An emergency core cooling system comprising three 100% redundant trains,
- Turbine hall auxiliary systems to provide the turbine generator set with lubrication and cooling, and recycle the turbine steam condensed in the condenser,
- System of purification, control and residual release of gaseous releases system.

An Incident Simulation

- **Reactor underwent total core meltdown that resulted in a partial breach of the containment dome at 10 m above the reactor core.**
- **The reactor was simulated as a 1000-MWe Pressurized Water Reactor (PWR) reactor.**
- **Used the Nuclear Regulatory Commission (NRC) Radiological Assessment System for Consequence Analysis (RASCAL) 3.0.4 code**
- **The radiation release lasted 48 hours.**

Radiation Inventory

Nuclide	Ci	Nuclide	Ci	Nuclide	Ci
Ba-137m	1.1E+06	La-140	4.4E+05	Tc-99m	2.0E+05
Ba-140	6.0E+06	Mo-99	2.0E+05	Te-127	3.7E+05
Ce-144	1.5E+05	Np-239	2.2E+06	Te-127m	6.5E+02
Cs-134	2.0E+06	Pr-144	1.5E+05	Te-129	4.0E+05
Cs-135	1.0E-02	Pr-144m	2.7E+03	Te-129m	5.3E+05
Cs-136	6.1E+05	Pu-239	2.2E-01	Te-131	1.5E+05
Cs-137	1.3E+06	Rb-87	3.2E-08	Te-131m	6.6E+05
Cs-138	2.4E-07	Rb-88	4.5E+04	Te-132	9.5E+06
I-129	3.2E-04	Rh-103m	1.8E+05	U-235	4.2E-14
I-131	1.7E+07	Rh-106	4.9E+04	Xe-131m	3.3E+05
I-132	1.7E+07	Ru-103	1.8E+05	Xe-133	5.4E+07
I-133	1.6E+07	Ru-106	4.9E+04	Xe-133m	1.7E+06
I-134	8.2E-02	Sb-127	4.9E+05	Xe-135	1.1E+07
I-135	2.2E+06	Sb-129	5.4E+04	Xe-135m	3.8E+05
Kr-85	2.3E+05	Sr-89	3.7E+06	Y-90	5.1E+03
Kr-85m	1.5E+05	Sr-90	1.8E+05	Y-91	2.1E+05
Kr-87	1.5E+01	Sr-91	6.8E+05	Y-91m	2.7E+05
Kr-88	4.4E+04	Tc-99	2.4E-03		

Deposition Pattern for This Scenario