2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: Integrated Retrofit Solutions

Integrated Retrofit Solutions

Improve productivity, comfort and aesthetics; lower embodied carbon; and decrease thermal loads by 75%

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- WBS 03.02.02.131

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

- Goal: develop and demonstrate overclad panel design and installation system that standardizes mass customization for retrofits of residential and commercial building envelopes.
- Outcome: retrofit package that decreases thermal loads in residential and commercial buildings by 75%.
- Impact: case studies demonstrate feasibility, prove benefits, reduce uncertainty, and promote retrofits.

TEAM & PARTNERS

OAK RIDGE National Laboratory

KCDC Knoxville's Community Development Corporation

THE UNIVERSITY of TENNESSEE UT

LG Life's Good

DBTech

Pella

The Planning Agency PA

STATS

Performance Period: Oct 2022 to Sept 2027

DOE Budget: $5M, Cost Share: $1.25M

Milestone 1: Path toward 75% decrease in thermal loads

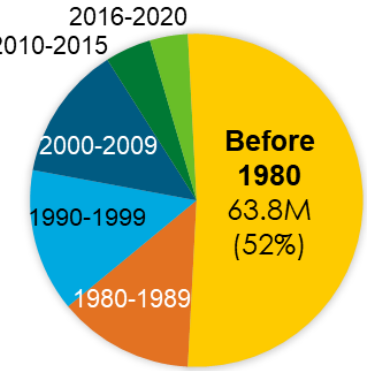
Milestone 2: Retrofitted duplexes and performed measurement and validation

Milestone 3: Retrofitted Boys and Girls Club and performed measurement and validation

Problem and Goals

- Nearly 50% of residential and commercial buildings were built before energy codes.
  - Older building envelopes have minimal insulation and have high air leakage rates.
- Less than 2% of residential building envelopes have energy-related retrofits each year because these are difficult.
  - State of the art envelope retrofits: intrusive, disruptive, labor intensive, and costly partly because **each building is unique.**
- **Goals:**
  - Develop and demonstrate overclad panel design and installation system that standardizes mass customization for retrofits of residential and commercial building envelopes.
  - Demonstrate that overclad panels packaged with added roof insulation and HVAC and water heater replacement reduce thermal loads by 75%.

Residential Buildings
Residential Energy Consumption Survey (RECS), 2020



Impact

- Impact:
  - Set path to retrofit 64M housing units and 2.7M commercial buildings.
  - 64M retrofitted homes will lead to at least $17B in energy bill savings per year.
- End deliverables to DOE
  - Data that demonstrates 75% decrease in thermal loads in existing residential and commercial buildings by integrating building envelope, HVAC, and water heater retrofits.
  - Feedback from design and installation team on improvements to retrofit process to reduce cost.
  - Feedback from building owner and occupants on retrofit benefits: reduction in energy burden and improvements in comfort.

Alignment with National Building Blueprint

Cross-Cutting Goals

Equity – Integrate retrofit technologies applicable to multiple types of buildings to reduce the energy burden and improve the comfort of a wide variety of populations.

Affordability – Develop technologies that increase throughput (i.e., shorter design and installation time) to reduce cost without compromising quality or safety.

Resilience – Increase the passive efficiency of the envelope to improve structural durability and thermal resilience, extend habitability of structures during extreme heat/cold events with power outages, and decrease excess mortality.

Strategic Objectives

Increase building energy efficiency	Integrated envelope, HVAC and water heater retrofits maximize decrease in overall energy demand.
Accelerate onsite emissions reductions	Integrated envelope, HVAC and water heater retrofits reduce on-site emissions by lowering energy demand to enable electrification.
Transform the grid edge at buildings	Integrated envelope, HVAC and water heater retrofits reduce the burden of on-site distributed energy resources (DER)s.
Minimize building life cycle emissions	Extending the life of existing buildings with low-carbon building materials reduces their total life cycle emissions.

Approach: State of the Art and New Technologies

- Current envelope retrofit approaches
  - Drill and fill
  - Remove cladding and sheathing and add batts or spray foam
  - Labor intensive, disruptive to building occupants, and costly
- ORNL's new envelope retrofit approach
  - Overclad panel design and installation system that prioritizes productivity
    - Software that generates digital twin of existing building
    - Lightweight overclad panel designs
      - Prefabricated panels provide new cladding and heat, air and water barrier
      - Made with fiber reinforced composites to reduce weight
      - Most wall components assembled offsite to reduce onsite installation time
    - Real-Time Evaluator provides real-time feedback on connection and panel positions to expedite installation (funded by another project)
  - Integration of overclad panels with added attic/roof insulation and HVAC and water heater replacement to lower thermal loads by 75%

State of the Art

https://www.gni.ca/insulation-faqs/insulating-behind-drywall

https://rockymountainretrofoam.com/retrofoam-wall-insulation/

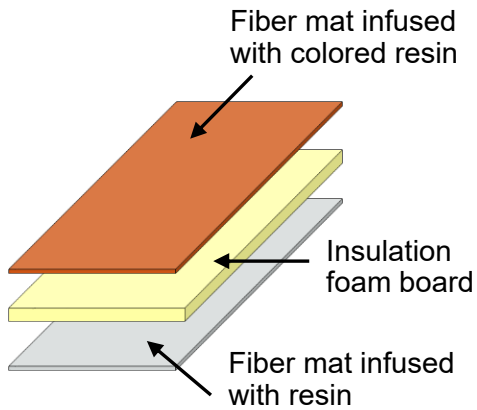
Overclad Panels

https://www.energiesprong.de/news-downloads/news/news-details/renovate-speed-erste-serielle-sanierung-nach-vier-monaten-abgeschlossen/

Approach: Novelty and Applicability

- Auto-CuBES: **Auto**matic point **C**lo**u**d **B**uilding **E**nvelope **S**egmentation
  - Provides wireframe drawing of existing façade with location of windows, doors & major features
  - Only software with 1/8-inch accuracy needed for prefab panel fabrication
  - Only software that generates digital twin in minutes, which saves design time and labor cost
  - Applicable to any wireframe drawing generation
- Lightweight overclad panel designs
  - Multifunctional panel (cladding + heat/air/water barrier) reduces onsite installation cost
  - Flexible and adaptable design as load bearing or non-load bearing
  - R30 panel weighs ~3.5 psf → light design reduces transportation and installation cost
  - Applicable to new and existing residential and commercial buildings
- RTE: Real-Time Evaluator
  - Provides real-time positioning feedback with 1/8-inch accuracy
  - Decreases installation time of prefab components and connections by at least 25%
  - Shorter installation time leads to lower crane and labor cost
  - Applicable to the assembly of any prefab system

Composite Overclad Panel Design



Approach: Barriers and Mitigation Strategies

- Auto-CuBES: **Auto**matic point **C**lo**u**d **B**uilding **E**nvelope **S**egmentation
  - Barriers: validation of accuracy → difficult to define the ground truth
  - Mitigation: find collaborators with point cloud files and validated measurements to verify accuracy of Auto-CuBES
- Lightweight overclad panel designs
  - Barrier: identify of contractor willing to install a new technology
  - Mitigation: ask the panel manufacturer to do the installation
- RTE: Real-Time Evaluator
  - Barrier: find demonstration sites in which preliminary testing has limited effect on productivity
  - Mitigation: identify industry partners that see benefit in the technology and are willing to help search for adequate demonstration sites

Approach: Commercialization and Stakeholder Engagement

- Auto-CuBES
  - Copyright TXu 2-412-058
  - Validation: National Research Council Canada and Hearths Labs
- Overclad panels
  - Patent application #18/375,104
  - Panel manufacturer: DB Technologies
  - Window and window connection manufacturer: Pella
- Real-Time Evaluator
  - Patent application #18/509,721
  - Advisors: Precast/Prestressed Concrete Institute, Structural Building Components Association

Approach: Demonstration and Validation

- Partnered with Knoxville's Community Development Corporation (KCDC)
  - Provides housing options in Knoxville and Knox County specifically designed to meet the needs of families, seniors and disabled low-income residents
- Retrofit demonstration: building envelope, attic insulation, HVAC, water heater
  - Residential: two duplexes (~1,200 ft^2 per building)
  - Commercial: Boys and Girls Club (~12,000 ft^2)
- Validation
  - Collect energy data before and after retrofit to show 75% decrease in thermal loads
  - Gather feedback from building owner and occupants on benefits from retrofit

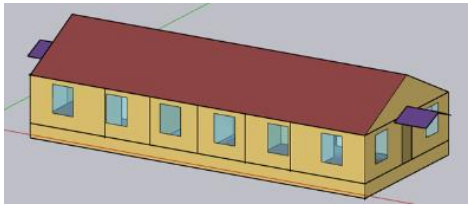
KCDC
Knoxville's Community Development Corporation

Progress: Path Toward 75% Thermal Load Reduction

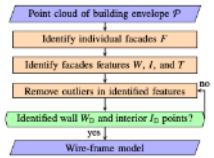
Components		Baseline		Retrofitting strategies
		Original (1940s)	Existing	
Exterior wall insulation		None	None	R15
Attic insulation		None	R-12[2]	R-60[1]
Window U - value		1.22[3]	0.511[4]	0.3[1]
Infiltration (ACH4)		0.75[3]	0.45[5]	0.15[1]
HVAC	Cooling efficiency	3.14 COP[6]	3.14 COP[8]	3.9 COP[9]
	Heating efficiency	100%[6]	3.1 COP[8]	4.5 COP[9]
Water heater efficiency		89%[7], electric	89%[7], electric	3.2%[10], electric
Energy use intensity (kBtu/ft² per year)		88.4	38.3	15.3
Energy saving by using retrofit strategies		82.7%	60.0%	-

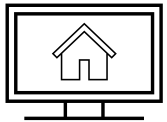
Selected preliminary technologies accordingly

[1] IECC 2021 residential building;
[2] 3.5" poor blown rock insulation at the existing KCDC buildings;
[3] Information on the single-family house from PNNL report;
[4] KCDC buildings' window measurement data;
[5] based on the measurements from existing KCDC buildings; the infiltration rate was based on the measured average air leakage rate 9ACH50 (9ACH50 / 20 = 0.45ACH4) for two duplex buildings;
[6] pre-1980 DOE prototype residential buildings used packaged thermal air conditioner (PTAC);
[7] installed water heat from existing KCDC buildings;
[8] existing KCDC buildings use packaged thermal heat pump (PTHP);
[9] LG HVAC system high efficiency (VRF);
[10] EnergyPlus example files (heat pump water heater).

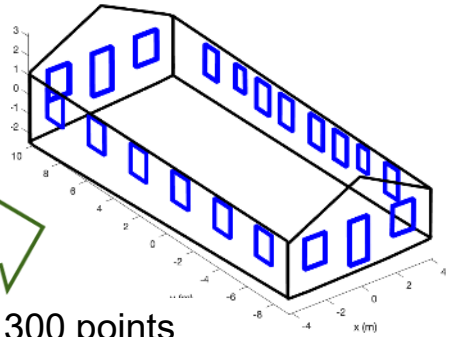


Progress: Auto-CuBES





Accurate wireframe model

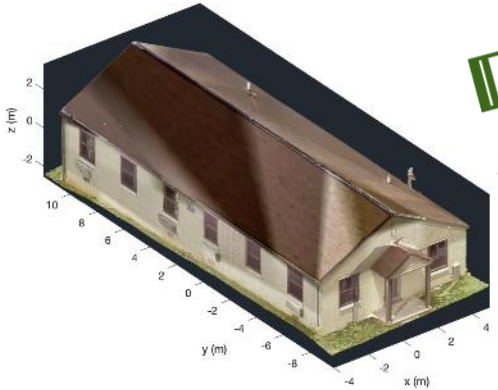


300 points

Point cloud data

User calibration

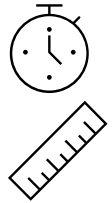
Auto-CuBES



32M points

ML-Assisted fast and accurate digital twin generation

- Scanned duplexes
- Automatic segmentation in **12 minutes**
  - Other semi-automated point cloud segmentation methods take >4 hours
- Validated windows dimensions had **1/8" accuracy**
  - Other methods subject to ~½" human error

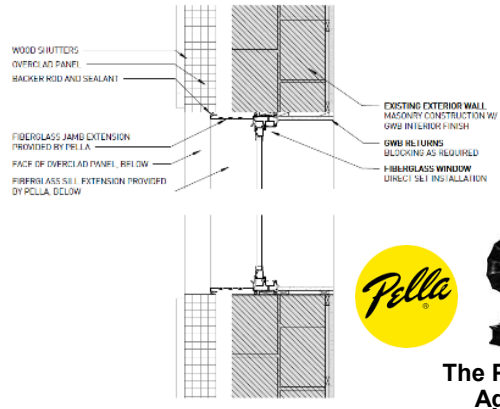


Maldonado et al. Automatic point Cloud Building Envelope Segmentation (Auto-CuBES) using Machine Learning. Int. Symp. Automation and Robotics in Construction, 2023.

Progress: Panel and Connection Designs and Testing

- Manufactured full-scale panels and connections
- Got preliminary approval from building owner and architect on panel's aesthetics
- Ongoing panel system tests at third-party lab
  - ASTM E330 (structural): passed
  - ASTM E283 (air): improving details before retesting
  - ASTM E331 (water): improving details before retesting
  - ASTM E84 (fire): improving formulation before retesting
  - Exposure to outdoor conditions
- Feasible panel-to-window connection design that passed ASTM E1105 (water)
- Designed 90%+ of construction details for permit submission

DBTech | The University of Tennessee | The Planning Agency



Progress: Lessons

- Difficulties taking a new technology, i.e., overclad panels, from lab to actual buildings
  - Need to better estimate time to complete tasks and set more realistic timeline
    - Iterative tests in third party labs to meet code compliance, i.e., test → improve → test
    - Working with collaborators whose area of expertise is not construction
  - Find partners/contractors that want to work with a new technology
    - Must have a clear value proposition
    - Must reduce uncertainty and risk
    - Must have good network
- For envelope retrofit demonstration projects, research team members may need to assume general contractor (GC) role and manage design and construction schedule
  - Few GCs will take a research project w/o very high fees
  - Significant time is required to identify subcontractors and execute subcontracts
  - Timeline is continuously changing due to unexpected requests from various partners

Future Work

- Overclad Panel System
  - Pass standardized tests through third-party labs for code compliance
  - Reduce the embodied carbon using biobased resins and/or natural/recycled fibers
- Duplexes Retrofit
  - Finalize and submit permit package. Currently at 90%+.
  - Complete retrofit by spring 2025
  - Complete measurement and validation by spring 2026
- Boys and Girls Club Retrofit
  - Finalize and submit permit package by winter 2025
  - Complete retrofit of Boys and Girls Club by spring 2026
  - Complete measurement and validation by spring 2027

Ongoing Complementary Work:
Additional Technologies that Enable Standardized Mass Customization

- Deep-CuBES
  - Reduces segmentation time of Auto-CuBES from mins to secs
  - BTO's Emerging Technologies
- Real-Time Evaluator (RTE)
  - Real-time feedback on connection and panel positions to expedite installation
  - BTO's Emerging Technologies
- **F**ast, **A**ccurate, **M**inimally **I**ntrusive (FAMI) Installation System
  - Cable driven parallel robot that autonomously installs overclad panels using the positioning data from the RTE
  - BTO's Residential Building Integration
- **P**ipeline for **A**ffordable, energy-efficient, and **T**ime-saving **H**ousing retrofits (PATH)
  - Digital platform that integrates and optimizes Auto/DeeP-CuBES, RTE and FAMI
  - ORNL's Lab Directed Research & Development Program

Plans Beyond the End of the Project

- Lower embodied carbon of overclad panels
  - Ongoing development of low-carbon, biobased insulation foams
  - Ongoing development of low-carbon, bio-based fire retardants
- Demonstrate and validate PATH
  - Integration of Auto/DeeP-CuBES, lightweight overclad panels, RTE and FAMI
- License and commercialize
  - Auto/DeeP-CuBES
  - Lightweight, low-carbon overclad panels
  - Real-Time Evaluator
  - FAMI
  - PATH

Thank you

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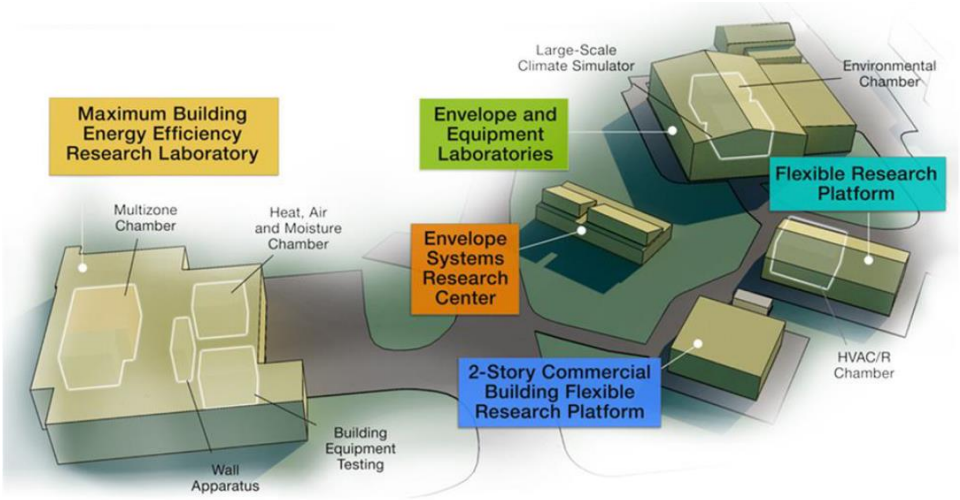


The **Building Technologies Research and Integration Center (BTRIC)** at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
85 industry partners
18 university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

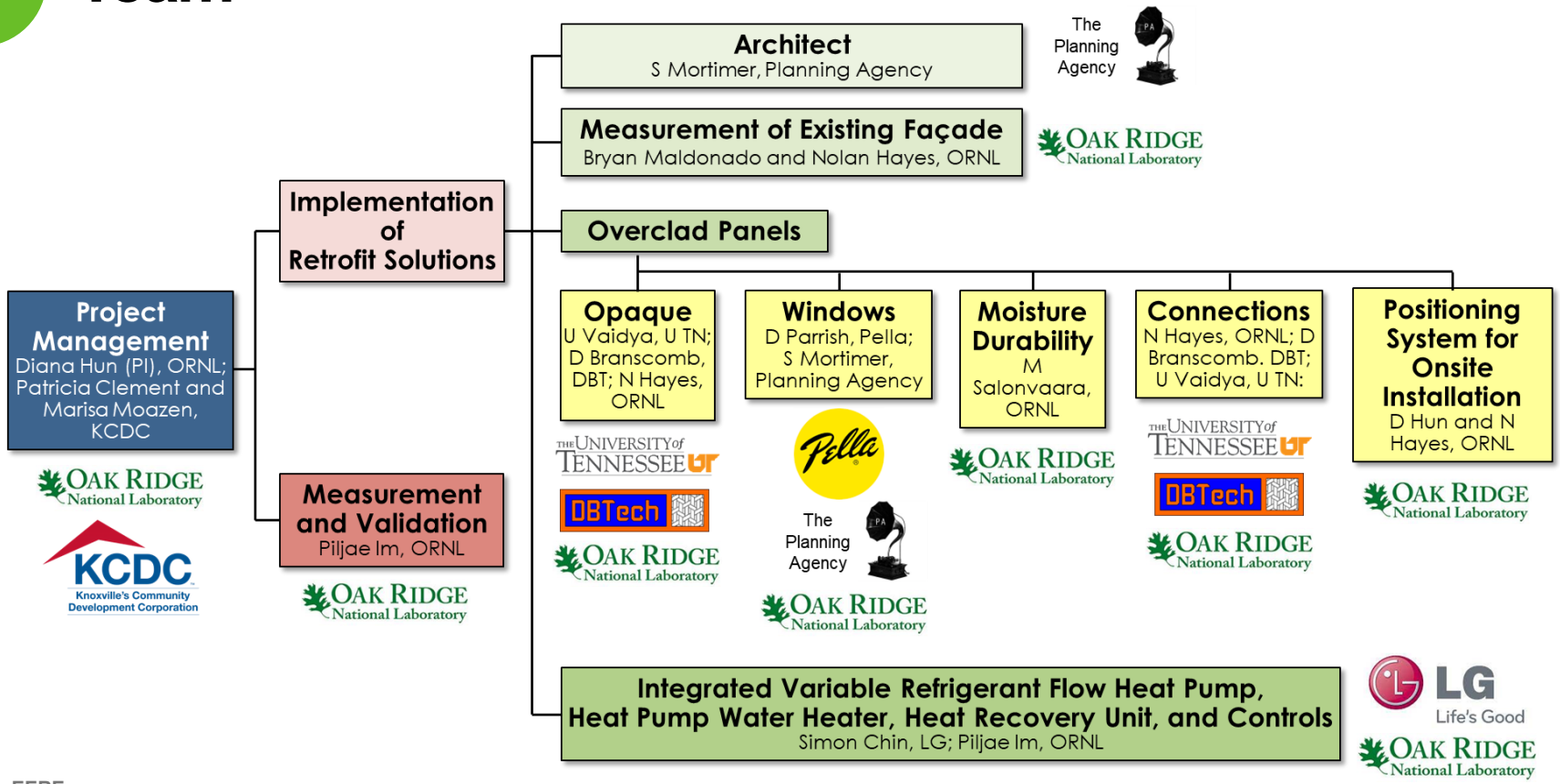
Project Execution

	FY2023				FY2024				FY2025			
Planned budget												
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Measured leakage rate of duplexes												
Q2 Initial wireframe drawings for panel manufacturer												
Q3 Preliminary T2M plan with panel manufacturer												
Q4 Energy models for duplexes that identify path to 75% in thermal loads												
Current/Future Work												
Q1: Complete construction drawings and other required documentation for permit application for duplex retrofits												
Q2: Secure building permit for duplex retrofits												
Q2: Complete retrofit of duplexes												
Q3: Meet building code air leakage requirement in the first retrofitted duplex												
Q4 Complete construction drawings and other required documentation for permit application for Boys and Girls Club retrofit												

Planned Go/No Go Completed Approved no-cost extension

No-cost extensions due to owner request for a 3-month delay that was followed with repeats of overclad panel tests.

Team


Project Management
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Knoxville's Community Development Corporation
Implementation of Retrofit Solutions
Measurement and Validation
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OAK RIDGE National Laboratory
Architect
S Mortimer, Planning Agency
The Planning Agency
Measurement of Existing Façade
Bryan Maldonado and Nolan Hayes, ORNL
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Windows
D Parrish, Pella; S Mortimer, Planning Agency
Pella
The Planning Agency
OAK RIDGE National Laboratory
Moisture Durability
M Salonvaara, ORNL
OAK RIDGE National Laboratory
Connections
N Hayes, ORNL; D Branscomb. DBT; U Vaidya, U TN:
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