U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: SPENT FUEL CHARACTERIZATION OVERVIEW

PRESENTER: RAY B. STOUT

PRESENTER'S TITLE AND ORGANIZATION:
TECHNICAL AREA LEADER
WASTE FORM CHARACTERIZATION
LAWRENCE LIVERMORE NATIONAL LABORATORY
LIVERMORE, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (415) 423-3965

AUGUST 28-29, 1990

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SPENT FUEL (SF) OVERVIEW

OUTLINE

- INTRODUCTION
- DISTRIBUTION ASPECTS OF PHYSICAL, CHEMICAL, AND RADIONUCLIDE PROPERTIES VERSUS BURNUP AND FISSION GAS RELEASE
- CONCEPTUAL MODELS UNDER DEVELOPMENT TO PLAN TESTS AND TO DESCRIBE SF RESPONSES

WHY PERFORM SPENT FUEL CHARACTERIZATION?

OBJECTIVE OF SF CHARACTERIZATION ACTIVITIES:

TO PROVIDE DATA, TESTING, AND MODELS THAT DESCRIBE DEGRADATION AND RADIOACTIVE RELEASE RESPONSES OF SF FOR WASTE PACKAGE AND SYSTEM PERFORMANCE ASSESSMENTS IN THE YUCCA MOUNTAIN PROJECT

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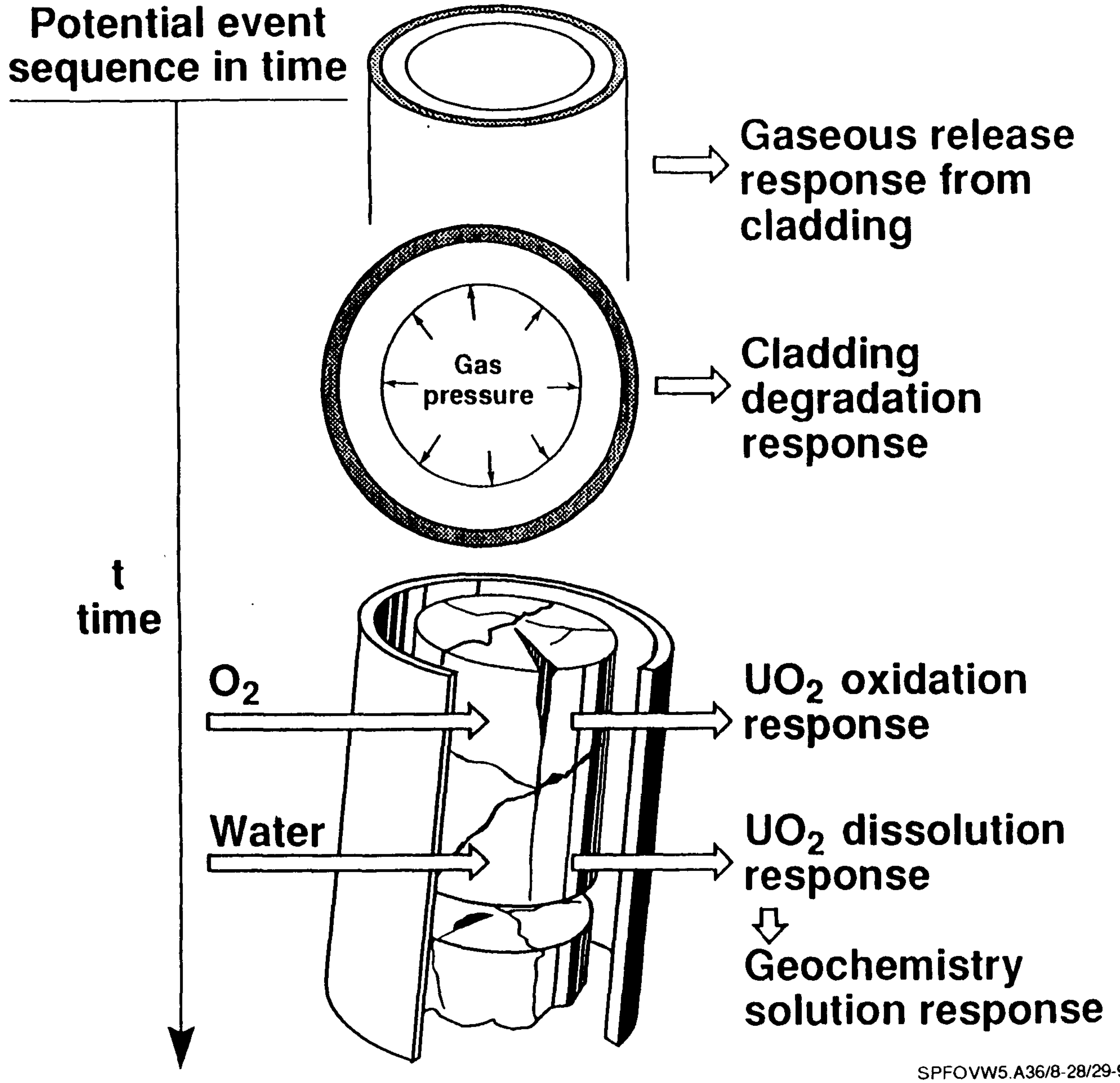
SPENT FUEL RESPONSE OVERVIEW



SPENT FUEL CHARACTERIZATION OVERVIEW

(CONTINUED)

- PRELIMINARY WASTE FORM CHARACTERISTICS REPORT (MARCH 91)

- CONTENTS OF REPORT
  - PHYSICAL PROPERTY DATA FOR EXISTING AND PROJECTED SFWF INVENTORIES
  - RADIONUCLIDE DATA FOR EXISTING AND PROJECTED SFWF INVENTORIES
  - MODELS AND TEST DATA FOR SPENT FUEL DEGRADATION

NUCLEAR FUEL
INSERT

TYPICAL PWR CORE ARRANGEMENT
INSERT

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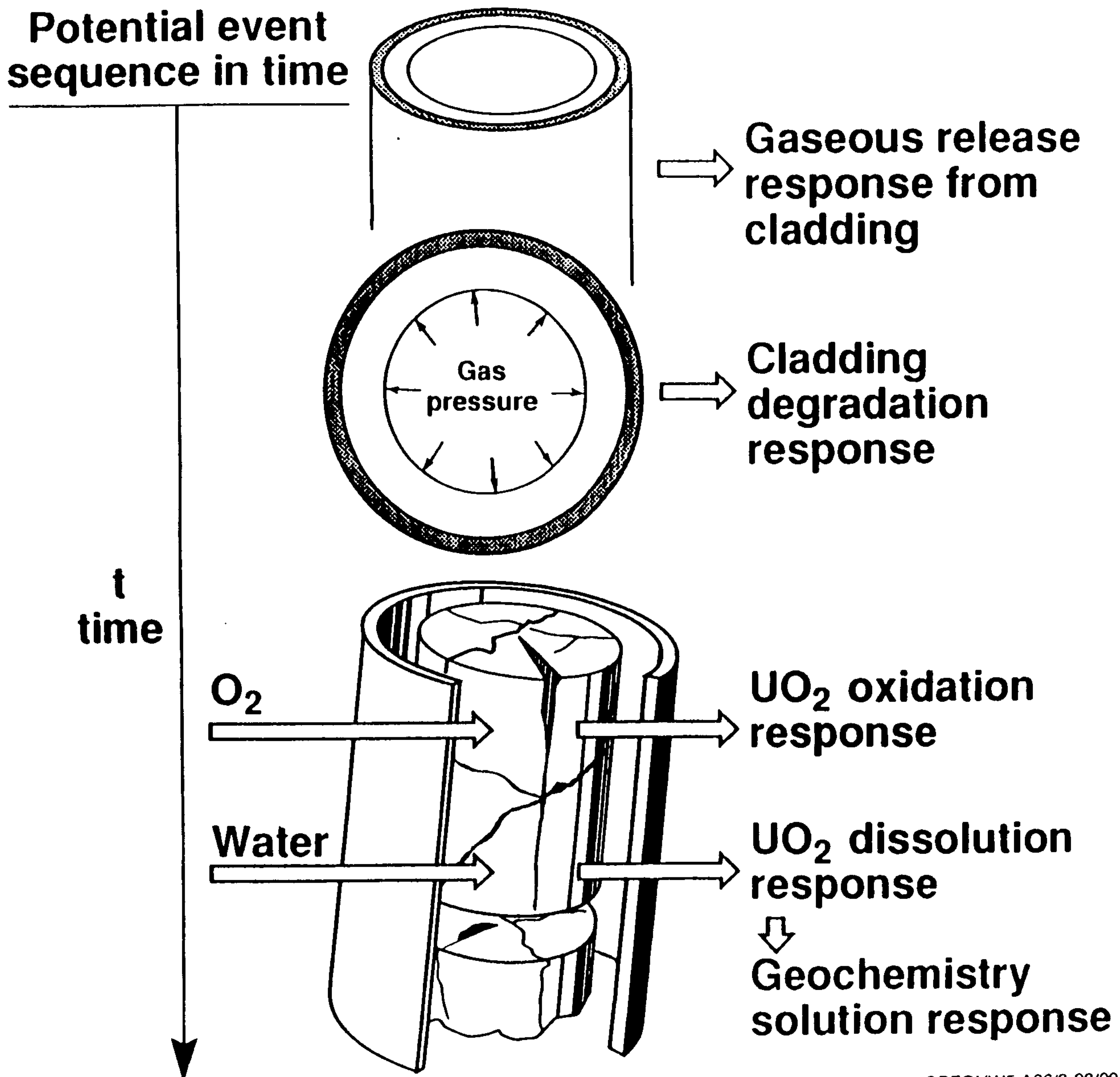
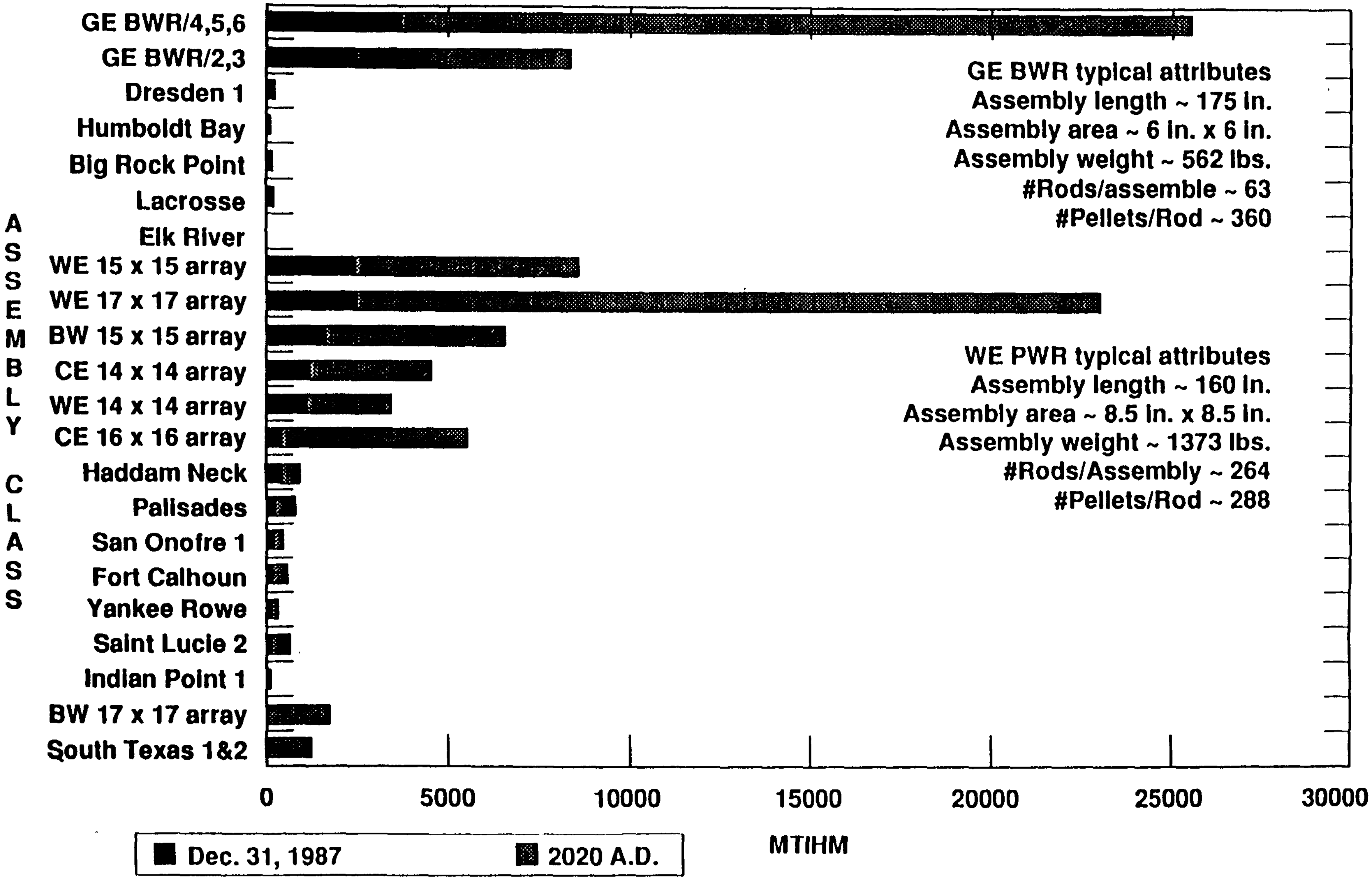
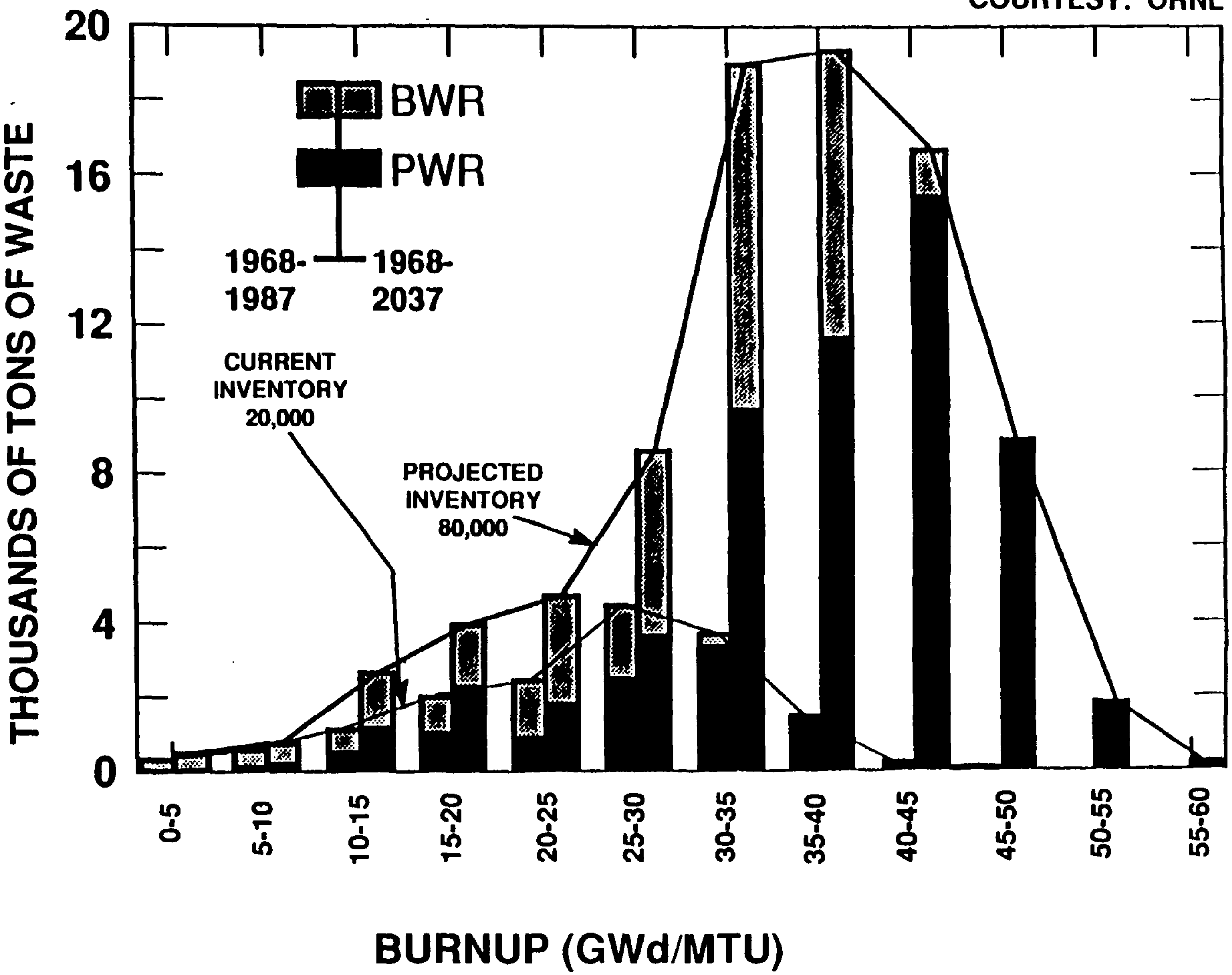


ASSEMBLY CLASS QUANTITIES AND TYPICAL DIMENSIONS

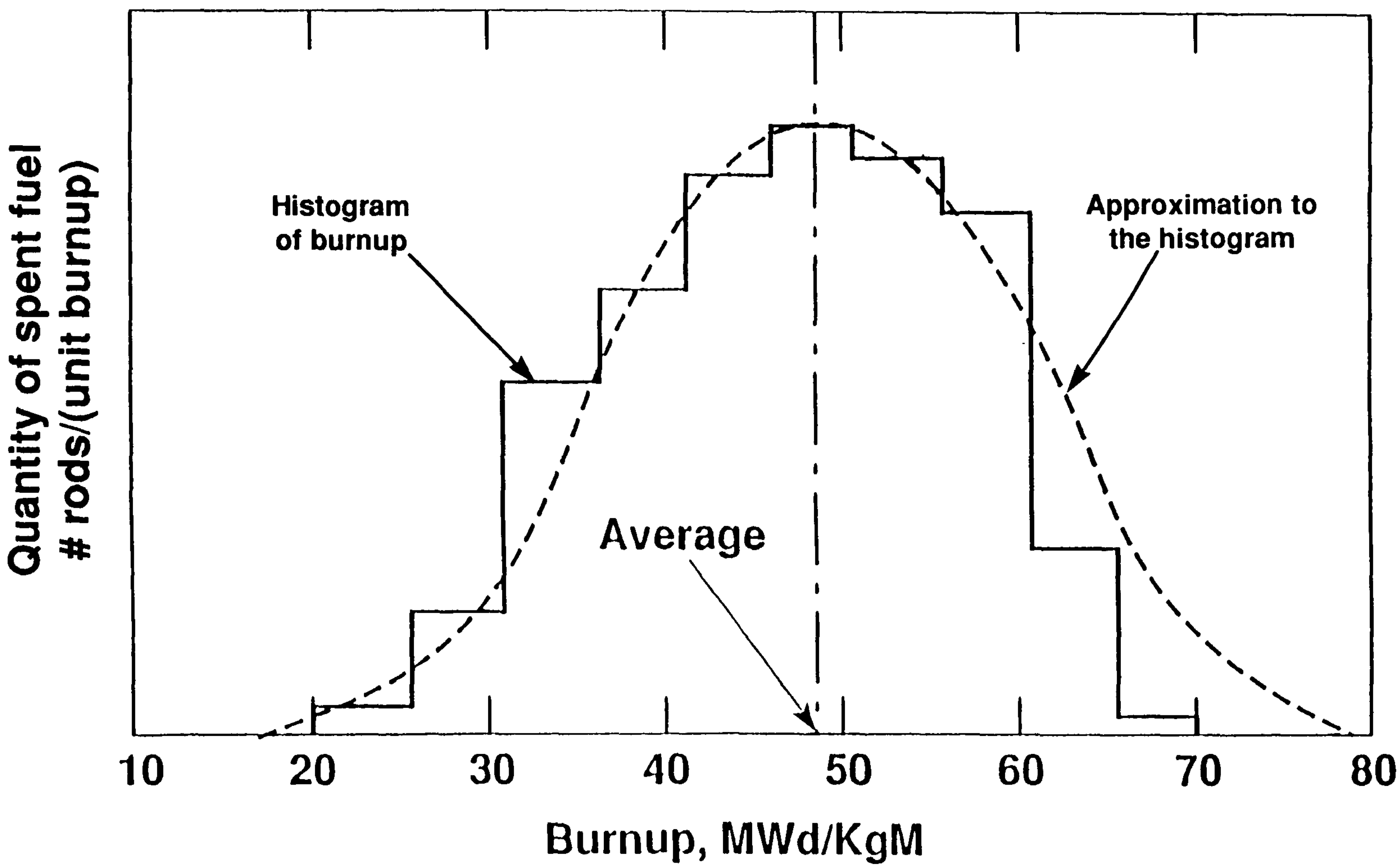


SPENT FUEL INVENTORY-
HISTORY AND PROJECTION

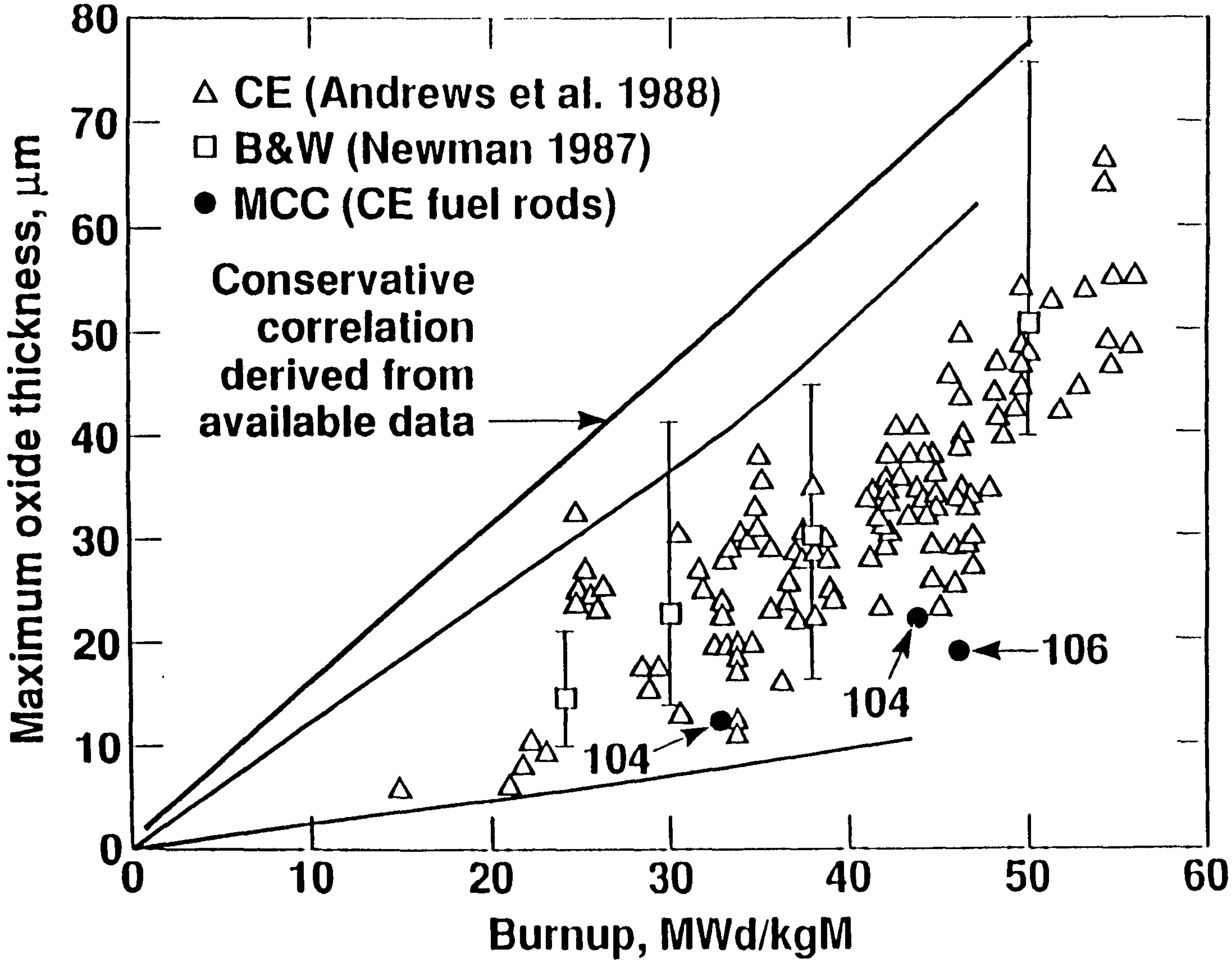
COURTESY: ORNL



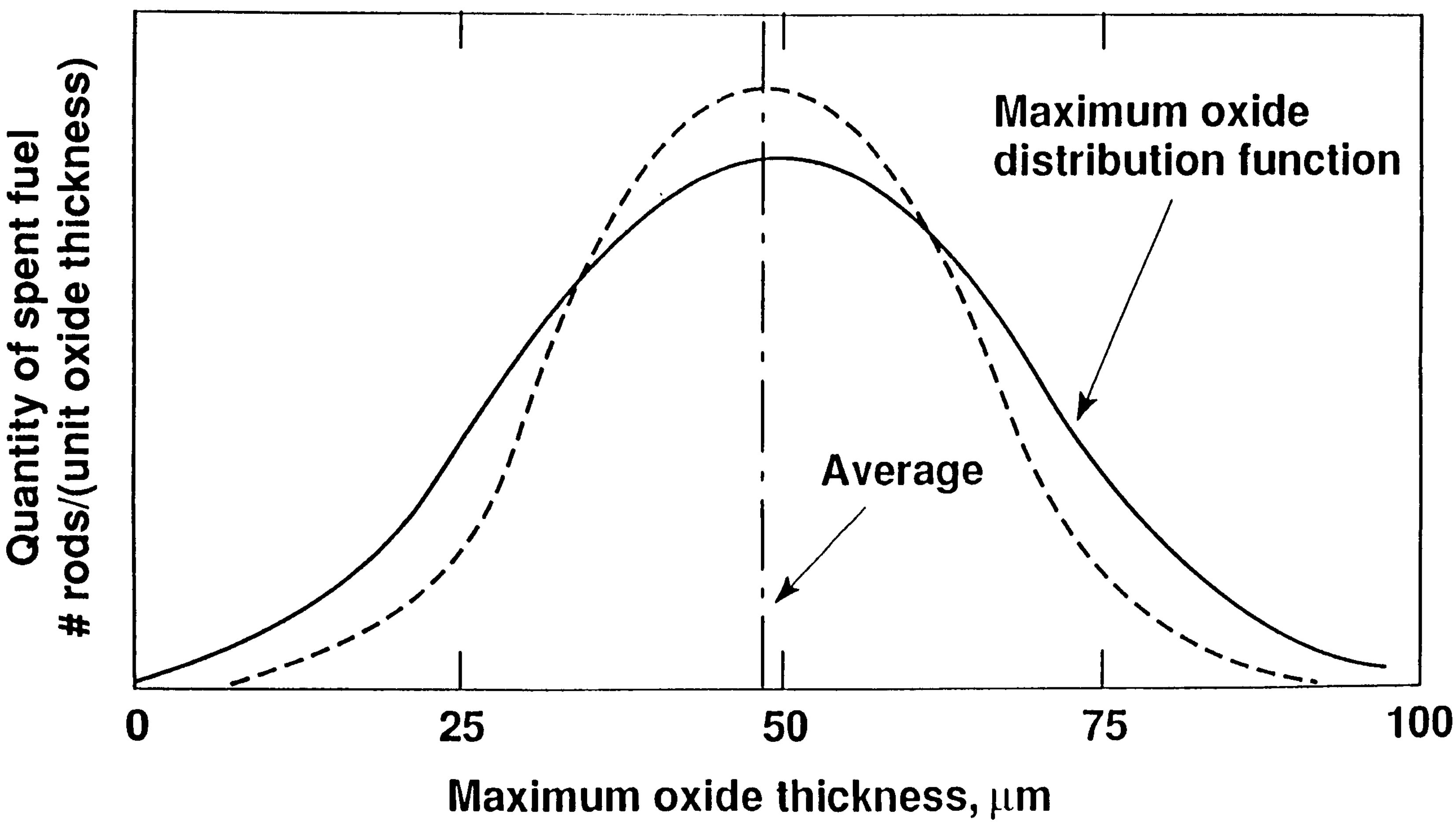
ILLUSTRATIVE ROD POPULATION DISTRIBUTION OF BURNUP



METHOD FOR CORRELATING MAXIMUM OXIDE THICKNESS WITH BURNUP



ILLUSTRATIVE ROD POPULATION DISTRIBUTION OF MAXIMUM OXIDE THICKNESS

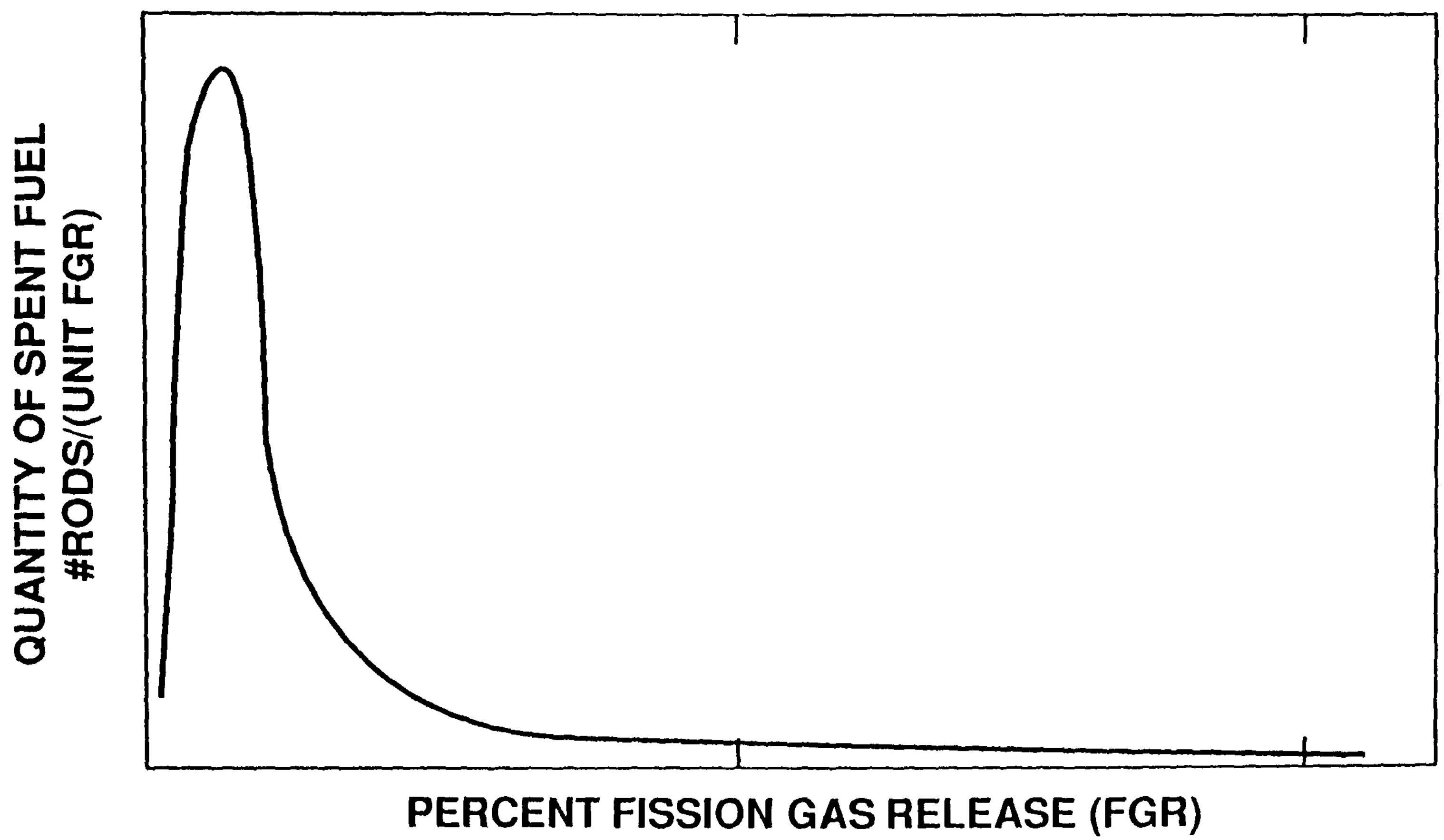


ROD POPULATION DISTRIBUTION FOR OTHER ATTRIBUTES

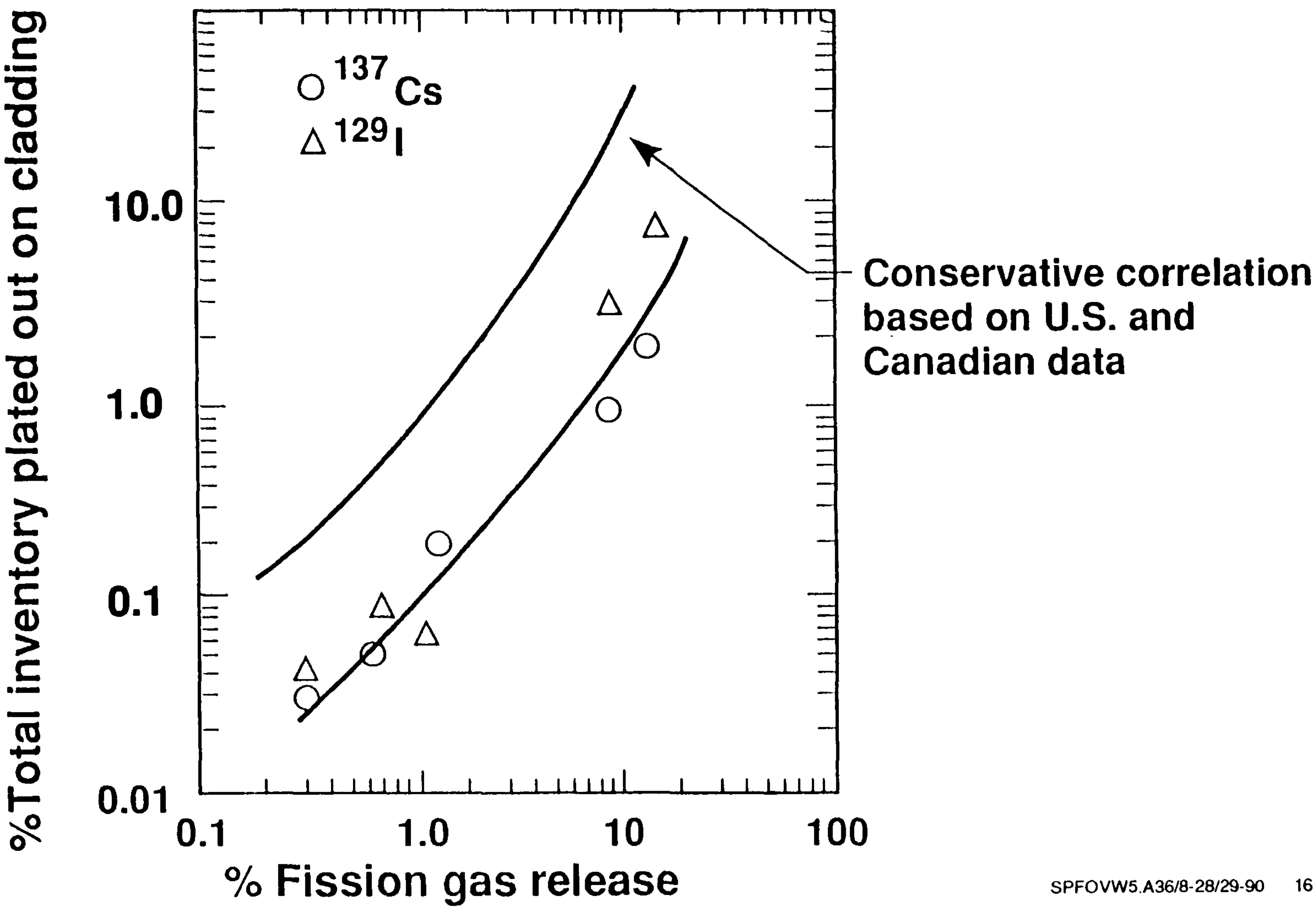
SOME EXAMPLES:

- RODS PER UNIT CARBON-14 VERSUS CARBON-14 IN CLADDING
- RODS PER UNIT HYDROGEN VERSUS HYDROGEN IN CLADDING
- RODS PER UNIT DECAY HEAT VERSUS DECAY HEAT IN SPENT FUEL
- RODS PER UNIT RADIOACTIVE SPECIES VERSUS RADIOACTIVE SPECIES

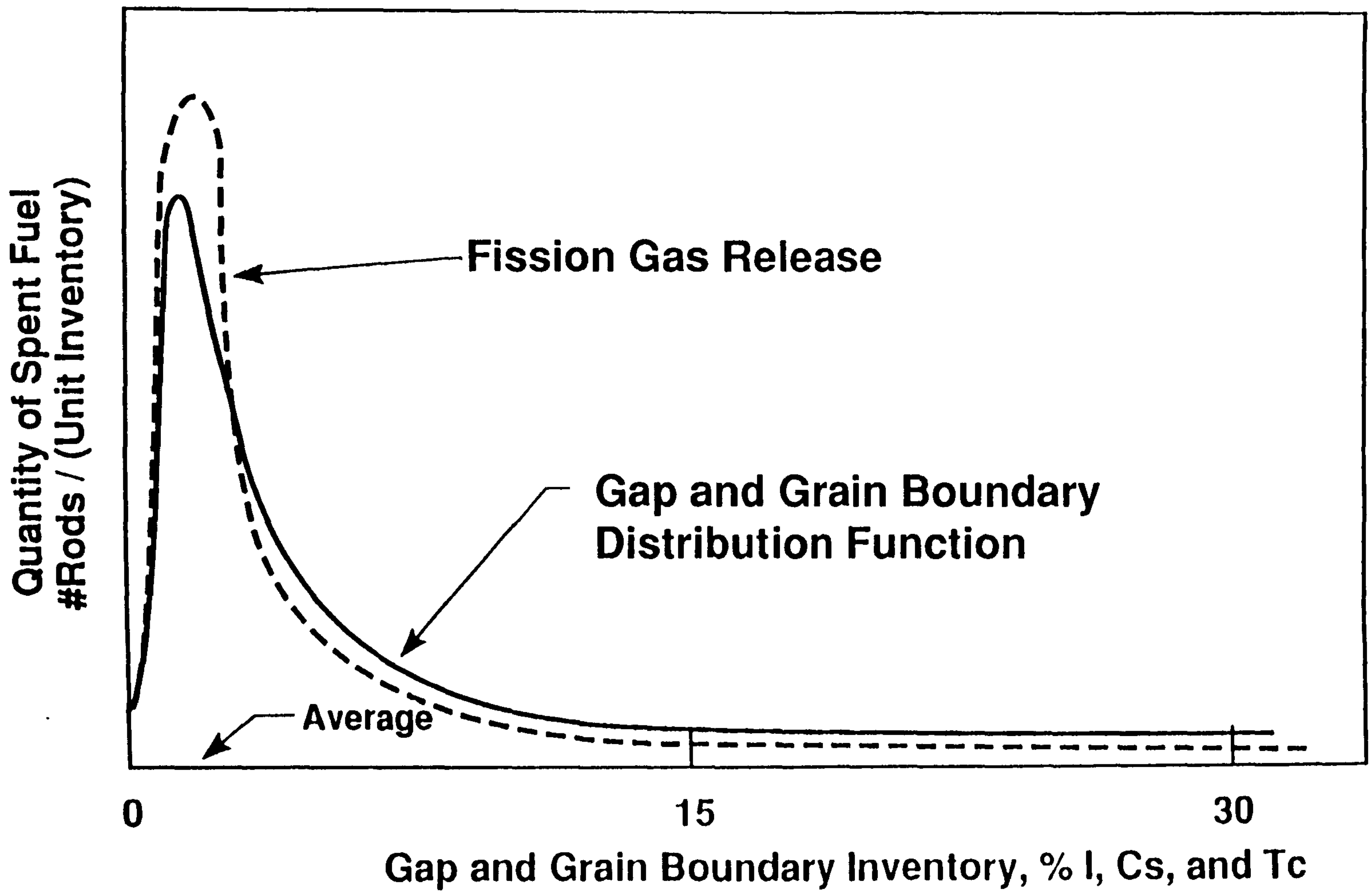
ILLUSTRATIVE ROD POPULATION DISTRIBUTION OF FISSION GAS RELEASE



METHOD OF CORRELATING GAP AND GRAIN BOUNDARY INVENTORY WITH ROD-AVERAGE FISSION GAS RELEASE



ILLUSTRATIVE ROD POPULATION DISTRIBUTION OF GAP AND GRAIN BOUNDARY INVENTORY



SPENT FUEL OVERVIEW

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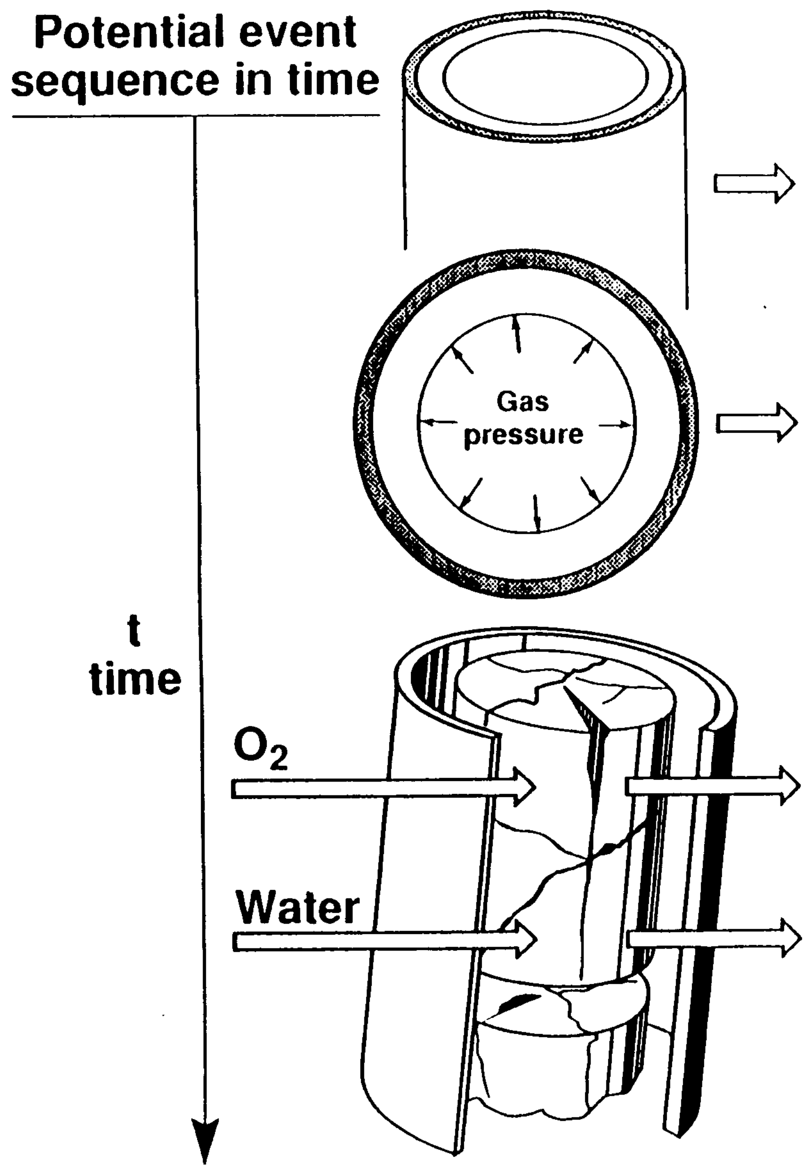
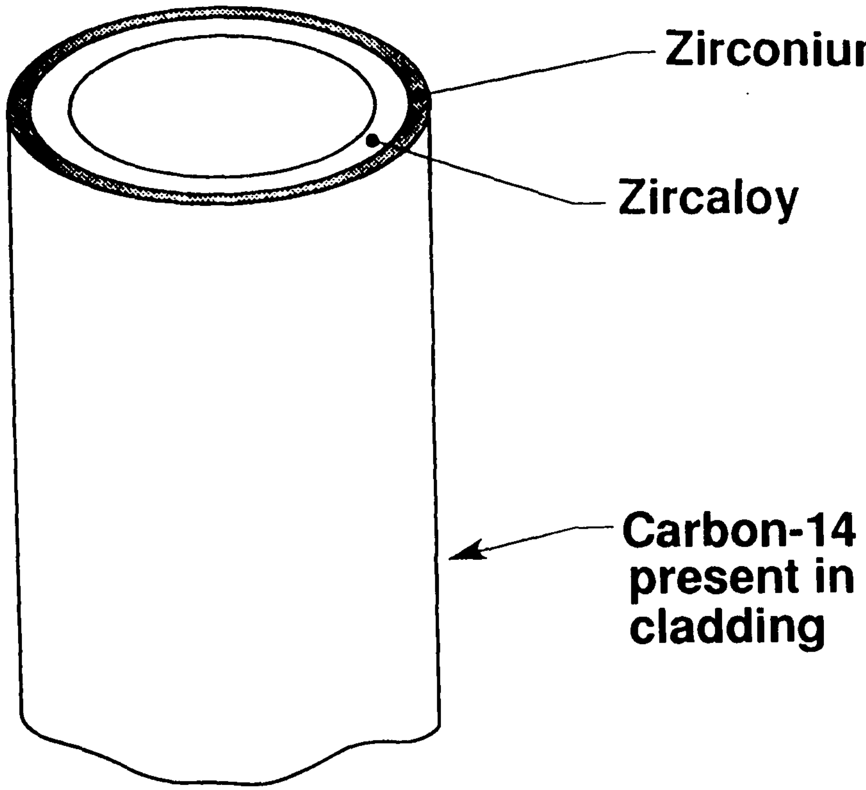


Gaseous release response from cladding	HARRY SMITH (PNL)
Cladding degradation response	HARRY SMITH (PNL)
UO_2 oxidation response	ROBERT EINZIGER (PNL)
UO_2 dissolution response	CHARLES WILSON (PNL) HERMAN LEIDER (LLNL)
⇩ Geochemistry solution response	CAROL BRUTON (LLNL)

GASEOUS RELEASE (CARBON-14) FROM CLADDING

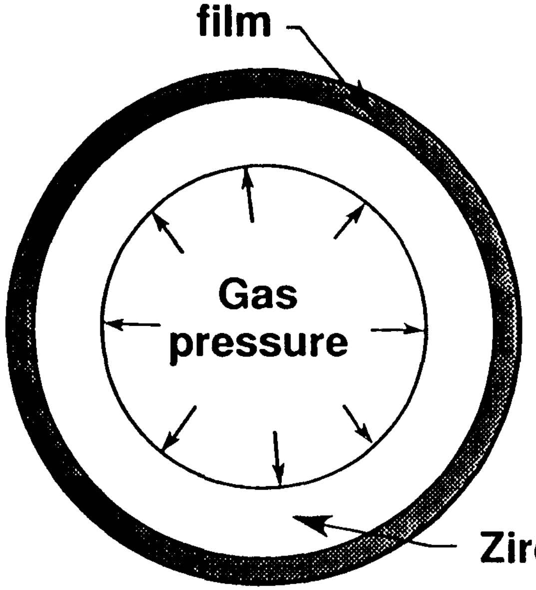


APPROXIMATELY 2% OF TOTAL CARBON-14 INVENTORY RELEASED RAPIDLY (~350°C) IN 8 HOURS

MODEL -
DIFFUSION EQUATION

ZIRCALOY CLADDING DEGRADATION

Oxide film failure -
stress corrosion cracking inhibitor



Thin-walled tube
Radius/thickness ~8

OXIDE FILM IS HIGHLY PROTECTIVE BECAUSE OF THE LARGE INCREASE (~10%-15%) IN VOLUME (RESULTS IN LARGE COMPRESSIVE STRESS STATE IN FILM) THAT OCCURS WHEN ZIRCONIUM TRANSFORMS TO ZIRCONIUM OXIDE.
GAS PRESSURE - DUE TO INITIAL GAS PRESSURE OF FUEL ROD PLUS FISSION GAS RELEASED PRESSURE

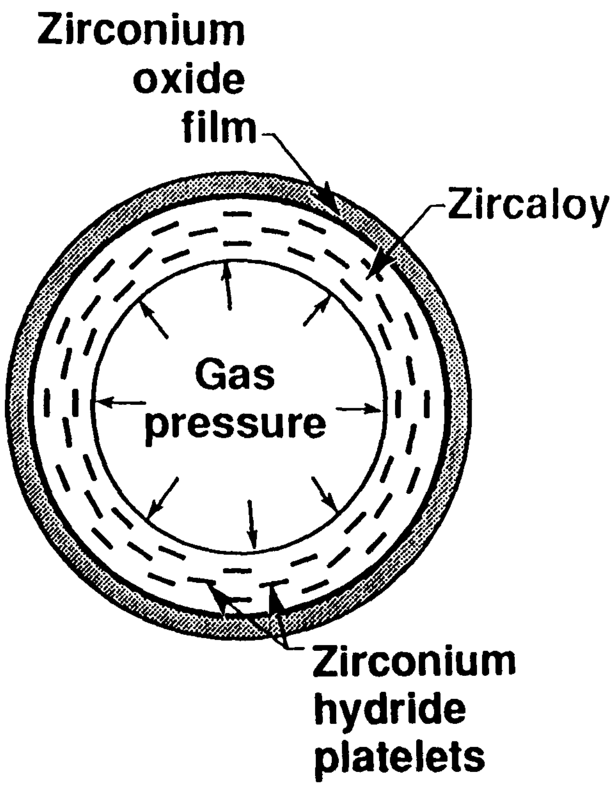
MODEL - CLAD FORMATION RESPONSE DUE TO PRESSURE FOR ELASTIC, PLASTIC (CREEP), THERMAL AND HYDRIDE PLATELET STRAINS IN THE MATERIAL

RESULT: GAS PRESSURE - TEMPERATURE - HYDRIDE - TIME DEPENDENT FAILURE RESPONSE

ZIRCALOY CLADDING DEGRADATION

(CONTINUED)

Hydride platelet precipitation



HYDROGEN DIFFUSES INTO THE ZIRCALOY CLAD WHEN THE OXIDE FILM FORMS AT REACTOR OPERATING TEMPERATURES

HYDROGEN SOLUBILITY LIMIT IN ZIRCALOY IS ~160ppm AT 325°C AND DECREASES WITH TEMPERATURE

DURING COOLING, HYDROGEN PRECIPITATES AS BRITTLE ZIRCONIUM HYDRIDE PLATELETS WHOSE ORIENTATION DEPENDS ON STRESS

CIRCUMFERENTIAL PLANAR PLATELETS SHOWN DO NOT LEAD TO DEGRADATION

RADIAL PLANAR PLATELETS (PERPENDICULAR TO ONES SHOWN) CAN LEAD TO A CRACK PROPAGATION PATHWAY THROUGH THE CLADDING THICKNESS

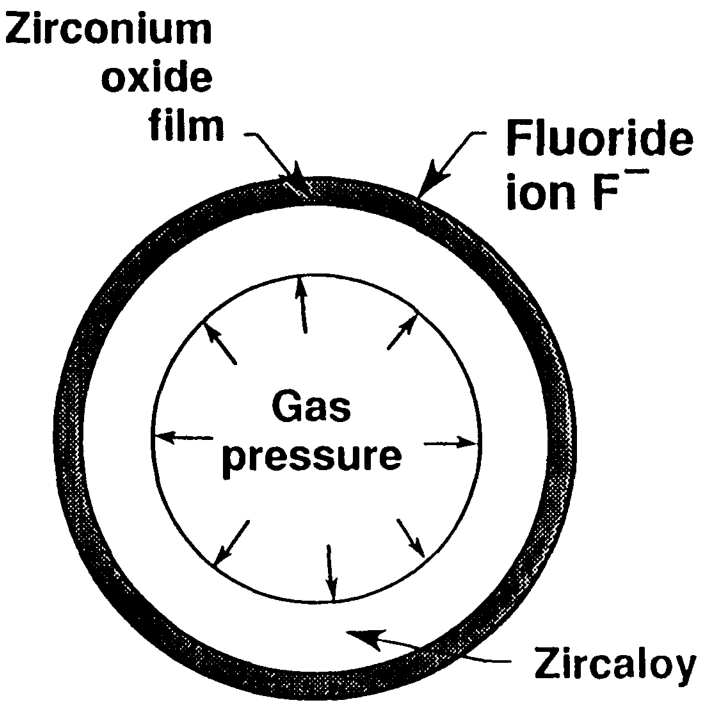
MODEL - HYDRIDE DEFORMATION COUPLED WITH HYDRIDE THERMODYNAMIC PRECIPITATION

RESULT: STRESS DEPENDENT PLATELET ORIENTATION AND FAILURE RESPONSE

ZIRCALOY CLADDING DEGRADATION

(CONTINUED)

Zircaloy–fluoride corrosion response



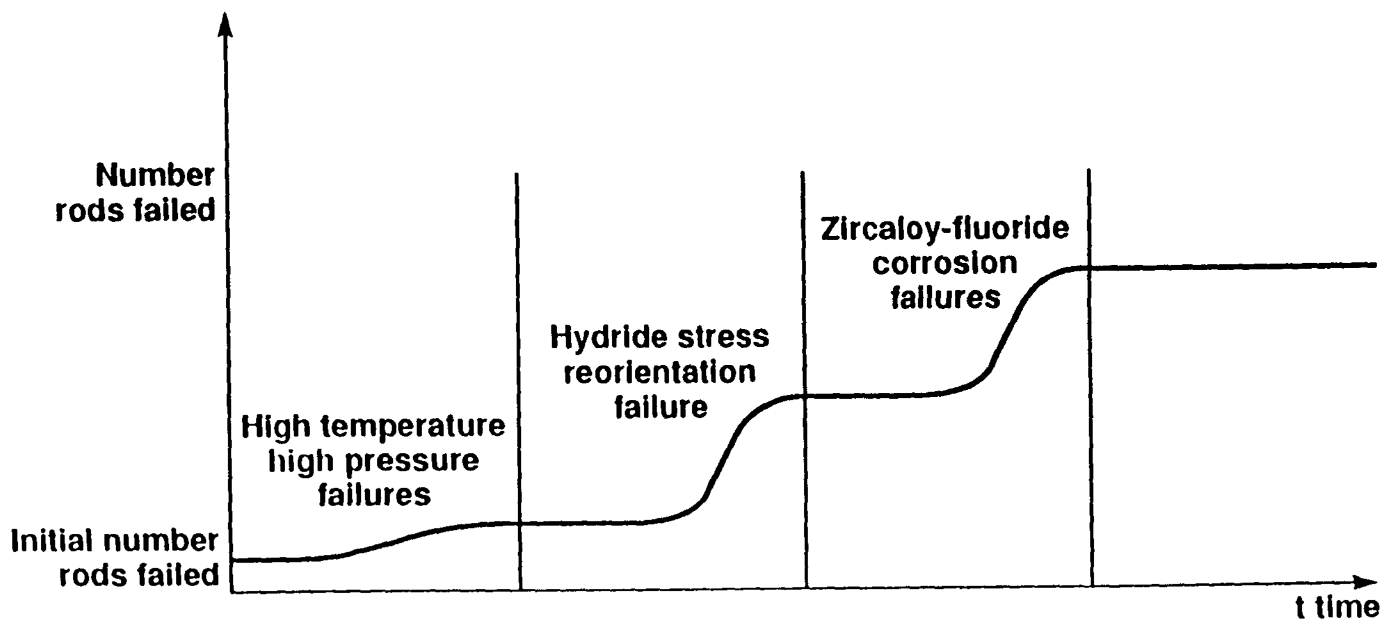
Thin-walled tube
Radius/thickness ~ 8

ZIRCALOLY HAS A PITTING CORROSION RESPONSE THAT IS LINEAR WITH RESPECT TO THE HYDROFLUORIC ACID CONCENTRATION. THE PITTING CORROSION REDUCES THE EFFECTIVE CLAD WALL THICKNESS WHICH RESULTS IN AN INCREASE IN STRESS. ALSO, PITTING COULD EVENTUALLY RESULT IN PINHOLE PATHWAYS THROUGH THE CLADDING.

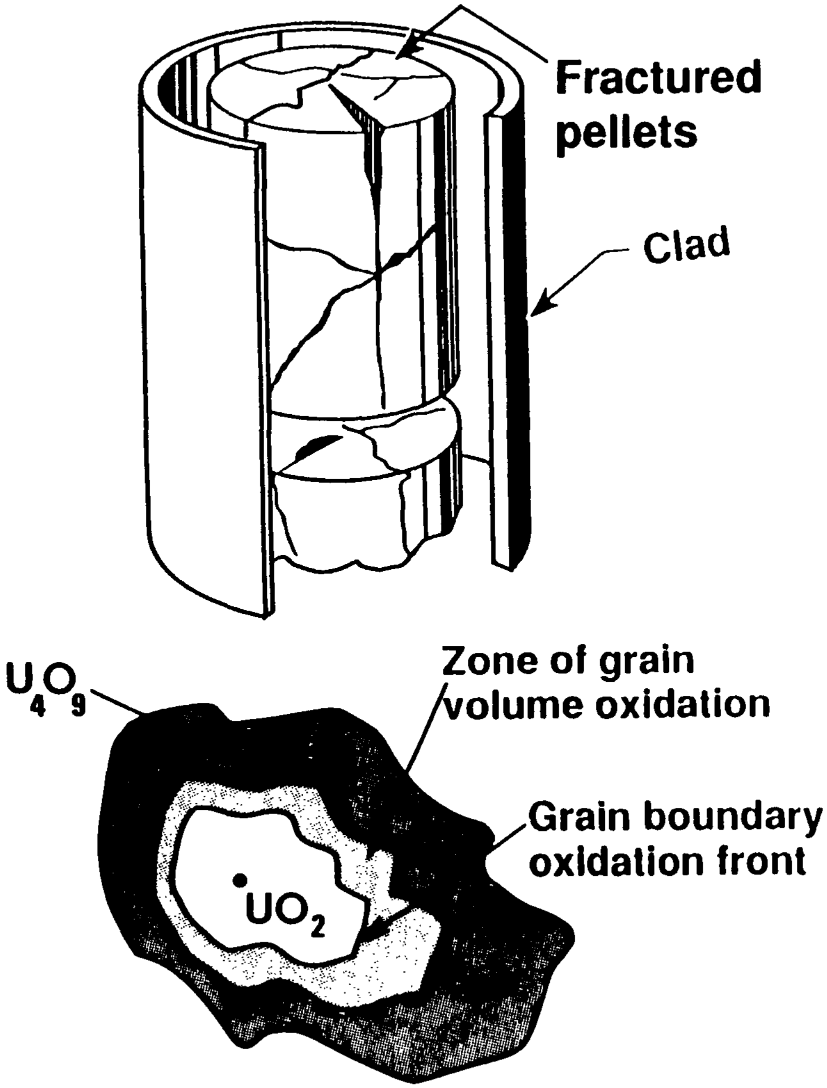
MODEL - ELECTRO-CHEMICAL CORROSION

ZIRCALOY CLADDING DEGRADATION - EXPECTED TOTAL MODELING RESPONSE

SCHEMATIC OF CUMULATIVE RESPONSE CURVE FOR PROBABLE NUMBER OF FAILED SPENT FUEL RODS AT A TIME t



SPENT FUEL OXIDATION RESPONSE



Fragment cross-section

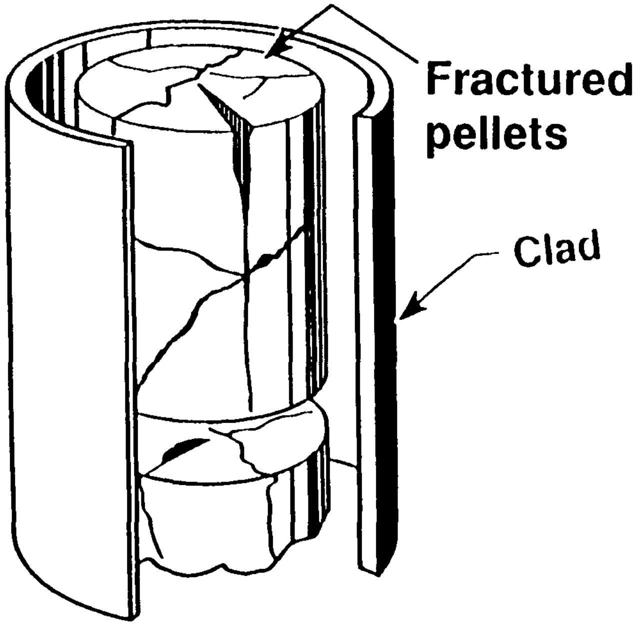
FUEL PELLETS, NOMINALLY 0.5cm TO 0.6cm RADIUS AND ~2cm LENGTH, FRACTURE INTO FRAGMENTS DUE TO THERMAL STRAINS DURING FIRST FULL POWER CYCLE.

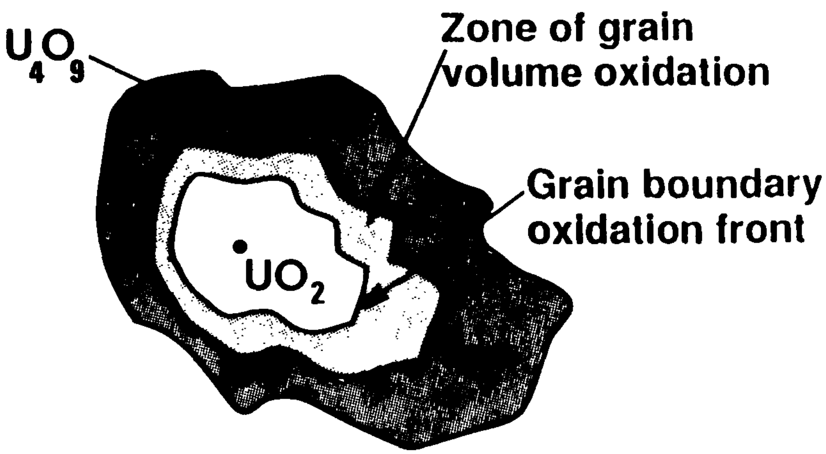
FUEL FRAGMENTS OXIDIZE AFTER CLADDING BREACH.

MODEL - OXIDATION KINETICS DEPEND STATISTICALLY ON FRAGMENT SIZES AND SHAPES IN A TEST SAMPLE; ANY FRAGMENT CAN BE SUBDIVIDED INTO DIFFERENT SIZED PYRAMIDAL VOLUME SUBSETS TO OBTAIN A STATISTICAL DISTRIBUTION FUNCTION.

SPENT FUEL OXIDATION RESPONSE

(CONTINUED)

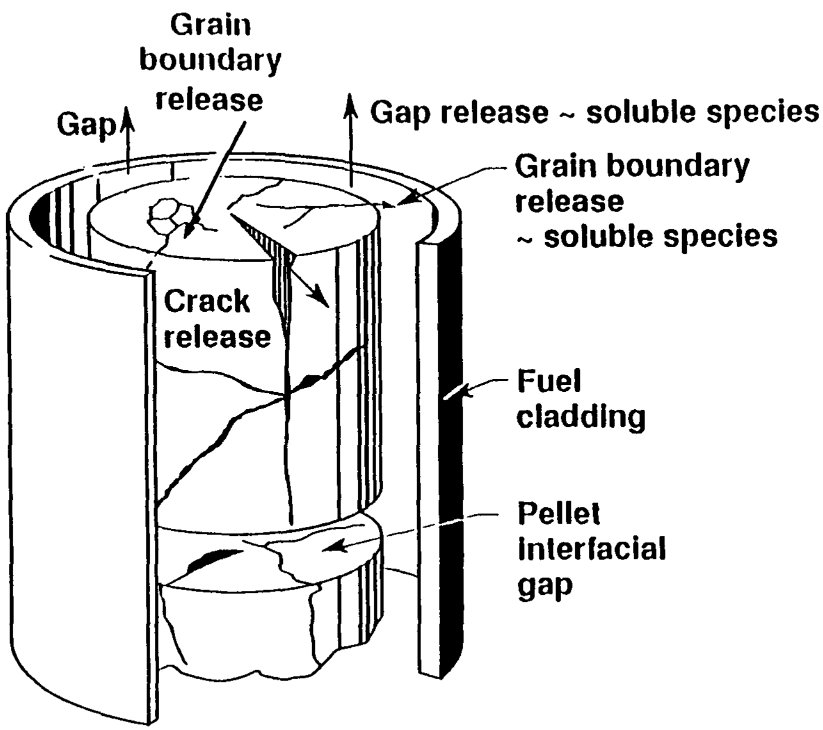




Fragment cross-section

RESULTS: TESTS ON SPENT FUEL FRAGMENTS HAVE SHOWN A GRAIN BOUNDARY OXIDATION FRONT MOVING INTO FRAGMENTS, FOLLOWED BY A SPATIAL ZONE WHERE OXIDATION OF INDIVIDUAL GRAIN VOLUMES OCCUR

SPENT FUEL RADIONUCLIDE RELEASE

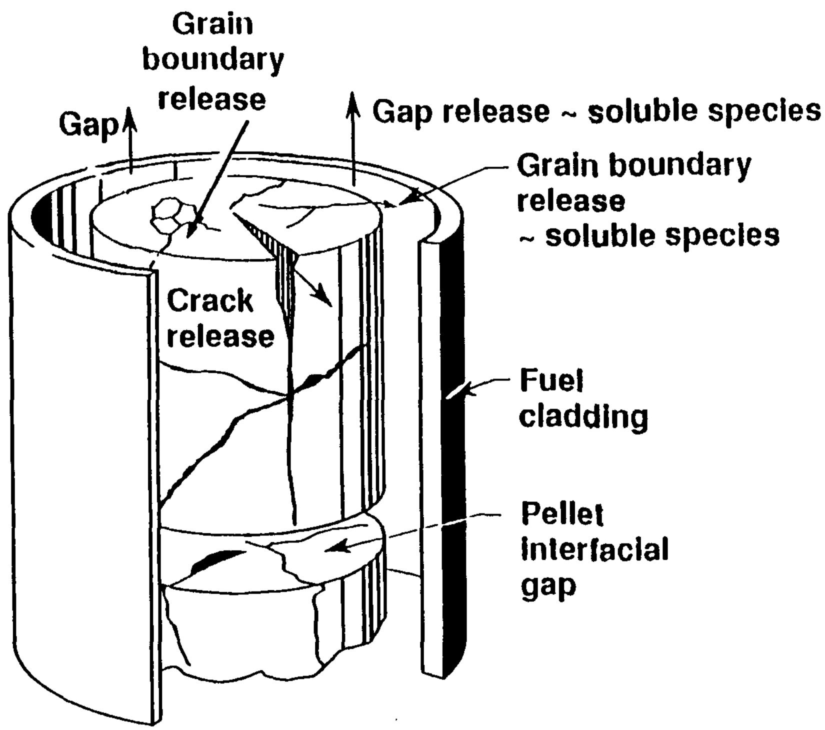


AQUEOUS RELEASE OCCURS FROM THE PELLET-CLADDING GAP, FROM CRACKS AND GRAIN BOUNDARIES, AND FROM FUEL GRAINS. RELEASE CAN DEPEND ON AREA, TEMPERATURE, BURNUP, SOLUBILITY, WATER CHEMISTRY, AND WATER FLOW RATE

MODEL - THERMOCHEMICAL APPROACH TO DESCRIBE THE DISSOLUTION RATES AND RELEASE OF SOLUBLE SPECIES SUCH AS Cs, I, Tc, Sr, AND C, AND RELEASE OF THE SOLUBILITY LIMITED SPECIES SUCH AS THE ACTINIDES

SPENT FUEL RADIONUCLIDE RELEASE

(CONTINUED)



RESULTS: "FLOWRATE" CONTROL AND SEMI-STATIC EXPERIMENTS PROVIDE INPUT TO MODELS WITH COUPLING TO EQ 3/6 GEOCHEMICAL SIMULATION

SPENT FUEL TESTING

- MECHANISTIC MODEL DEVELOPMENT BASED ON SHORT-TERM TESTING NECESSARY TO OBTAIN LONG TIME RESPONSE
- TESTING PERFORMED OVER A RANGE OF EXPERIMENTAL VALUES THAT EXCEED THE PREDICTED REPOSITORY CONDITIONS ON THE HIGH AND LOW SIDE WHENEVER POSSIBLE
- THIS MEANS THAT RESPONSE PREDICTIONS ON THE EXPERIMENTAL VARIABLES CAN BE MADE USING CONSERVATIVE INTERPOLATION RATHER THAN BY RISKY EXTRAPOLATIOIN