IRIS

International Reactor Innovative and Secure

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Presentation to NRC

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Attachment 2

PURPOSE

- Introduce IRIS
- Feedback from NRC Staff needed to maintain progress
- Outline needed testing program

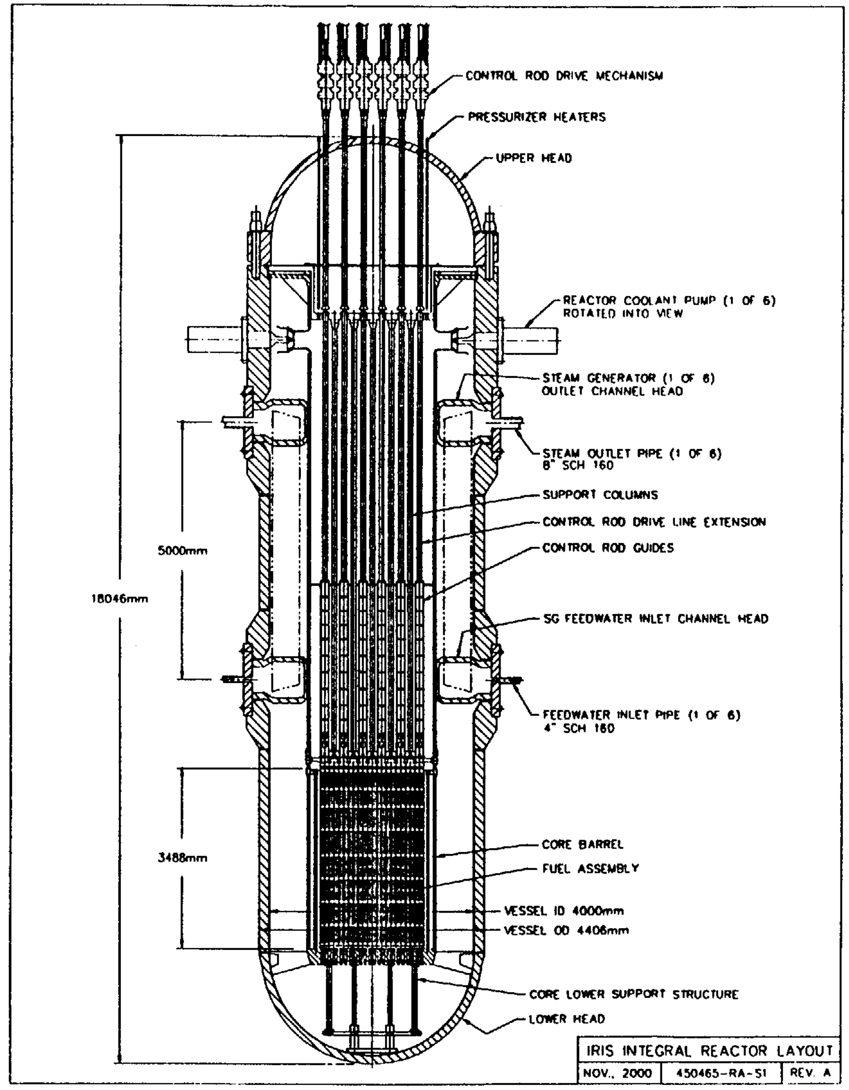
AGENDA

- Overview
  - Team Partnership
  - Funding
  - Schedular Objectives
- Neutronics and Fuel Selection
- Configuration (Integral vessel, internal shield, steam generators)
- Enhanced Safety Approach (Safety by Design)
- Maintenance Optimization
- Technology Gaps and Regulatory Issues
- Conclusions

OVERVIEW

IRIS is a Modular LWR, with Emphasis on Proliferation Resistance and Enhanced Safety

- Small-to-medium (100-300 MWe) power module
- Integral primary system
- 5- and 8-year straight burn core
- Utilizes LWR technology, newly engineered for improved performance
- Most accident initiators are prevented by design
- Potential to be cost competitive with other options
- Development, construction and deployment by international team
- First module projected deployment in 2010-2015



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WHY IRIS ?

Originally: To respond to DOE Generation IV solicitation

Design feature	Requirement			
	Proliferation resistance	Enhanced Safety	Economic competitiveness	Reduced waste
Modular design			✓	
Long core life (single burn, no shuffling)	✓		✓	✓
Extended fuel burnup			✓	✓
Integral primary circuit	✓	✓	✓	✓
High degree of natural circulation		✓		
High pressure containment with inside-the-vessel heat removal		✓	✓	
Optimized maintenance	✓		✓	

Evolved into: Attractive commercial market entry

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IRIS Consortium Members

Team Member	Function			Scope
	Engineering	Supplier	Development	
Westinghouse Electric LLC, USA	*		*	Overall coordination, leadership and interfacing, licensing
Polytechnic Institute of Milan, Italy (POLIMI)			*	Core design, in-vessel thermal hydraulics, steam generators, containment
Massachusetts Institute of Technology, USA (MIT)			*	Core thermal hydraulics, novel fuel rod geometries, safety, maintenance
University of California at Berkeley, USA (UCB)			*	Core neutronics design
Japan Atomic Power Company, Japan (JAPC)	*		*	Maintenance, utility feedback
Mitsubishi Heavy Industries, Japan (MHI)	*	*	*	Steam generators, modularization
British Nuclear Fuels plc, UK (BNFL)	*	*	*	Fuel and fuel cycle, economic evaluation
Tokyo Institute of Technology, Japan (TIT)			*	Novel fuel rod geometries, detailed 3D T&H subchannel characterization, PSA
Bechtel Power Corp., USA (Bechtel)	*	*	*	Balance of plant, cost evaluation, construction
University of Pisa, Italy (UNIPI)			*	Containment analyses, transient analyses
Ansaldo, Italy	*	*	*	Steam generators, reactor systems
National Institute Nuclear Studies, Mexico (ININ)			*	Core neutronics
NUCLEP, Brazil	*	*		Containment, vessel, pressurizer
ENSA, Spain	*	*		Reactor internals, steam generators, vessel
Nuclear Energy Commission, Brazil (CNEN) (Pending)	*		*	Transient, structural analyses, testing
Oak Ridge National Laboratory, USA (ORNL) (Pending)	*		*	Core analyses, safety, cost evaluation, testing
Associates				
University of Tennessee, USA			*	Modularization, transportability
Ohio State University, USA			*	Novel In-Core Power Monitor

FUNDING

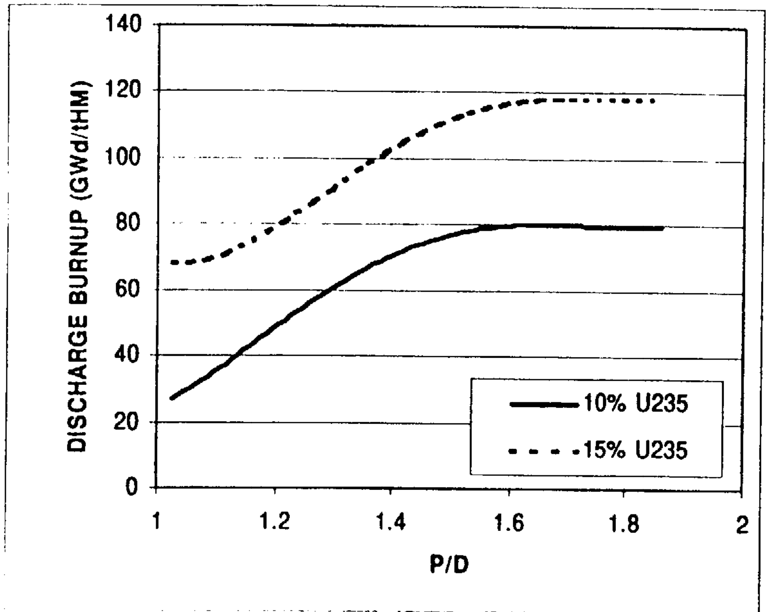
DOE NERI	~ $1.6M over 3 years		
	(9/99 - 8/02)		
Consortium Members	~ $4M	in	2000
	~ $8M	in	2001
	$10-12M anticipated in 2002		

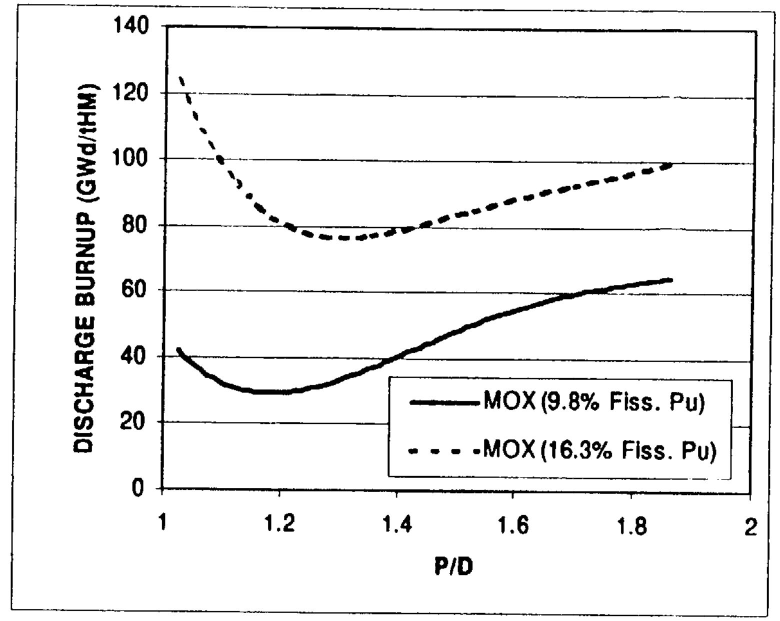
IRIS SCHEDULAR OBJECTIVES

• Assess key technical & economic feasibilities (completed)	End 2000
• Perform conceptual design, preliminary cost estimate	End 2001
• Perform preliminary design	End 2002
• Pre-application submitted	?
• Complete SAR	2005
• Obtain design certification	2007
• First-of-a-kind deployment	2010-2015

NEUTRONICS AND FUEL SELECTION

VARIOUS CONFIGURATIONS YIELD LONG LIFE



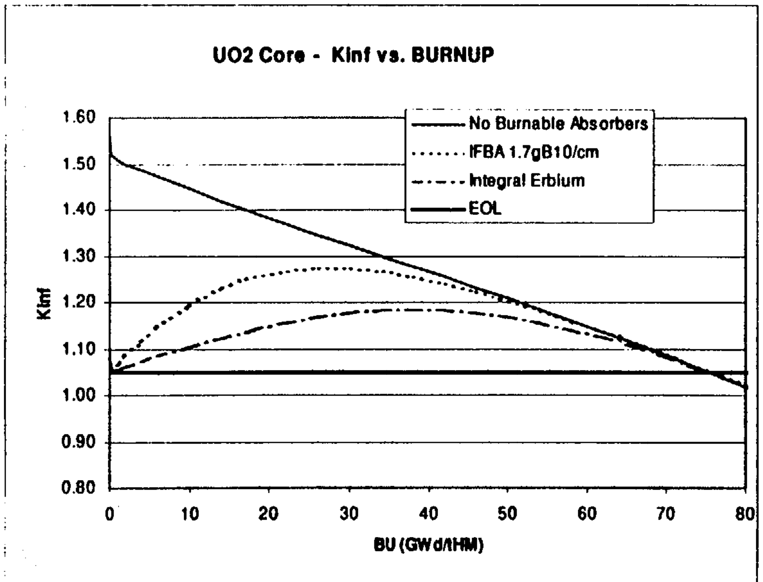


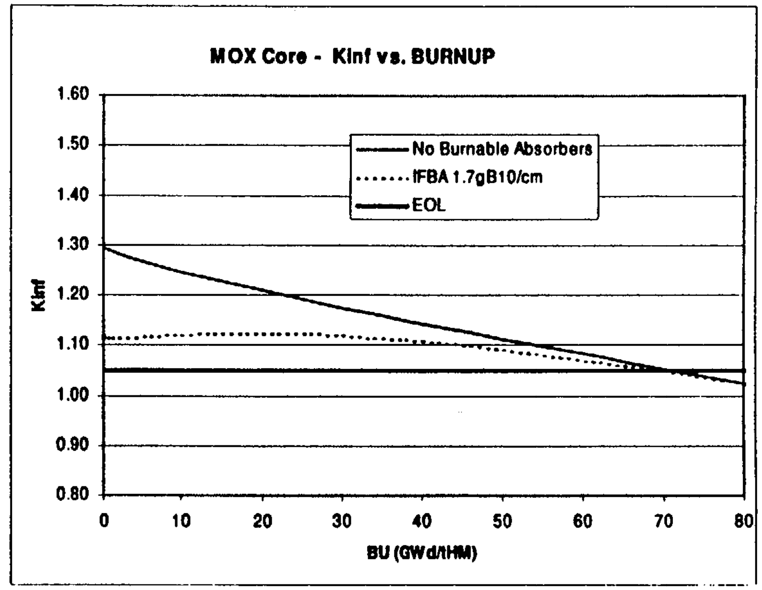
(Discharge burnup based on End-of-Life Kinf = 1.075)

- UO_2 fuel
  - open lattice
- MOX fuel
  - lower enrichment - open lattice
  - higher enrichment - tight lattice

EXCESS REACTIVITY CONTROL BY BURNABLE ABSORBERS

Lattice cell analyses, EOL assumed at Kinf=1.05
IFBA = Integral Fuel Burnable Absorber (ZrB_2 coating)
Er = Erbium mixed with fuel





UO_2:

- IFBA reduces reactivity swing Δk from 50% to 22%
- Erbium reduces reactivity swing Δk from 50% to 14%

MOX:

- IFBA reduces reactivity swing Δk from 25% to 7%

UO_2 VERSUS MOX

UO_2 FUEL

- commercial PWR experience
- U.S. policy

MOX FUEL

- lower initial excess reactivity
- fuel fabrication available (BNFL)
- disposal of available plutonium
- of interest to international IRIS partners

ENRICHMENT CONSIDERATIONS

- 8-year core requires higher enrichment than current practice
  - New fabrication facilities
  - Regulatory approval
- 8-year core will attain higher burnup than current state-of-the-art
  - Data and models needed
  - Licensing review
- Not consistent with early deployment objective

IRIS DESIGN OPTIONS

IRIS 5-YEAR DESIGN
- CURRENT FUEL TECHNOLOGY
- PROVIDES MINIMUM-RISK PATH FORWARD
- (DETAILED CORE DESIGN IN PROGRESS)

IRIS 8-YEAR DESIGN
- BOTH UO_2 and MOX MAY BE USED
- EMPHASIZES PROLIFERATION RESISTANCE
- (SCOPED INTERCHANGEABLE CORE DESIGN)

TIGHT LATTICE CORE/HIGHER ENRICHMENT/NOVEL FUEL TYPES
- POTENTIALLY FURTHER EXTEND CORE LIFE
- (RESEARCH EFFORTS CONTINUING)

IRIS 335 MWe CORE DESIGN APPROACH

PROLIFERATION RESISTANCE

IMPROVED ECONOMICS

PATH FOR FUTURE ENHANCEMENTS

FUEL AVAILABLE NOW

EARLY DEPLOYMENT

DEMONSTRATES EXTENDED MAINTENANCE

PROVES INTEGRAL REACTOR FEATURES

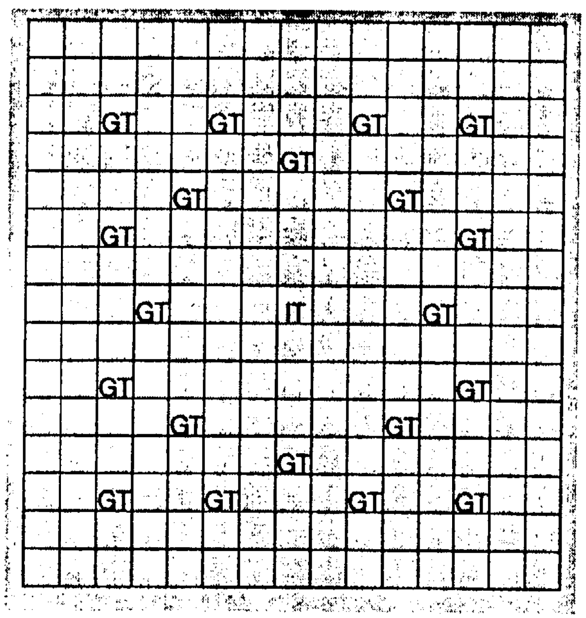
FIRST CORE FUEL ASSEMBLY DESIGN UTILIZES CURRENT TECHNOLOGY

- 1000 MWt
- 89 FA, square lattice
- 5-year core lifetime
- 4.95 w/o U235
- 15x15 square lattice
- 14 ft active core height
- extended gas plenum
- ZIRLO-type cladding
- Pitch = 0.592"
- p/d = 1.4
- 1 instrumentation tube
- 20-24 control rod "fingers"
- 4 kW/ft average power
- ~40-45,000 MWd/tHM average discharge burnup

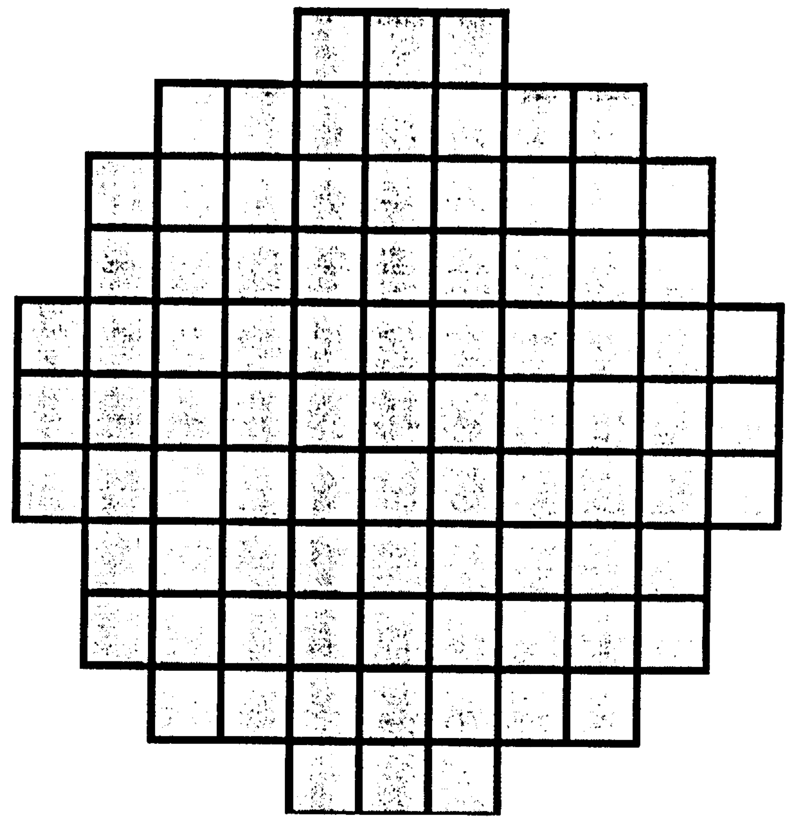
IRIS 335 MWe FUEL ASSEMBLY AND CORE CONFIGURATION

FUEL ASSEMBLY INCORPORATES EXISTING W DESIGN FEATURES:

- 15x15 fuel assembly
- XLA (14 ft active core)
- Robust design



CORE CONFIGURATION (1000 MWt) INCLUDES 89 FUEL ASSEMBLIES



5/2/01
Viewgraph 20

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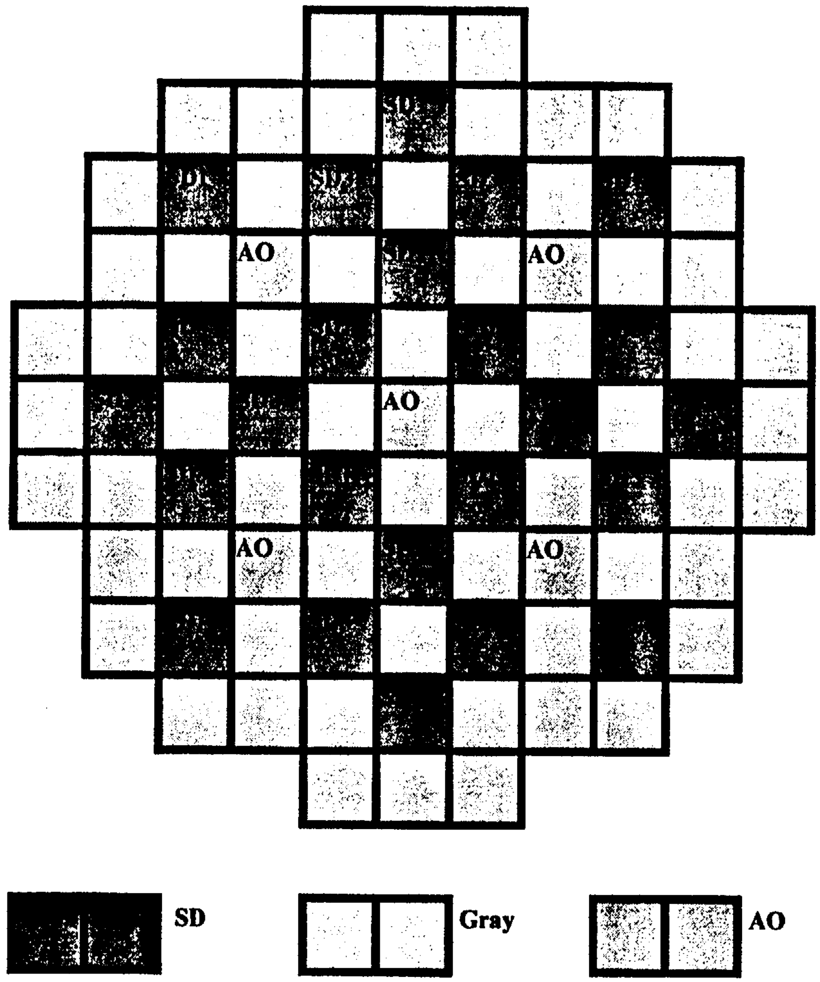
CONTROL RODS

Shutdown (black) - SDB1, SD2, SD3 (8 RCCA each bank)
Excess reactivity control (gray) - 4 banks, 8 RCCA each
Axial offset control



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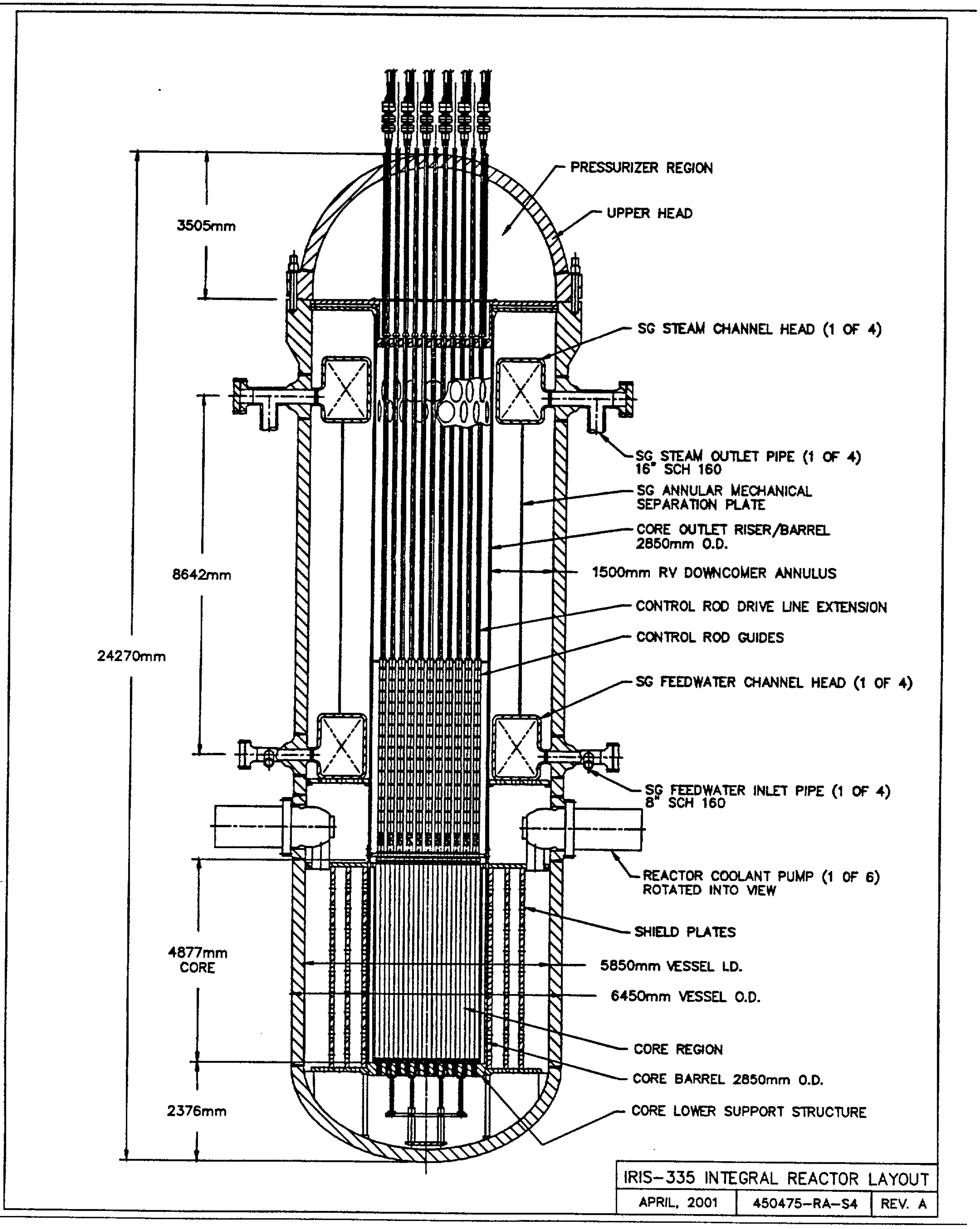
CONFIGURATION

335 MWe Vessel



INTERNAL SHIELDS

Steel volume fraction (%)	Vessel Activation at shutdown (Bq/g)	Ratio	Dose rate(*) (μSv/h)	Ratio
20	310	1	3	1
↓ 20+B_4C (**)	10	1/31	0.006	1/500
30	30	1	0.14	1
↓ 30+ B_4C (**)	8	1/4	0.002	1/70

(*) Evaluated on the inner biological shield surface
(**) A boron carbide fraction of 10% is considered in the shield

Dept. of Nuclear Engineering - Politecnico di Milano - Italy - 2001 April

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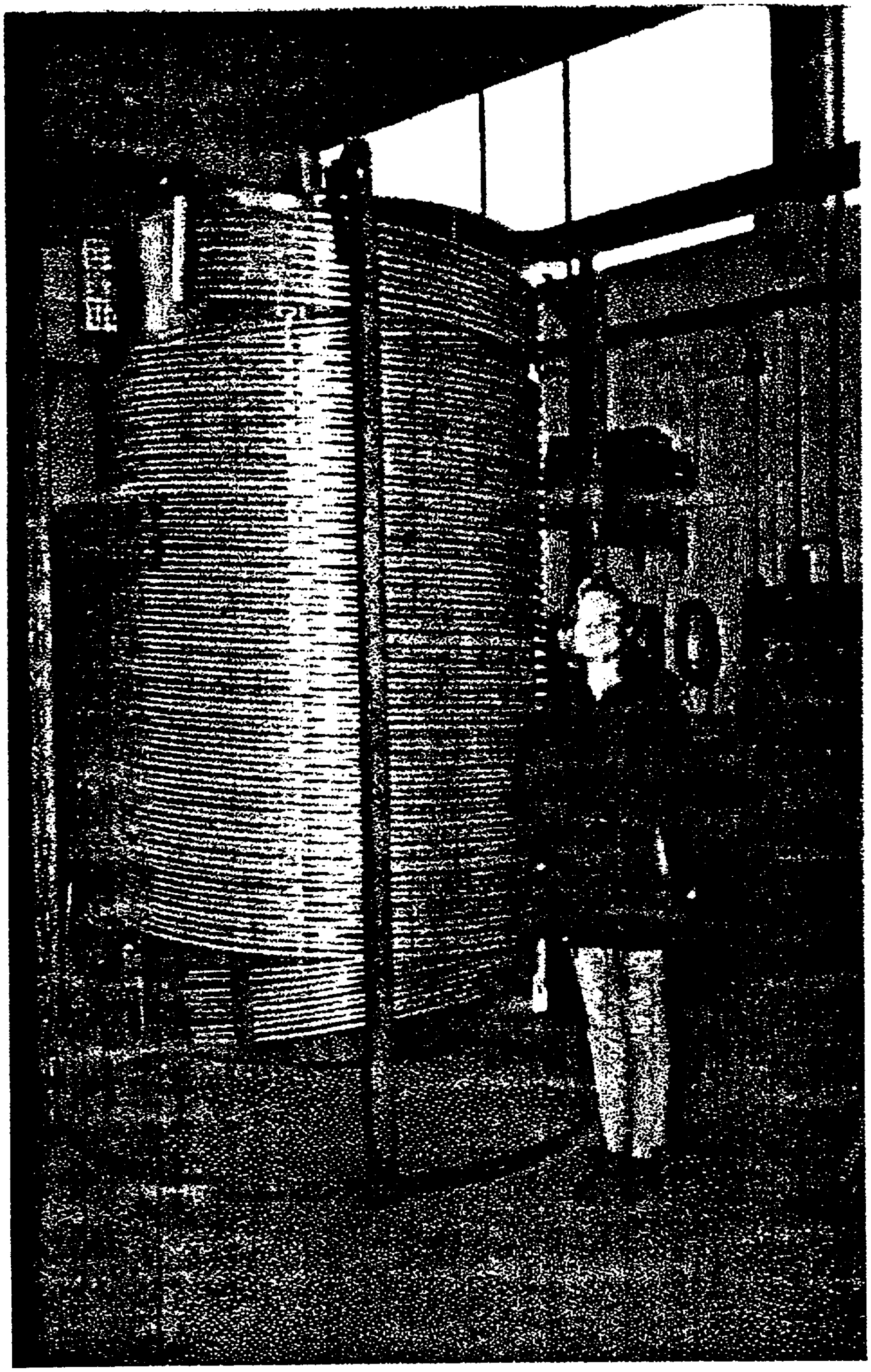
INTERNAL SHIELDS

- No restrictions to workers in containment
- Simplified decommissioning
- Vessel (minus fuel) acts as sarcophagus

ANSALDO
Ansaldo Nucleare



20 MW mock-up of the helical-tube SGU
Test campaign at SIET

HELICAL STEAM GENERATOR

- LWR and LMFBR experience
- Fabricated and tested
- 8 SGs practically identical to Ansaldo modules will be installed in IRIS
- Test confirmed performance (thermal, pressure losses, vibration, stability)

ENHANCED SAFETY APPROACH
(Safety by Design)

SAFETY PHILOSOPHY

- Generation II reactors cope with accidents via active means
- Generation III reactors cope with accidents via passive means
- Generation IV reactors (IRIS) emphasize prevention of accidents through "safety by design"

IMPLEMENTATION OF IRIS SAFETY BY DESIGN

Design Characteristic	Safety Implication	Related Accident	Disposition
Integral reactor configuration	No external loop piping	Large LOCAs	Eliminated
Tall vessel with elevated steam generators	High degree of natural circulation	LOFAs (e.g., pump seizure)	Either eliminated (full natural circulation) or mitigated consequences (high partial natural circulation)
	Can accommodate internal control rod drives	Reactivity insertion due to control rod ejection	Can be eliminated
Low pressure drop flow path and multiple RCPs	N-1 pumps keep core flow above DNB limit, no core damage occurs	LOFAs (e.g., RCP shaft break or rotor seizure)	Condition IV accident eliminated
High pressure steam generator system	Primary system cannot over-pressure secondary system	SGTR	Automatic isolation, accident terminates quickly
	No SG safety valves required	Steam and feed line breaks	Reduced probability. Reduced consequences
Once through SG design	Low water inventory		
Long life core	No partial refueling	Refueling accidents	Reduced probability
Large water inventory inside vessel	Slows transient evolution Helps to keep core covered	Small-medium LOCAs	Core remains covered with no safety injection
Reduced size, higher pressure containment	Reduced driving force through primary opening		
Inside the vessel heat removal			

IRIS CONTAINMENT

- It performs containment function

<u>plus</u>

- In concert with integral vessel, it practically eliminates LOCAs as a safety concern

<u>On first principles</u>

Pressure differential (driving force through rupture) is lower in IRIS because

- Containment pressure higher (lower volume, higher allowable pressure)
- Vessel pressure lower (internal heat removal)

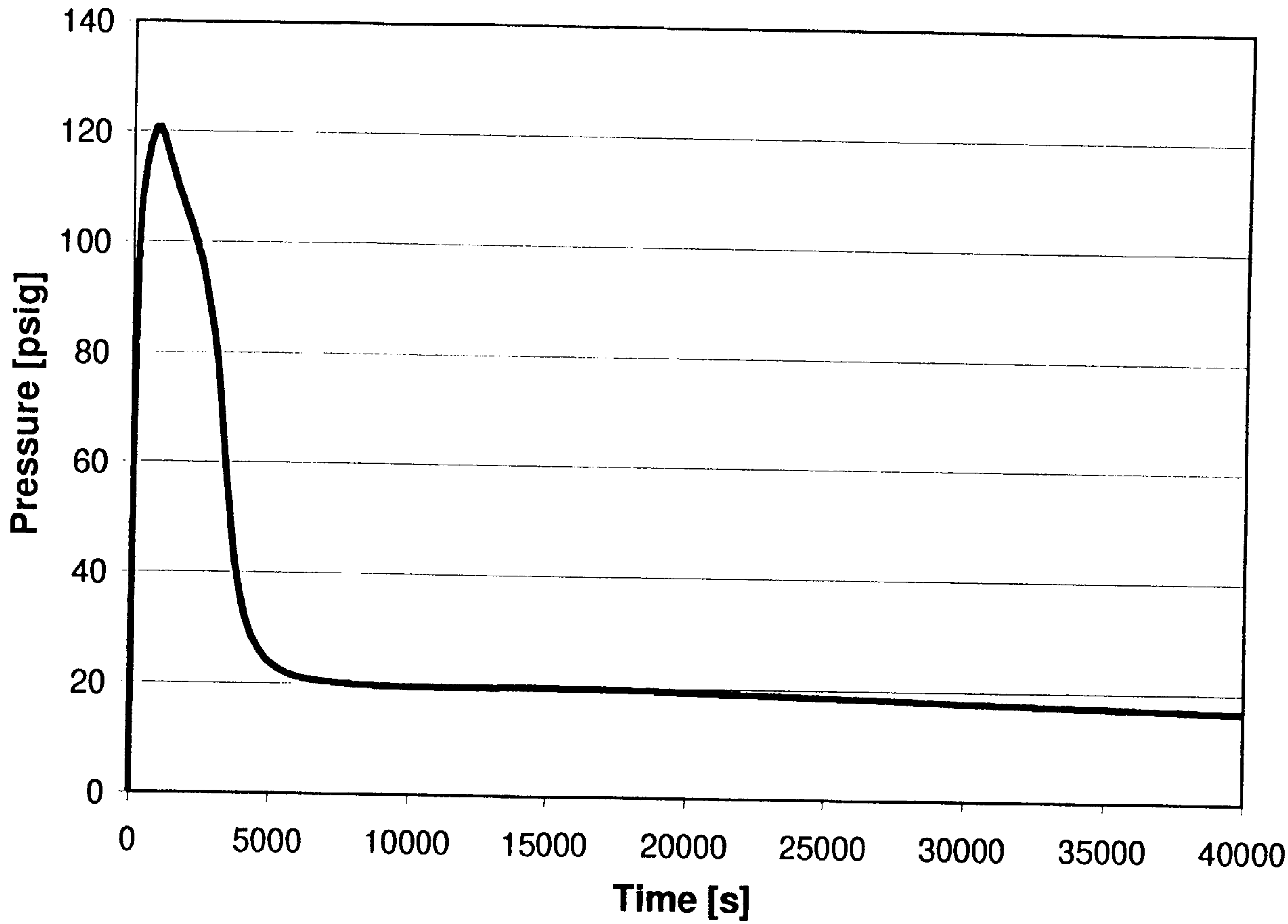
IRIS CONTAINMENT (100/335 MWe)

- Spherical, steel containment, 20/25 meter diameter
- ~15/12 bar_g design pressure (220/175 psig)
- Small, elevated suppression pool limits peak pressure to ~ 9 bar_g (130 psig) and can provide gravity driven core makeup if needed
  - 150/375 m^3 water
  - 300/750 m^3 air
- RV in cavity that floods to level above core
- External air/water cooling of steel shell
- Refueling performed through closure head directly into fuel building

ANALYSES PERFORMED

- **Break size: 1, 2, 4"**
- **Elevation: Bottom of vessel, above core (inside and outside cavity), 12.5 m above bottom**
- **No water makeup or safety injection**
- **Three codes provided consistent results**
  - Proprietary (POLIMI)
  - GOTHIC (Westinghouse)
  - FUMO (Univ. Pisa)

HIGHER CONTAINMENT PRESSURE DECREASES QUICKLY



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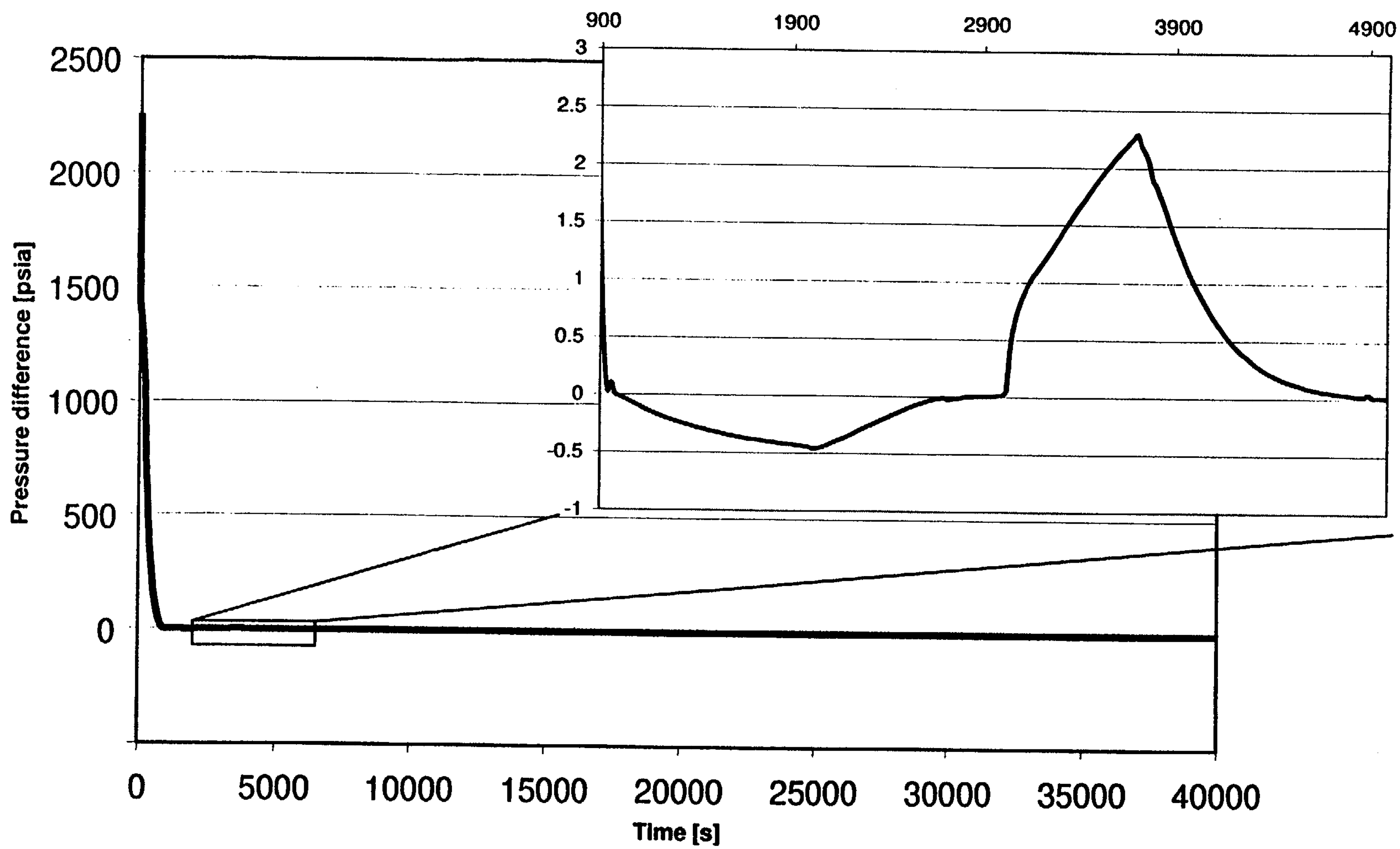
REACTOR VESSEL/CONTAINMENT PRESSURE DIFFERENTIAL EQUALIZES QUICKLY



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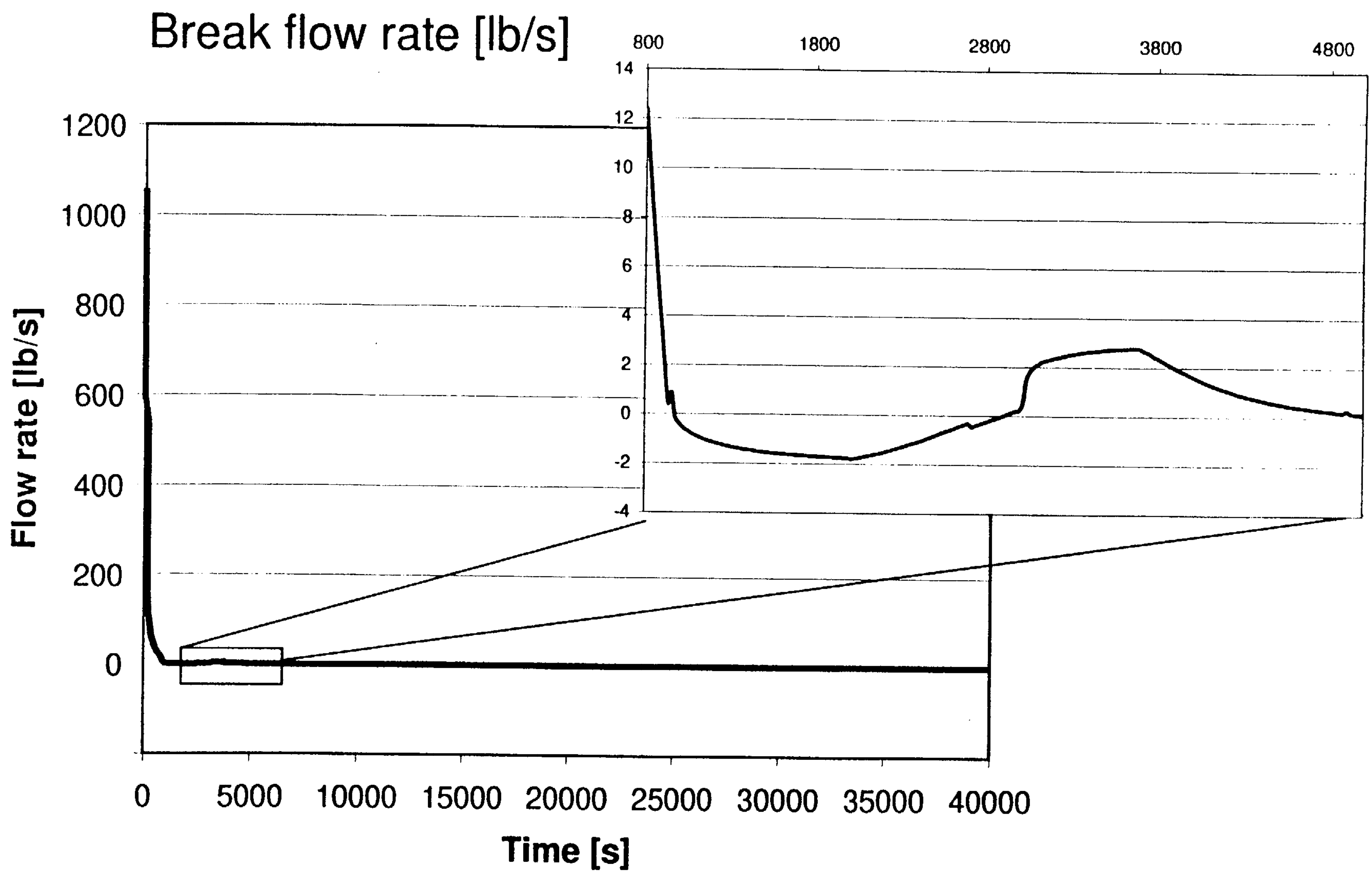
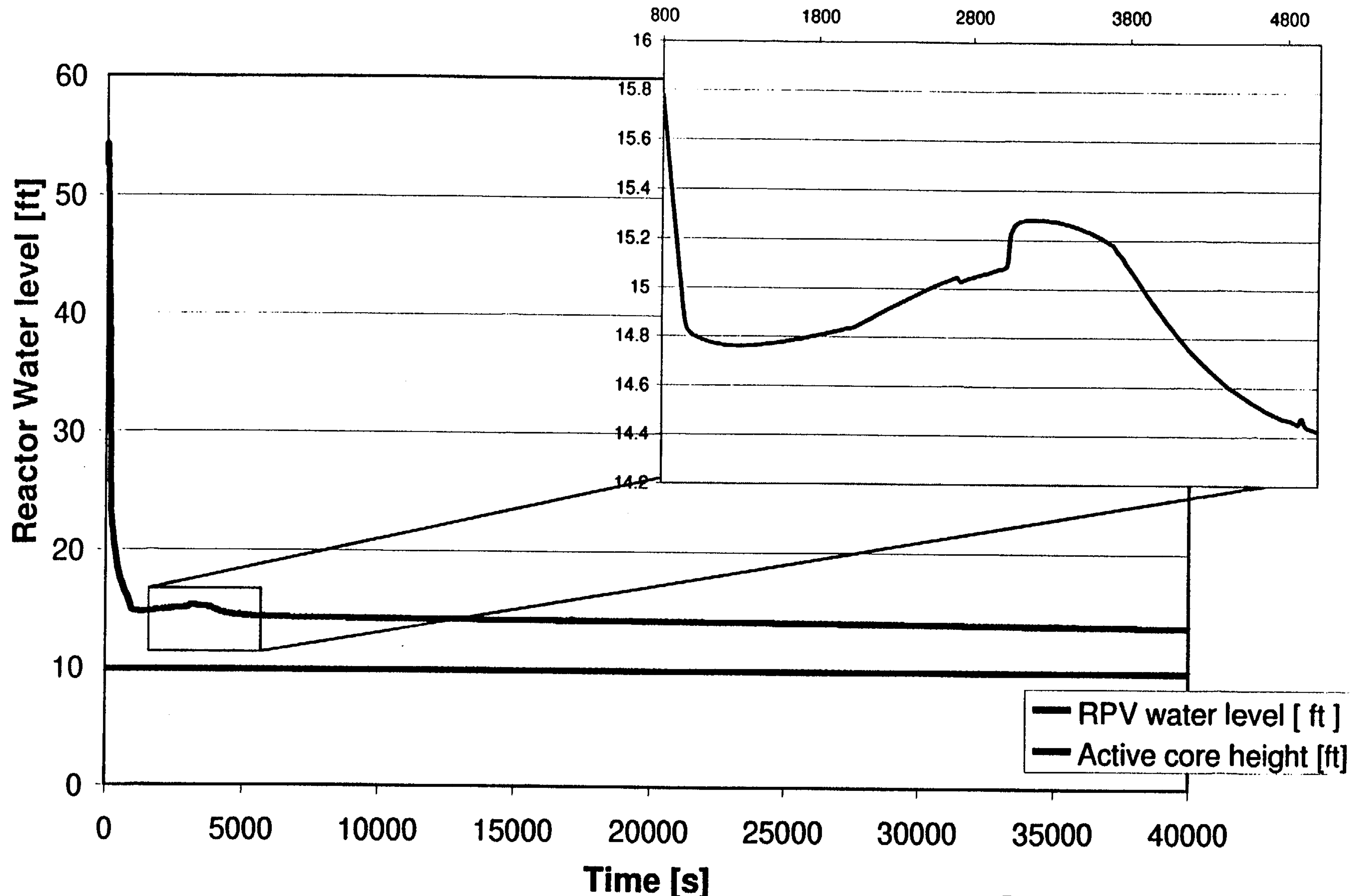
COOLANT FLOW THROUGH RUPTURE DROPS QUICKLY



CORE REMAINS SAFELY COVERED FOR EXTENDED PERIOD OF TIME



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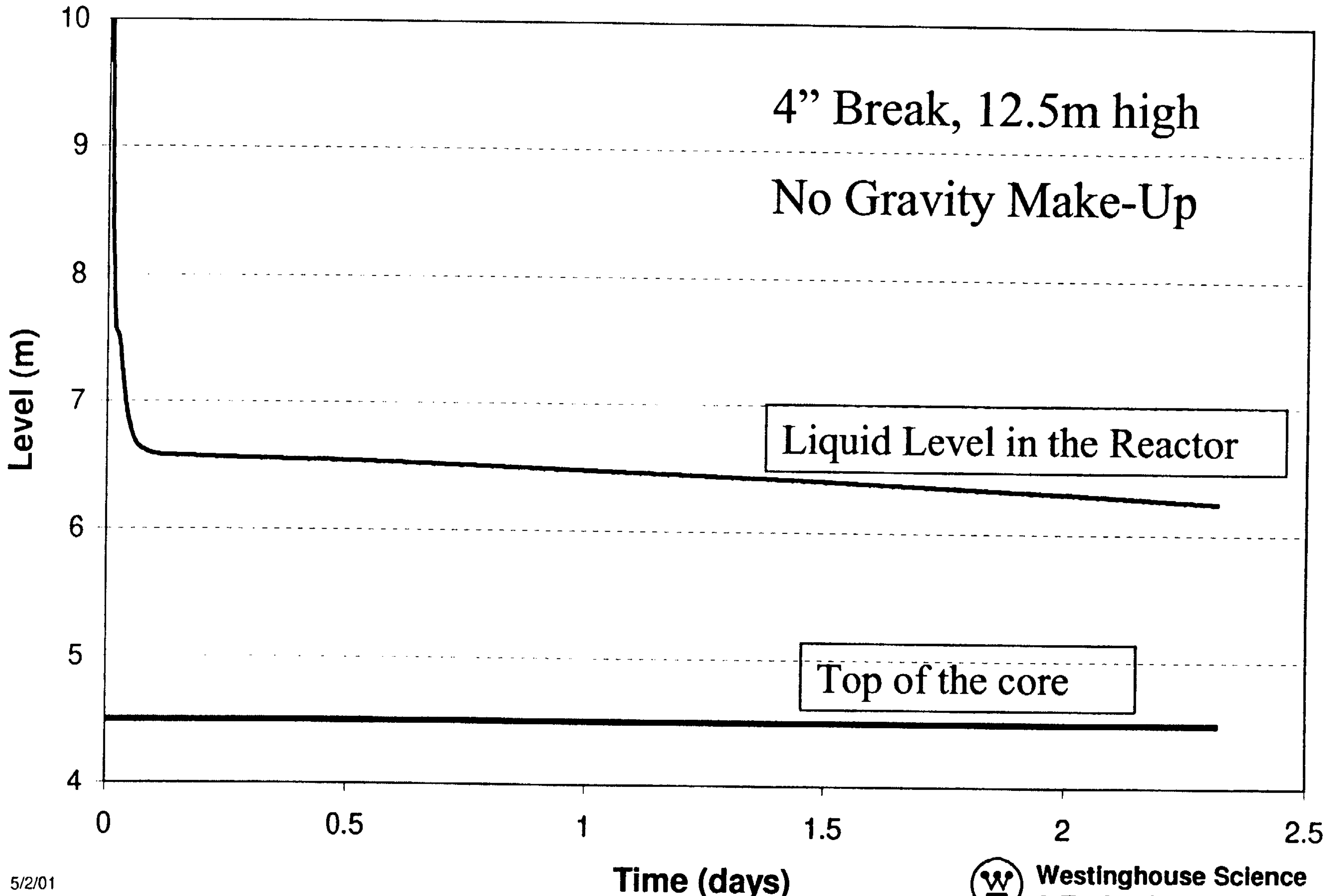
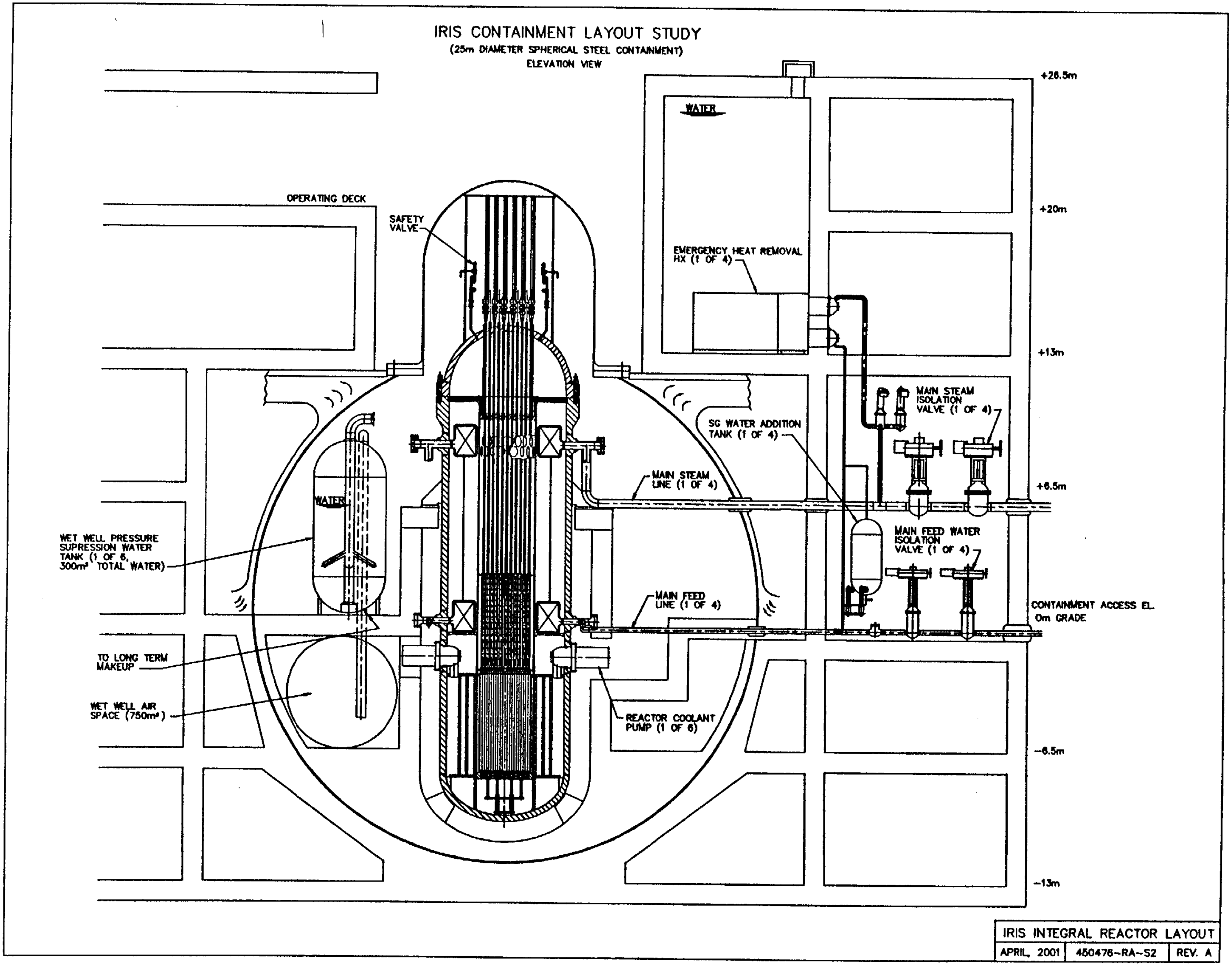
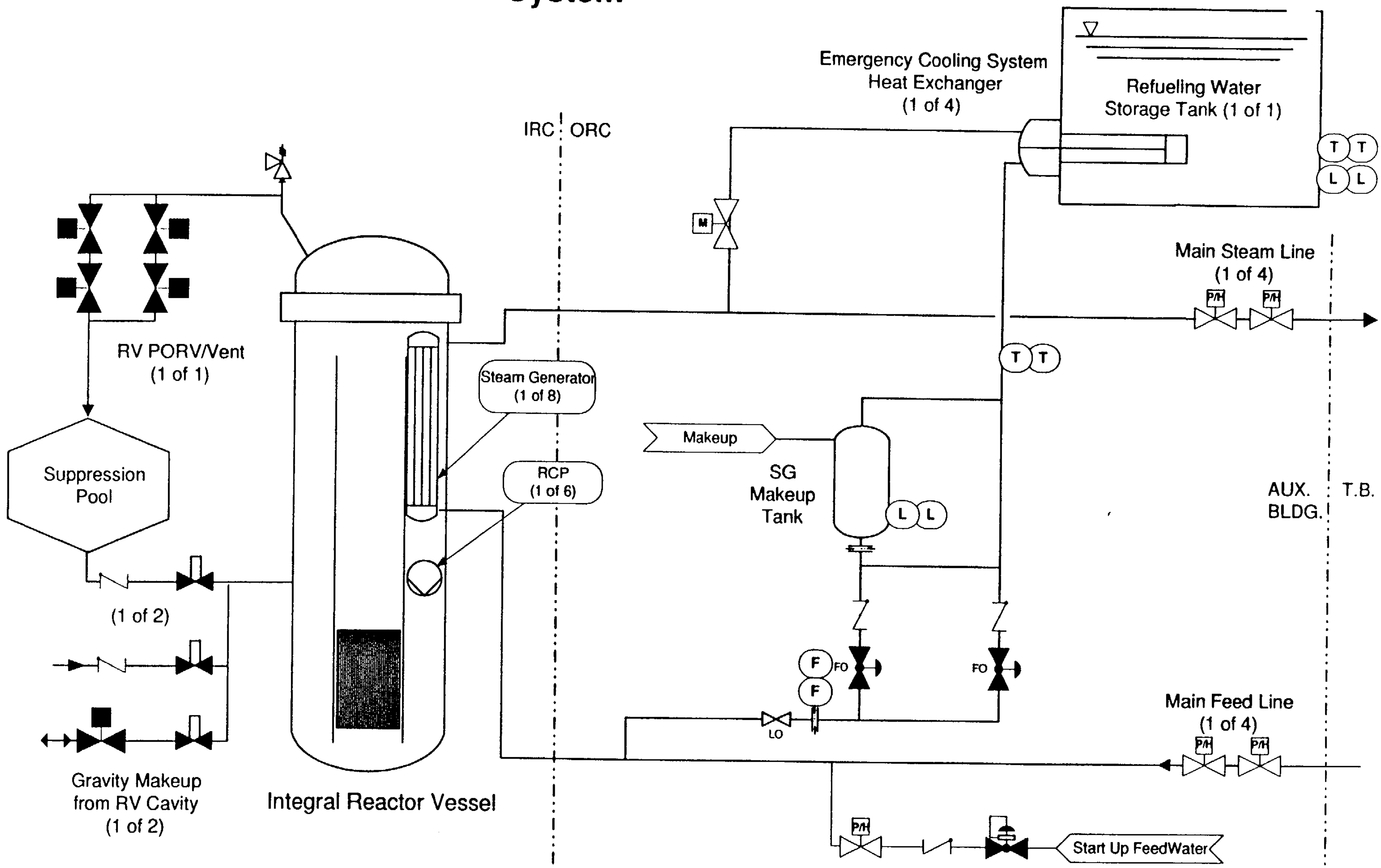
CORE STILL UNDER 2 METERS OF WATER AFTER 2 DAYS




IRIS CONTAINMENT LAYOUT STUDY
(25m DIAMETER SPHERICAL STEEL CONTAINMENT)
ELEVATION VIEW
OPERATING DECK
SAFETY VALVE
WATER
EMERGENCY HEAT REMOVAL HX (1 OF 4)
MAIN STEAM ISOLATION VALVE (1 OF 4)
SG WATER ADDITION TANK (1 OF 4)
MAIN STEAM LINE (1 OF 4)
MAIN FEED WATER ISOLATION VALVE (1 OF 4)
MAIN FEED LINE (1 OF 4)
WATER
WET WELL PRESSURE SUPRESSION WATER TANK (1 OF 6, 300m³ TOTAL WATER)
TO LONG TERM MAKEUP
WET WELL AIR SPACE (750m³)
REACTOR COOLANT PUMP (1 OF 6)
CONTAINMENT ACCESS EL. 0m GRADE
+28.5m
+20m
+13m
+6.5m
-6.5m
-13m
IRIS INTEGRAL REACTOR LAYOUT
APRIL, 2001
450476-RA-S2
REV. A

IRIS Emergency Heat Removal System



IRIS - Safety by Design (LOFA)

- Condition IV loss-of-flow-accident (LOFA) is the sudden reduction in core flow caused by a pump shaft break or rotor seizure event resulting in DNB and fuel damage.
- These LOFA consequences are eliminated in IRIS
- Primary system flow path delta-P is very low
  - 60 ft. vs 250 to 350 ft. ΔP in loop type reactors
  - RCP's have flat head vs flow curve, and excess runout flow capability
- Multiple RCP's (6)
- Core flow maintained at 83% of full flow with n-1 RCPs
- With low power density core, no DNB, no core damage

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IRIS - Safety by Design (SGTR)

- Current SGTR event causes radiation release, potential containment bypass, operator action to depressurize
- IRIS SG's, piping and isolation valves are designed for full RCS pressure - primary system cannot over-pressure
- SG tube rupture recovery greatly simplified
  - Steam and feed isolation valves of faulted SG automatically closed
  - SG fills, primary/secondary side pressure equalizes, terminating the leak
  - No operator actions required, other than normal shutdown and cooldown
- Adequate redundancy for continued heat removal assured by multiple SG's, steam/feed paths, normal and emergency heat removal

IRIS - Safety by Design (SLB & FLB)

- IRIS has high pressure SG's, piping, and isolation valves
  - No SG safety valve needed, thus no corresponding SLB
  - Increased margin to pipe rupture
- 8 modular, once-through SG's connected to 4 steam and feed piping connections
  - Once-through design contains very little water inventory, thus very little release to containment following SLB
  - 3 of 4 normal and emergency heat removal paths available
- IRIS design reduces both the probability and severity of credible and major steam and feed line breaks

IRIS - Safety by Design (Station Blackout)

- Relevant IRIS safety systems:
  - Reactor trip (same as other LWRs)
  - Decay heat removal (passive, following one time valve actuation)
  - Primary system water inventory and NC core cooling (safety by design)
  - Containment cooling (passive)
- Necessary actuations and monitoring are battery powered for extended time ($\geq$ 3 days)
- Canned RCP's have no seals (no consequential LOCA)
- Station blackout is not a core damage event for IRIS

Resolution of AP-600 Class IV Accidents in IRIS

	Accident	IRIS Safety by Design	
1.	Steam system piping failure (major)	Reduced probability Reduced consequences	*
2.	Feedwater system pipe break		
3.	Reactor coolant pump shaft seizure or locked rotor	Reduced consequences No core damage occurs	*
4.	Reactor coolant pump shaft break		
5.	Spectrum of RCCA ejection accidents	Can be eliminated	
6.	Steam generator tube rupture	Reduced consequences	*
7.	Large LOCAs	Eliminated	
8.	Design basis fuel handling accidents	Reduced probability	

* Can be reclassified as Class III

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INTERNAL CONTROL ROD SYSTEM

Conventional control rod drive mechanisms configuration is the current reference for IRIS first deployment. However a fully internal configuration has many advantages:

- Eliminates head penetrations
  - Simpler, more economical vessel design and fabrication
  - No stress corrosion cracking of penetration and seals (maintenance, replacement)
  - No Class IV rod ejection accident (safety by design)
- Eliminates long drivelines
  - Seismic concern alleviated
  - Cost reduction
  - Better utilization of internal space
- Simplifies containment

OPTIONS FOR INTERNAL CONTROL SYSTEM

A. Internal control rod drive mechanisms (CRDMs)

A1. Hydraulically driven motion

- In operation in NHR-5 Chinese reactor
- Design and tested for Argentina CAREM reactor
- Analyses and proof of principle tests performed by POLIMI

A2. Electromagnetically driven motion

- Design and extensive testing by MHI and JAERI for Japan MRX marine reactor

B. Liquid control rods

- Manometer type design patented by EdF
- In same positions as mechanical rods
- Fine sensitivity to power shaping

IRIS POSITION ON CONTROL SYSTEM

- Internal system is the logical solution for IRIS and integral configuration in general
- Hydraulically driven internal CRDMs are proven
- Materials behavior for electromagnetically driven internal CRDMs still a question for IRIS
- More investigation of liquid rods is necessary
- Development effort and schedule are critical for application to IRIS
- Conventional system remains the reference until there is consensus that the internal system is mature and can replace it

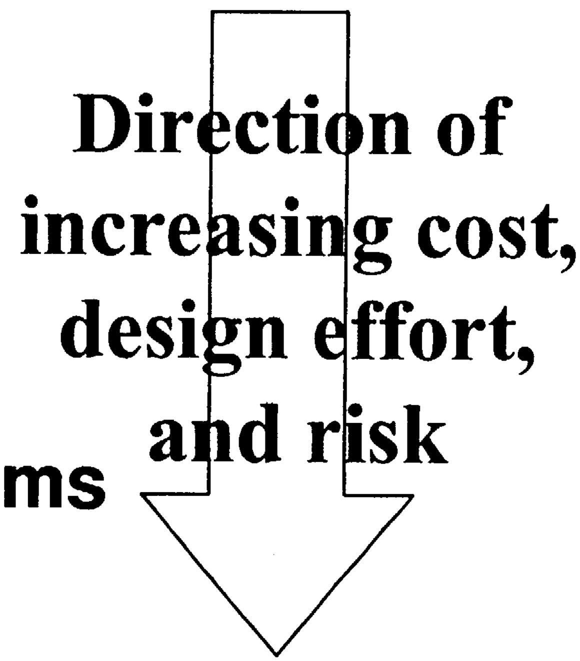
MAINTENANCE OPTIMIZATION

Surveillance Strategy

"*defer if practical, perform on-line when possible, and eliminate by design where necessary*"

Design where necessary:

- **Utilize existing components**
- **Utilize existing technologies**
- **Request rule changes**
- **Develop new components/systems**
- **Develop new technologies**



Objective

Enable the target IRIS operating cycle length by eliminating maintenance-related barriers

Steps to achieving this objective:

- **Identify barriers in an existing PWR program**
- **Identify barriers due to IRIS design differences**
- **Focus the IRIS design effort to eliminate these identified barriers**
- **Develop techniques to eliminate emerging barriers**

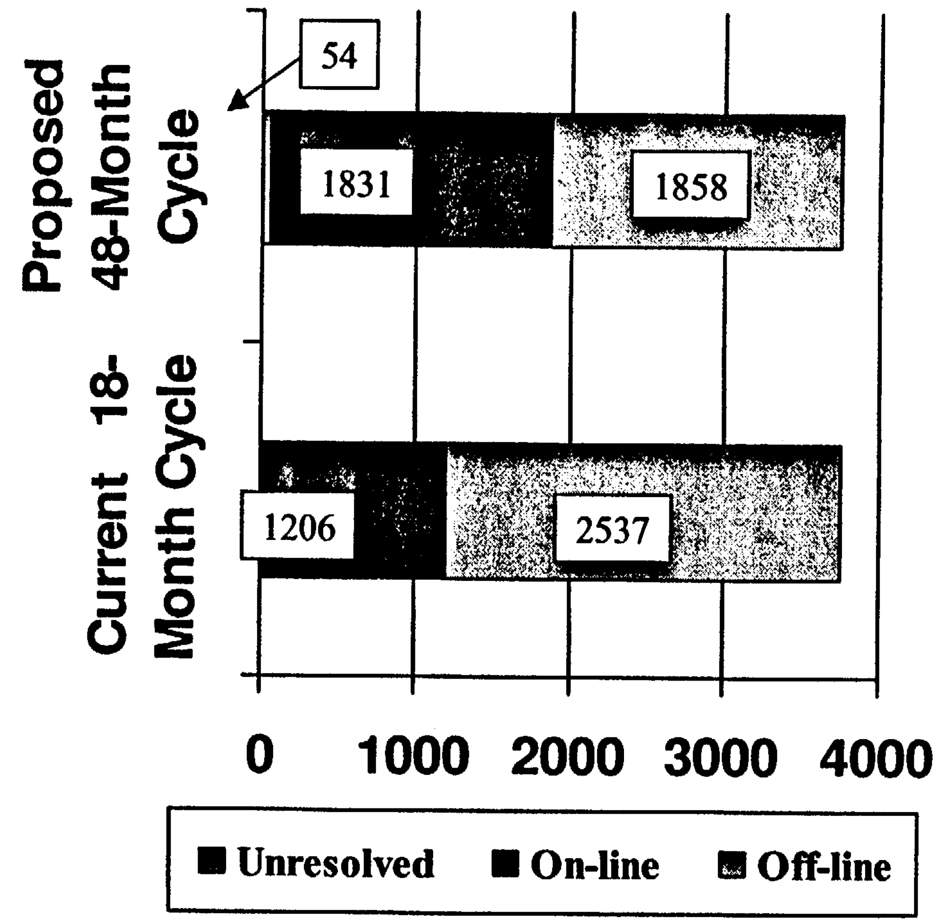
The Bottom Line

- IRIS must utilize components and systems which are either *accessible on-line* for maintenance or *do not require any off-line* maintenance for the duration of the operating cycle
- IRIS must utilize *high reliability* components and systems to minimize the probability of failure leading to unplanned down-time during the operating cycle

Extended Fuel Cycle Project

- Study completed in 1996 investigated extending PWR to 48 month cycle
- Recategorized all off-line maintenance as either:
  - Defer to 48 months
  - Perform on-line
  - Unresolved

PWR Surveillance Program Comparison



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Designs in Service

Years of Relevant Data

- No impetus exists for currently operating plants to transition to very long cycles
  - Extensive backfit required
  - Plant cycles synchronized with demand
  - Finally good at outage management
- Possess significant amount of material history which can aid in justifying surveillance deferral

How can we unlock this data for evaluation?

Outline

- **Strategy Overview**
- **Identifying Cycle Length Barriers**
- **Known Barriers**
- The "Big Seven"
- **Closing Comments**

"Big Seven":

- Relief valve testing
- Steam generator inspection
- Main condenser cleaning
- Safety system testing
- Main turbine throttle control
- Rod control system testing
- Reduced power window items

MAINTENANCE ISSUES RESOLUTION

- Issues identified
- Tasks assigned
- Review progress in October 2001
- Major obstacles not expected

IRIS AND GENERATION IV GOALS

Design feature	GOAL		
	Sustainable development	Safety and Reliability	Economics
Modular design		✓	✓
Long core life (single burn, no shuffling)	✓		✓
Extended fuel burnup	✓		✓
Integral primary circuit	✓	✓	✓
High degree of natural circulation		✓	
High pressure containment with inside-the-vessel heat removal		✓	✓
Optimized maintenance	✓	✓	✓

ISSUES

DEVELOPMENT APPROACH

- No need for prototype since no major technology development is required

- First-of-a-kind IRIS module can be deployed in 2010 or soon after

- Future improvements can be implemented in later modules (Nth-of-a-kind)

TECHNOLOGY GAPS

Identified technology gaps which need to be resolved.

For first-of-a-kind:

- Safety by design testing confirmation
  - Mockup of IRIS vessel/containment and associated safety systems. Possible facilities APEX (Oregon State Univ.), SPES (SIET, Italy), PANDA (PSI, Switzerland)
- Integral steam generator
  - Performance and reliability testing
  - Ansaldo has already tested a 20 MW helical steam generator
- Maintenance optimization
  - Address issues preventing four-year maintenance interval. Includes design, testing, instrumentation, procedures, regulatory
- Steam generator inspection procedure
  - Develop procedures, testing, regulatory

TECHNOLOGY GAPS (Cont'd.)

- System performance modeling
  - Select best analytical code capable of modeling IRIS, modify and run it

For first-of-a-kind/Nth-of-a-kind

- Internal control system
  - Assess alternatives, choose best and complete development

For Nth-of-a-kind

- High burnup fuel demonstration
  - Obtain data necessary for licensing
- Extended cycle operation
  - Qualify fuel and fuel assemblies for 8-10 years straight burn cycle
- Licensing of higher enrichment fuel
  - Assure regulatory approval

IMPORTANT REGULATORY ISSUES

- Establish review process to support goal of design certification by 2007
  - Periodic NRC/project interfacing
  - Initiate long lead testing
- License a first-of-a-kind since IRIS is based on proven LWR technology (precedent: AP600)
- Successful resolution of technology gaps
- Assess IRIS design and operational characteristics versus current PWR regulations and requirements
  - Two major areas:
    - » Safety by design. Some accidents scenarios not applicable
    - » Extended maintenance. Evaluate compatibility with current regulations
- Licensing of higher enrichment fuel for subsequent IRIS modules
  - Higher enrichment fabrication facilities
  - Higher burnup fuels
- Multiple modules (shared control room)
- How to translate into licensing IRIS improved safety "story". For example, can siting requirements (exclusion, low population zones) be relaxed?

SUMMARY AND CONCLUSIONS

- IRIS is part of BNFL/Westinghouse advanced reactors portfolio
- DOE and large international support
- IRIS specifically designed to address Gen IV requirements
- Modularity and flexibility address utility needs
- Enhanced safety through safety by design and simplicity
- IRIS is based on proven LWR technology, newly engineered for improved performance
- Major design choices completed
- Continuing interaction with and feedback by NRC and ACRS will be extremely beneficial
- Testing program needs to start in 2002 on selected high priority tests

Testing and Research Needs

Testing and Research Needs: Safety by Design

- Safety by design is a key feature of the IRIS design which allows the elimination of traditional safety systems such as the ECCS. It is therefore necessary that correctly simulated tests be performed to corroborate analytical predictions of the IRIS response to a gamma of safety challenging events.
- A mockup of the IRIS vessel/containment and associated safety related systems will be built, utilizing existing facility such as APEX (Oregon State Univ., USA), SPES (SIET, Italy) or PANDA (PSI, Switzerland). Properly simulated tests will be performed to investigate the system response to specified transient and accident conditions.
- Testing specifications, directions and data evaluation will be performed by Westinghouse supported by most of the academic team members. Construction of the facility and performance of the testing will be performed by the selected facility operator which will be funded by DOE.
- Successful resolution of this need is critical to IRIS deployment. We judge this to be the most critical item

Testing and Research Needs: Integral Steam Generator

- The IRIS steam generator has several unique features: it is located inside the vessel; the primary flow is on the outside of the tubes; the currently preferred design is a helical tube bundle. It also has an expanded safety role in the vessel/containment thermal-hydraulic coupling
- An extensive testing program of a reasonably sized module would be required to demonstrate performance and reliability, and ability to perform required safety functions. It might be beneficial to perform an integral vessel-containment-steam generator-emergency heat removal system test. This will be performed in FY 05-07 in cooperation with the safety by design testing.
- Ansaldo, Italy, is currently performing the preliminary steam generator design. In the first three years the steam generator will be tested "per se". Later, interactive testing with the integral vessel/containment will be performed at the same facility as the safety by design and funding will be shared with DOE.
- The development of a steam generator suitable for integral vessel layout, exhibiting satisfactory performance and reliability and capable of performing required safety functions is one of few engineering development issues facing the IRIS design.

Testing and Research Needs: Maintenance Optimization

- A key distinguishing IRIS feature is the extended (at least four years) maintenance shutdown interval. The various issues which have been identified to prevent attainment of this goal need to be removed.
- Solutions might include some or all of the following: reassessment of maintenance needs in light of the IRIS design characteristic; adequate instrumentation and diagnostic; new designs of components to allow ease of inspection; regulatory rule abrogations or changes.
- Westinghouse has overall responsibility for its implementation, but primary responsibility for individual components will be of the partner with design responsibility for that component. All the other IRIS team members will provide support as appropriate. NRC will be requested to review the proposed regulation amendments. Laboratories will support enhanced instrumentation and diagnostic.
- Successful attainment of the 4 years' maintenance interval will significantly reduce O&M costs, allow attainment of high capacity factors and dramatically increase IRIS attractiveness to utilities.

Testing and Research Needs: Steam Generator Inspection

The IRIS SG tubes are in compression under external primary system pressure and function differently than the traditional SG tubes. The required inspections and procedures must be modified and tailored responding to the different functions and failure modes of the IRIS SG tubes to assure SG performance and to implement the IRIS extended maintenance approach.

<u>Sharing of Development Responsibilities:</u>

- Industry defines the design functions and failure modes of the SG tubes
- Industry proposes amendment to SG inspection requirements and procedures
- NRC amends the SRP requirements as necessary
- Laboratories support industry to develop and test inspection procedures for defined failure modes

Testing and Research Needs:System Performance Modeling

- The IRIS integral vessel/coupled small containment requires modeling of the system performance during normal and abnormal conditions as input to the design of the control system and the mitigation of transient initiators.
- Performance Modeling will determine the differences between the performance characteristics of a standard PWR and IRIS, and it will also provide a basis for licensing of the IRIS transient performance.
- Model the IRIS system response and the interaction of different subsystems based on first principles, system modeling and test data. Existing reactor performance simulation codes will be assessed and a reference code will be selected and modified as necessary to appropriately simulate IRIS conditions. The control system functional requirements will be established.
- IRIS consortium members will, with laboratories' assistance, evaluate existing codes and select the best candidate for IRIS simulation. They will subsequently model the system performance, predict the accident scenarios and verify predictions.

Testing and Research Needs: Internal Control Rod Drive Mechanisms

- The integral vessel configuration results in long drivelines which need to be engineered for seismic events. Also, the straight burn core requires more control rods than a conventional LWR. The integral configuration is ideal for locating the CRDMs inside the vessel. This is consistent with safety by design since the rod ejection accident is eliminated. Vessel head penetrations are eliminated resulting in simpler and cheaper design and elimination of stress corrosion cracking of seals and penetrations.
- Internal CRDMs can be electromagnetically or hydraulically actuated. Liquid control rods have also been proposed. A system will be selected, designed and tested. While it is advantageous to have this system ready for incorporation in the FOAK, it is possible that actual deployment will not occur until the subsequent IRIS modules.
- IRIS consortium will have primary responsibility for selection of CRDM system, design, and qualification. DOE supported laboratories and universities will provide testing and analyses. NRC evaluation and eventual approval of this novel system will be necessary.
- Successful demonstration of the internal CRDM system has many benefits in the areas of safety, economics, performance, and operation.

Testing and Research Needs: Extended Fuel Cycle

- IRIS fuel assemblies operating initially in a 4-5 year and subsequently in a 8-10 year fuel cycle must be qualified for operating for such a long time without interim inspection.
- No development is required for operating for 4 years under IRIS conditions. For reload core conditions the limiting performance parameters, primarily corrosion, must be predictable.
- Qualification testing is required of the fuel rod cladding, grids and assembly structures. Material testing and post-irradiation examination will confirm the adequacy of the materials, design and licensing data:
  - Westinghouse has the prime responsibility for data collecting, primarily Zirconium alloy corrosion, growth and hydriding data
  - Reactor operators (these could be the utilities who have joined the IRIS consortium) include low power fuel rods for extended low power operation in conventional PWRs
  - National Laboratories examine the data to support licensing
- Satisfaction of this need will provide the data necessary for designing and licensing fuel reloads up to 90 GWd/T-HM

Testing and Research Needs: Licensing of Higher Enrichment Fuel

- Reload cores of IRIS will use up to 9% enriched fuel. At this time no US facility is allowed to enrich the uranium at this level. Fuel vendors have no facilities licensed to package the fuel into assemblies and handle the fuel. To produce the higher enriched fuel and increase the core lifetime/burnup the present licensing barriers need to be raised:
  - Westinghouse and BNFL define fuel processing requirements, criticality limits and current licensing constraints
  - Amend the licensing requirements to produce and handle fuel with higher enrichment
  - Design or modify and license a production line to produce such fuel
- Requirements developed for handling and diluting weapons grade, high enriched uranium and MOX may provide a guide for changing the requirements.
- Providing the regulation and conditions for fabrication of fuel with higher enrichment will allow IRIS fuel reloads with a lifetime of 8 to 10 years. This results in reduced high level waste and improved economics.

Testing and Research Needs: High Burnup Fuel Demonstration

- The high burnup capability of IRIS type fuel must be demonstrated. Present fuel burnup is primarily limited by cladding corrosion, fuel rod internal pressure, enrichment in cores with a relatively high power density
- Some of the limitations of present fuel performance can be avoided in a low power density, highly moderated IRIS core. However, the high burnup achieved at a slow rate needs to be demonstrated in near prototypical tests to confirm the performance predictions and provide licensing data:
  - Industry will define and design the fuel to be tested
  - DOE and NRC will enable regulation to test 9% enriched fuel
  - Industry and DOE Laboratories will fabricate test rods for lead test assemblies
  - Reactor operations will enable testing of rods in reactors and prepare documentation for reactor licensing changes
  - IRIS consortium and DOE Laboratories will test rods/assemblies in reactors and evaluate results
- High burnup will allow the use of advanced reloads with reduced waste and economic advantages