DEVELOPMENT OF COOL COLORED ROOFING MATERIALS

Project Advisory Committee (PAC) Meeting

Collaborative R&D with Industry

LBNL and **ORNL**

Sponsored by the California Energy Commission

(Project Manager: Chris Scruton)

March 11, 2003; Conference Call

UT-BATTELLE
Oak Ridge National Laboratory

Berkeley Lab

Project Goals

- Bring cool colored roofing materials to market
- Measure and document laboratory and *in-situ* performances of roofing products
- Accelerate market penetration of cool metal, tile, wood shake, and shingle products
- Measure and document improvements in the durability of roofing expected to arise from lower operating temperatures

Project Advisory Committee (PAC) Members

1. Asphalt Roofing Manufacturers Association
2. Bay Area Air Quality Management District
3. California Institute for Energy Efficiency
4. Cedar Shake and Shingle Bureau
5. Cool Roof Rating Council
6. Environmental Protection Agency (EPA)
7. EPA San Francisco Office
8. Habitat for Humanity
9. National Roofing Contractors Association
10. Roof Tile Institute
11. DuPont Titanium Technologies
12. Cool Metal Roofing Coalition

Industrial Partners

- **On Board**
  - **3M**
  - **BASF / Custom-Bilt Metals**
  - **Elk Manufacturing**
  - **Ferro**
  - **GAF**
  - **MCA**
  - **ISP Minerals**
  - **Shepherd Color Company**
  - **Monier Lifetile**
  - **Hanson Roof Tile**
- On List
  - American Roof Tile Coating
  - DuroLast
  - Rising and Nelson Slate
  - Transmet Corp.

Project Team

- LBNL
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- ORNL
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  - Bill Miller wml@ornl.gov

Technical Tasks

- 2.4 Development of cool colored coatings
- 2.5 Development of prototype cool-colored roofing materials
- 2.6 Field-testing and product useful life testing
- 2.7 Technology transfer and market plan

2.4 Development of Cool Colored Coatings

- Objectives
  - Maximize solar reflectance of a color-matched pigmented coating
  - Compare performance of coated roofing product (e.g., a shingle) to that of simple smooth coating
- Subtasks
  - Identify and characterize pigments with high solar reflectance
  - Develop software for optimal design of cool coatings
  - Develop database of cool-colored pigments

2.4.1 Identify & Characterize Pigments w/High Solar Reflectance

- Objective: Identify and characterize pigments with high solar reflectance that can be used to develop cool-colored roofing materials
- Deliverables:
  - Pigment Characterization Data Report
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 30 %

Pigment Characterization Activities

- Paint preparation
- Paint film deposition
- Film property measurement
- Adaptation of Kubelka-Munk theory
- Software development
- Pigment classification

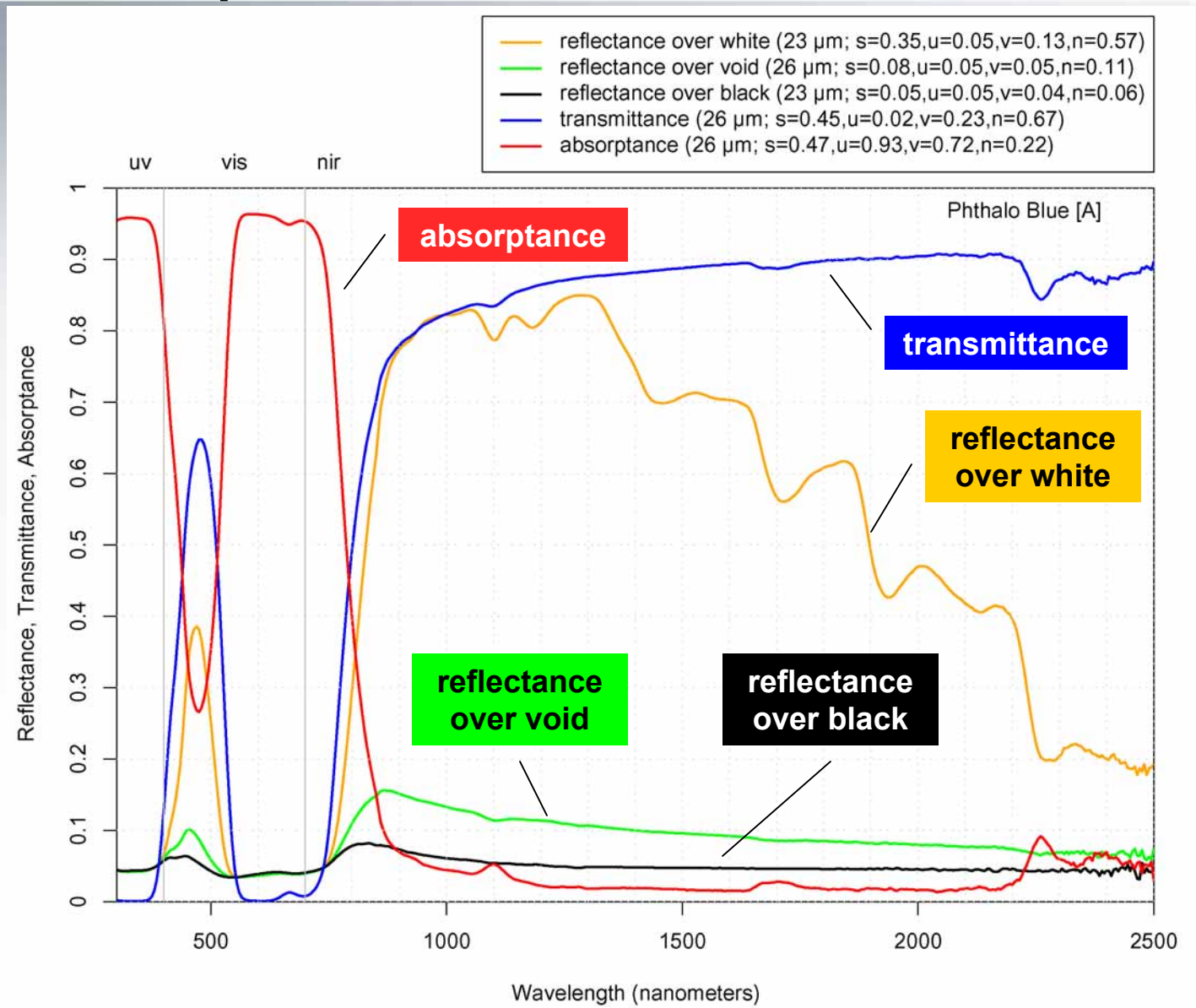
Paint & Film Preparation

- Paints purchased or prepared at LBNL
- Films supplied by BASF or prepared at LBNL
  - typically 25 microns (1 mil) thick
  - three backgrounds: opaque white, opaque black, none

phthalo blue
over opaque white

phthalo blue
over opaque black

Optical Measurement Example: Phthalo Blue



Measurement Progress

- Have characterized 58 pigments
- Another 50 or so yet to go
- Will also characterize mixtures of pigments, especially tints (mixtures with white)

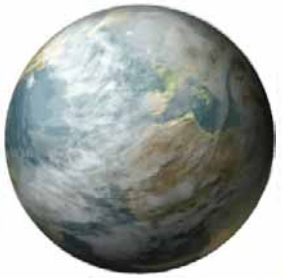
Adaptation of Kubelka-Munk Theory

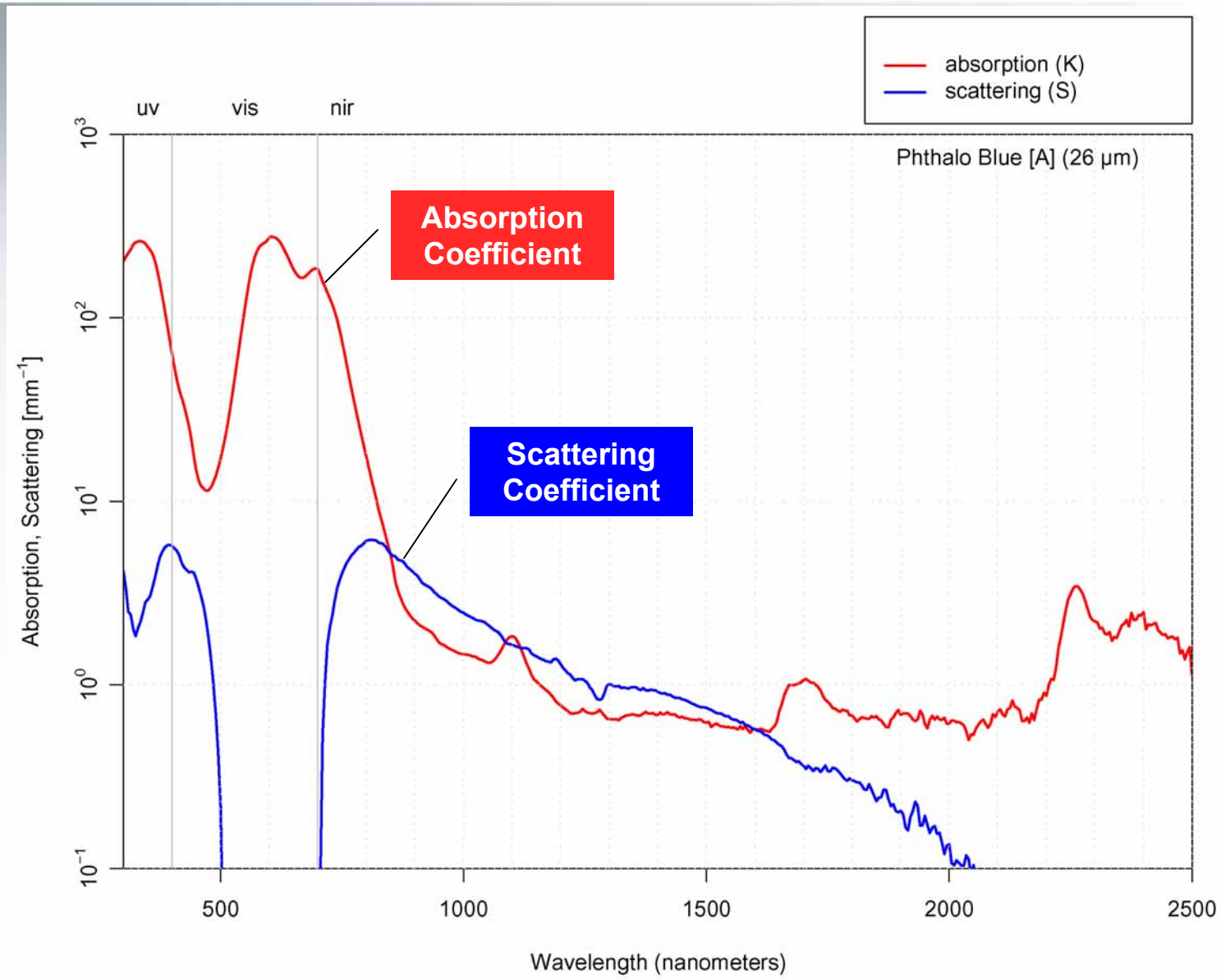
- Kubelka-Munk (K-M) theory relates *paint film* properties to *pigment* properties

PAINT FILM PROPERTIES		**PIGMENT PROPERTIES**
• **reflectance**	⟷	• **scattering coefficient**
• **transmittance**		• **absorption coefficient**
• **thickness**		

- K-M theory adapted by LBNL to better characterize pigments that weakly scatter light
- Weak scattering often found in the near-infrared (NIR) spectrum, about which we care greatly

Calculation Example: Phthalo Blue





Examples of Cool Pigments

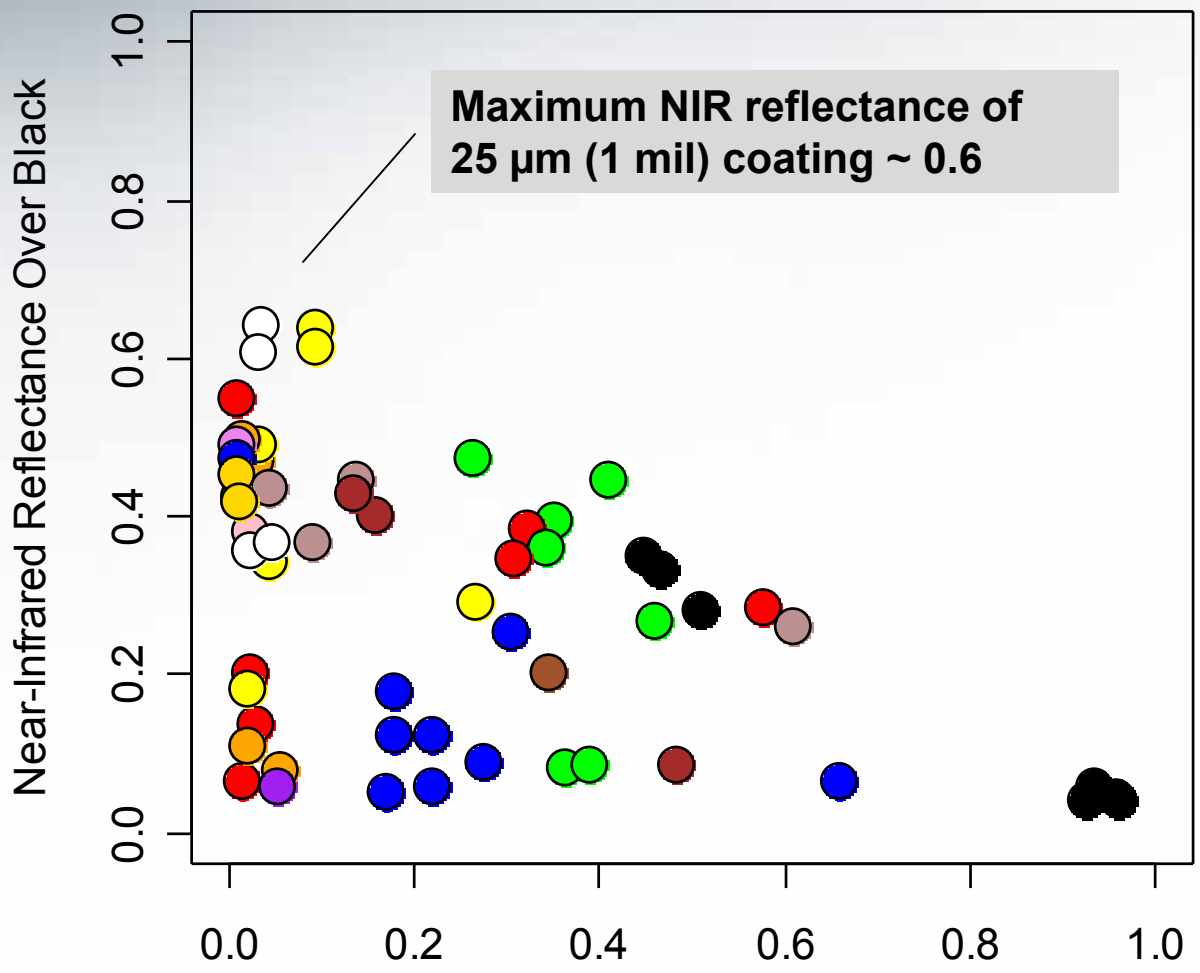
- Opaque, scattering pigments
  - TiO_2 white!
  - Nickel and chrome titanates – yellows
  - Infrared-reflective blacks – $(Fe,Cr)_2O_3$ – and many related compounds
  - Co_2TiO_4 – teal (bluish green)
  - TiO_2 on mica flakes - various colors
  - FeOOH yellow
  - Fe_2TiO_4 – iron titanium oxide spinel – brown
- Transparent pigments
  - Cobalt chromite and aluminate blues
  - Various organic pigments (phthalo blue, quinacridone red,…)

Examples of Hot Pigments

- Carbon black (also lamp black, ivory black)
- Fe_3O_4 black (magnetite)
- Copper chromite black
- Raw umber (brown)
- Burnt sienna (brown)
- Prussian blue ($C_6FeN_6 \cdot H_4N$)

NIR Properties of 25-µm Paint Films

Cool ..... *Hot*



Standalone

Needs NIR-Reflective Undercoat

Next Steps

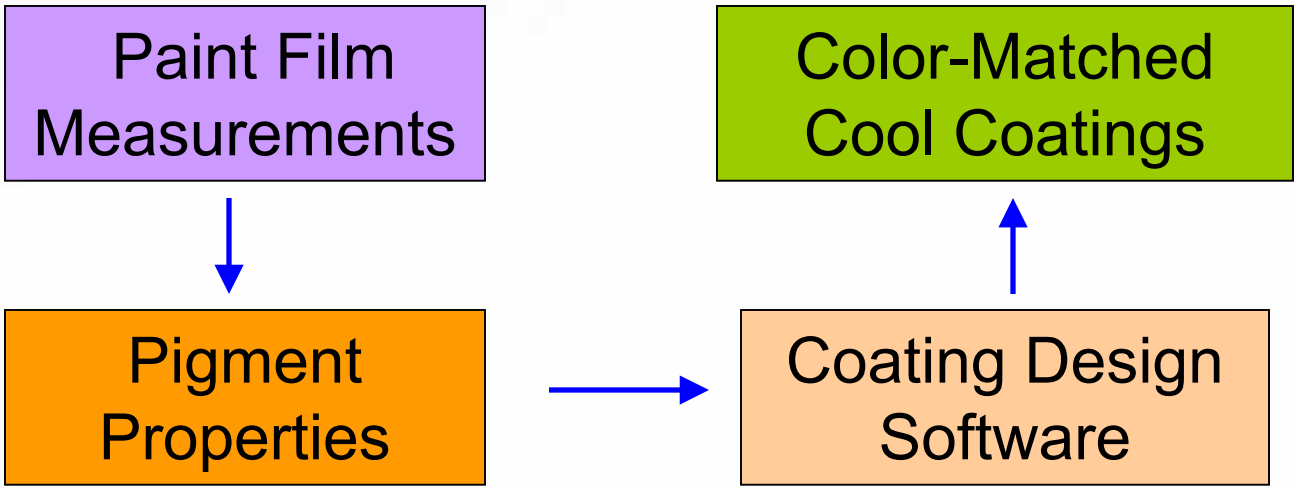
- Measure about 50 more pigments
- Finalize adapted K-M theory
- Characterize pigment mixtures
- Share detailed pigment characterizations with industrial partners
- Establish measurement protocols
- Characterization task feeds into the coating design task

2.4.2 Develop a Computer Program For Optimal Design of Cool Coatings

- Objective: Develop software for optimal design of cool coatings used in colored roofing materials
- Deliverables:
  - Computer Program
- Schedule: 11/1/03 – 12/1/04
- Funds Expended 5 %

Coating Design Software

- Estimate coating reflectance from pigment properties (absorption, scattering), film geometry (mixing, layering)
- Recommend pigments & geometry to match color, maximize solar reflectance



Software Development Path

- Pigment characterization software currently predicts reflectance of layers
  - film reflectance is function of scattering coefficient, absorption coefficient, thickness, and *background reflectance*
- Next step: predict reflectance of mixtures
  - are coefficients additive in proportion to concentration?
  - can we increase accuracy of mixture-performance prediction by using tint ladders (mixtures with increasing fractions of white)?
- Final goal: code suggests recipes for color-matched cool paints
- **Platform:** “R” programming language
  - free
  - available for PC, Mac, Unix
  - http://www.r-project.org

2.5 Development of Prototype Cool-Colored Roofing Materials

- Objective: Work with manufacturers to design innovative methods for application of cool coatings on roofing materials
- Subtasks:
  - Review of roofing materials manufacturing methods
  - Design innovative engineering methods for application of cool coatings to roofing materials
  - Accelerated weathering testing

2.5.1 Review of Roofing Materials Manufacturing Methods

- Objective: Compile information on roofing materials manufacturing methods
- Deliverables:
  - Methods of Fabrication and Coloring Report
- Schedule: 6/1/02 – 6/1/03
- Funds Expended 50 %

Focus: Application of Cool Colors to Roofing Products

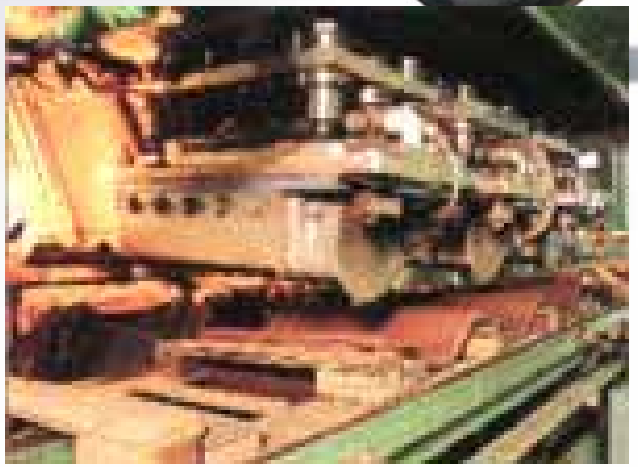
- Metal roofing
- Clay roof tiles
- Concrete roof tiles
- Wood shakes
- Asphalt shingles (granules)

Manufacturing Shingles: Elk Factory in Shafter, CA

- On February 19, we visited the Elk roofing shingle plant in Shafter, CA.

Manufacturing Shingles: Factory Floor

A Typical Tile Manufacturing Plant (Internet Images)



Next Steps

- Visit other roofing manufacturing plants
  - clay and concrete tile
  - metal
  - granules
- Prepare draft report
- Help needed to arrange plant visits
- Help needed to obtain literature on roofing manufacturing techniques

2.5.2 Design Innovative Engineering Methods for Application of Cool Coatings To Roofing Materials

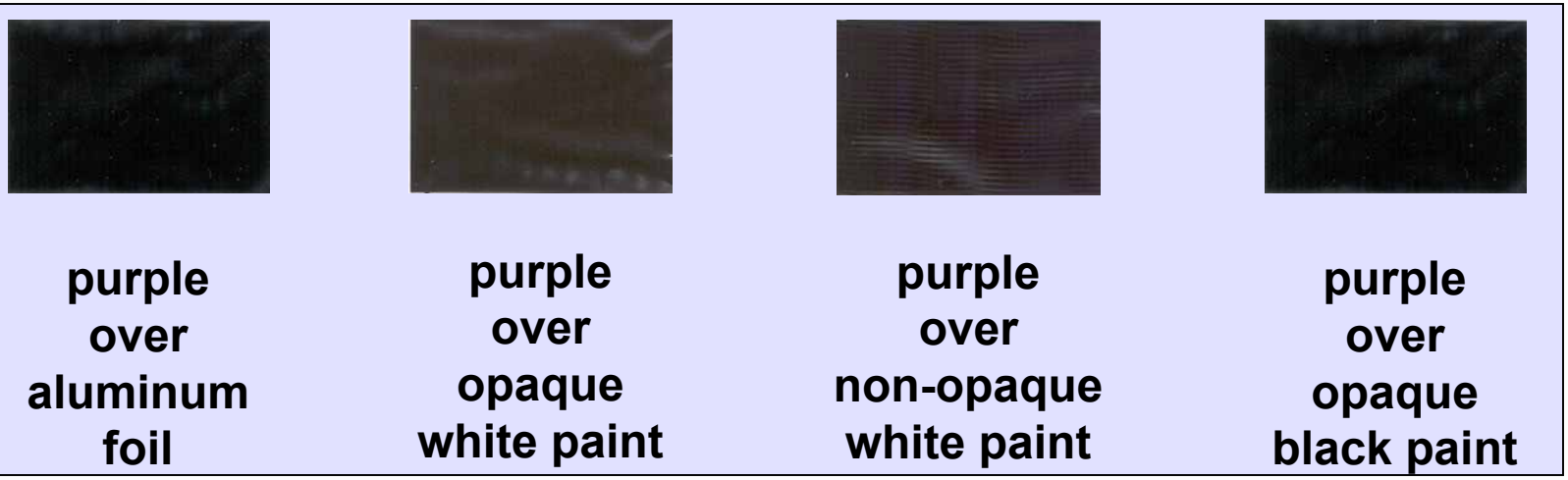
- Objective: Work with manufacturers to design innovative methods for application of cool coatings on roofing materials
- Deliverables:
  - Summary Coating Report
  - Prototype Performance Report
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 5 %

Innovative Engineering Methods: NIR-Reflective Undercoating

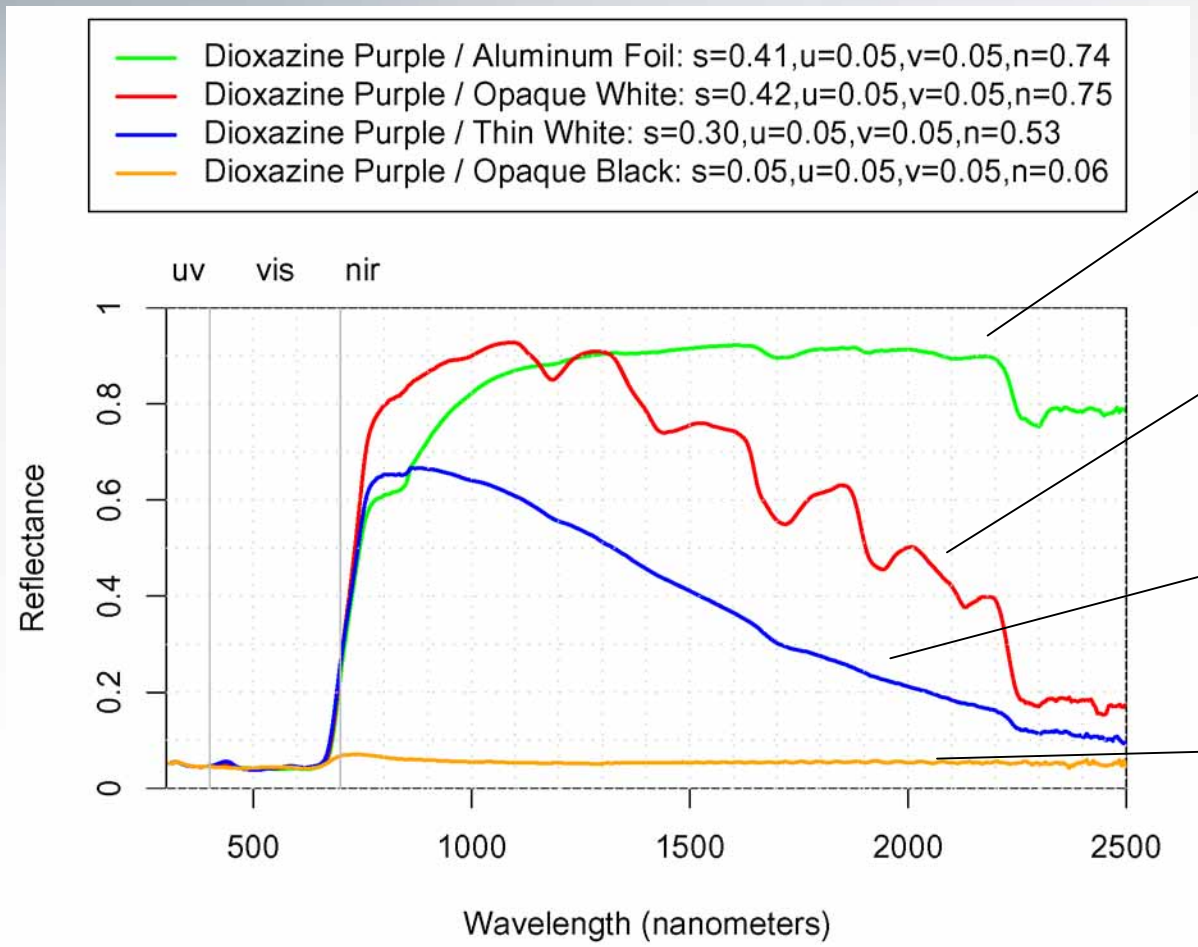
- All cool pigments must have low NIR absorption
- NIR-reflective undercoats (e.g., white, aluminum) improve performance of cool pigments, especially those with high NIR transparency
  - pigments with NIR transparency ≥ 0.5 include
    - dioxazine purple
    - phthalo blue, cobalt aluminum blue, cobalt blue
    - phthalo green
    - monstral red, acra red
    - yellow orange azo, acra burnt orange
    - chrome yellow, yellow medium azo, interference gold
- NIR-transparent films over white yield darker cool colors than obtained with tinting (mixing pigments with white)

Example: Dioxazine Purple Over Various Undercoats

- Two-layer system
  - top coat: thin layer of dioxazine purple (14-27 μm)
  - undercoat or substrate:
    aluminum foil (~ 25 μm)
    opaque white paint (~1000 μm)
    non-opaque white paint (~ 25 μm)
    opaque black paint (~ 25 μm)



Dioxazine Purple Reflectances



over aluminum
R_{solar} = 0.41

over opaque white
R_{solar} = 0.42

over non-opaque white
R_{solar} = 0.30

over opaque black
R_{solar} = 0.05

Next Steps

- Collaboration with industrial partners
  - pigments: identify/develop suitable undercoats with high NIR reflectance
  - granules: develop colored prototypes with high reflectance
  - metals and tiles: develop prototype two-layer coatings
  - shingles: implement methods for factory measurement of shingle NIR reflectance

2.6 Field-testing and Product Useful Life Testing

- Objective: Demonstrate, measure and document the building energy savings, improved durability and sustainability of cool colored roofing materials
- Subtasks:
  - Building energy-use measurements at California demonstration sites
  - Materials testing at weathering farms in California
  - Steep-slope assembly testing at ORNL
  - Product useful life testing

2.6.1 Building Energy-Use Measurements at California Demonstration Sites

- Objective: Setup residential demonstration sites, measure and document the energy savings of cool pigmented roof materials
- Deliverables:
  - √ Demonstration Site Test Plan
  - – Test Site Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 7 %

Cavalli Hills Subdivision Sacramento, CA

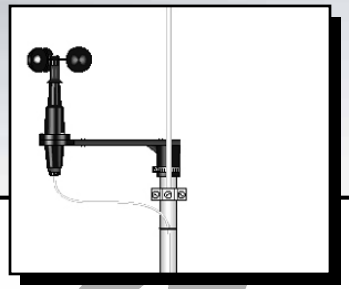
- Sacramento Municipal Utility District (**SMUD**) and ORNL are working together monitoring
  - Cool Roof Color Materials (CRCM)
  - Insulated Concrete Form (ICF) walls

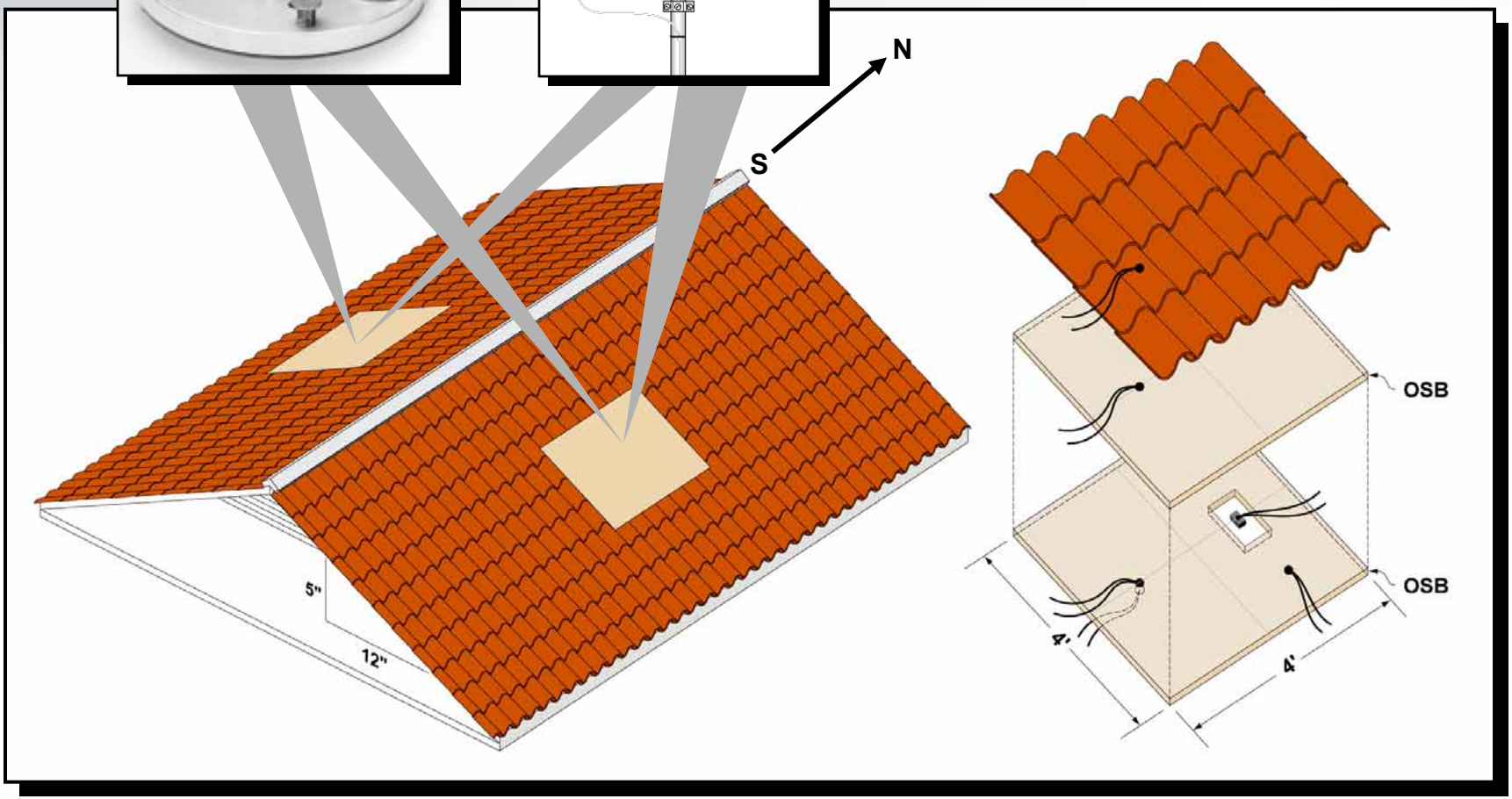
Mike Evans Construction building Cavalli Hills

Demonstration Home Instrumentation

Instrument	Description	Location	Attachment
East Facing Roof			
Thermocouple (Type T Cu/Con)	Unshielded bead	Deck	Taped
	Unshielded bead	Deck	Embedded between OSBs
Heat Flux Transducer	2-in by 2-in by 0.125-in thick	Deck	Embedded between OSBs
Anemometer	Wind Velocity	Near HFT	Mounting bracket
Pyranometer Li-Cor	Solar Irradiance	Near HFT	Mounting bracket
Thermocouple (Type T Cu/Con)	Unshielded bead	Deck underside	Taped
	30 AWG Unshielded bead	Spare for Roof Surface	Loctite Epoxy
West Facing Roof			
Thermocouple (Type T Cu/Con)	Unshielded bead	Deck	Taped
	Unshielded bead	Deck	Embedded between OSBs
Heat Flux Transducer	2-in by 2-in by 1/8-in thick	Deck	Embedded between OSBs
Anemometer	Wind Velocity	Near HFT	Mounting bracket
Pyranometer Li-Cor	Solar Irradiance	Near HFT	Mounting bracket
Thermocouple (Type T Cu/Con)	Unshielded bead	Deck underside	Taped
	30 AWG Unshielded bead	Spare for Roof Surface	Loctite Epoxy
Attic interior			
Vaisala 50Y	DB & RH Probe	Attic air 4-ft above insulation	Run along support wire
Thermocouple (Type T Cu/Con)	Shielded bead	Top of insulation	Laid atop insulation
	Unshielded bead	Sheet rock surface facing attic	Taped
Heat Flux Transducer	2-in by 2-in by 1/8-in thick	Sheet rock surface facing attic	Sandwiched between insulation and sheet rock
Vaisala 50Y	DB & RH Probe	Attic air 4-ft above insulation	Mounting bracket
House interior			
Vaisala 50Y	DB & RH Probe	Entering return grill	Duct mounted
Watt-hour meter	Form 16S kWHr	Total House Power	Meter base, hub & box
Watt-hour meter	Form 16S kWHr	HVAC Power	Meter base, hub & box

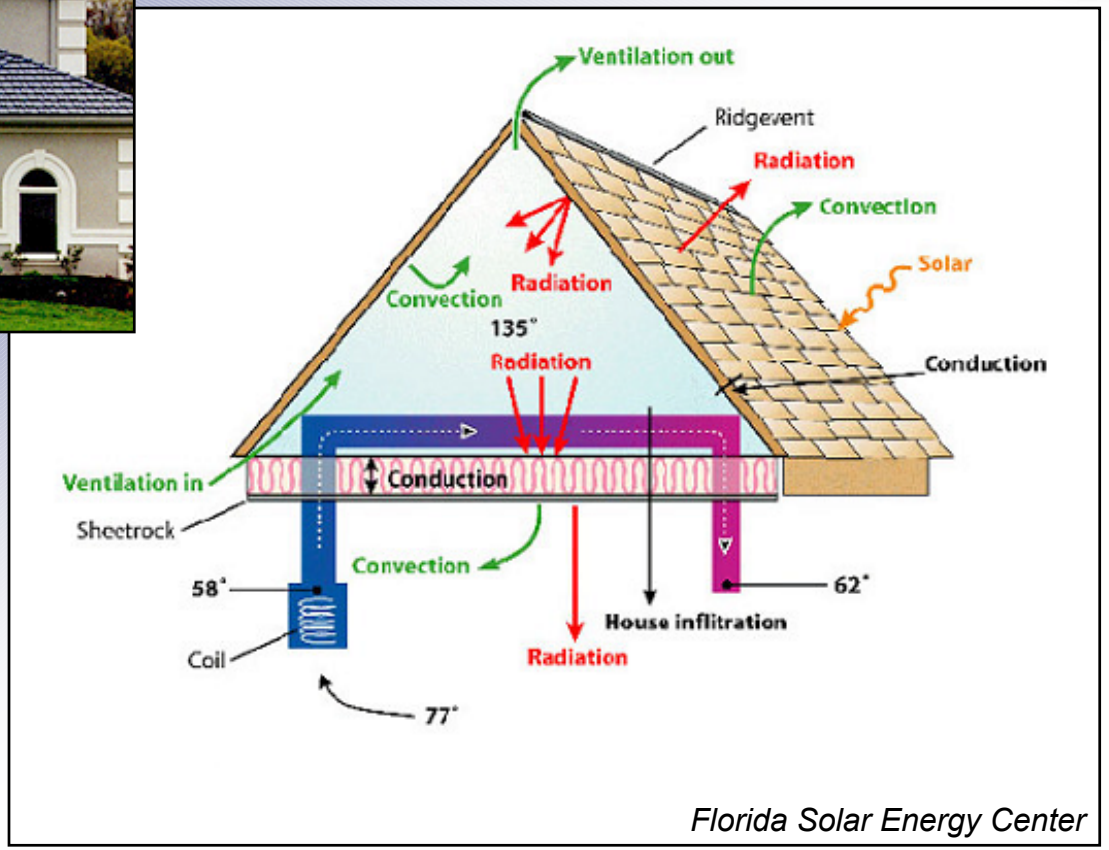
Roof Instrumentation





AtticSIM *(Attic Simulation)* Model

Roof Energy Balance



Florida Solar Energy Center

Implementation Stage for 2.6.1 OUR Next Steps

- **Endorse Memorandum of Understanding**
  Mike Evans Construction, SMUD and ORNL
- **Hanson Roof Tile of *Roof Tile Institute***
  Supplying “Hacienda” Concrete Tile

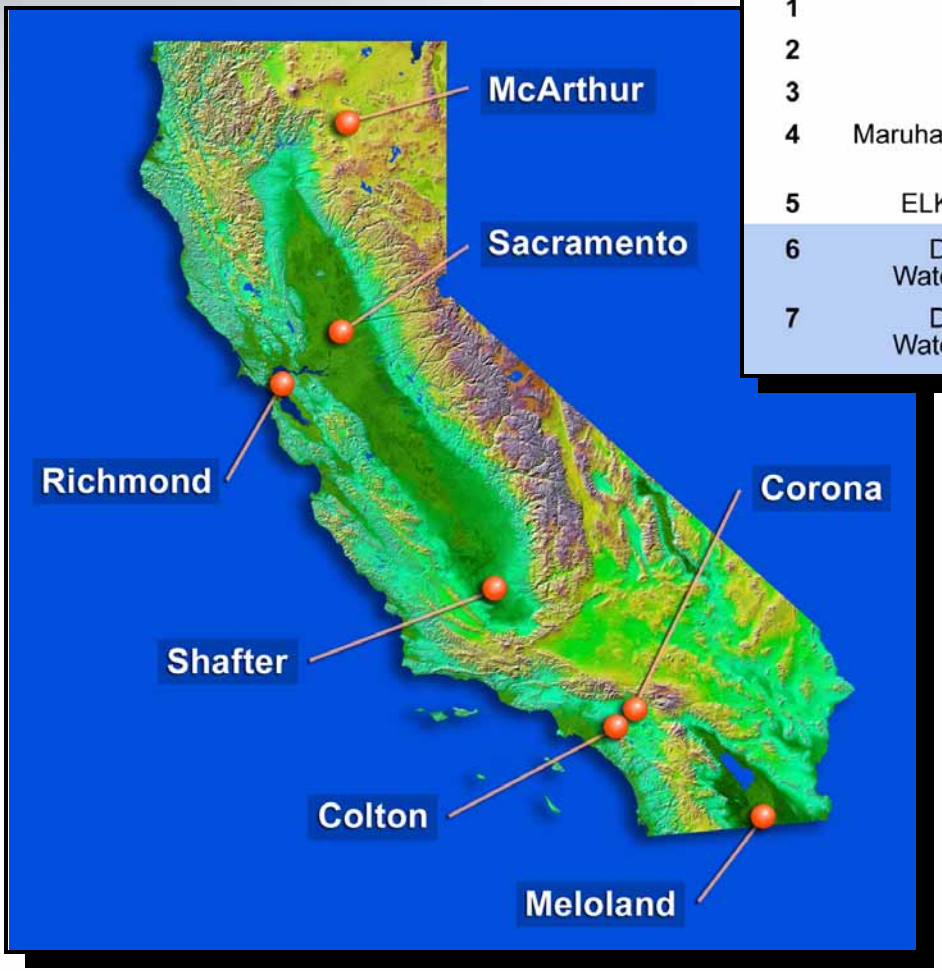
- **FERRO Corporation**
  Blending cool color pigments into Hanson’s concrete mix
- **Custom-Bilt Metals/Classic Products of *Cool Metal Roofing Coalition***
  Supplying painted metal shake or shingle
- **ORNL Contracts Dynamic Roofing**
  OSB Sandwich test panels shipped to Evans Construction
  ORNL and SMUD commission Data Acquisition Systems

2.6.2 Materials Testing at Weathering Farms in California

- Objective: Document the change in reflectance and emittance for roof products having cool color pigments
- Deliverables:
  - Weathering Studies Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 12 %

Exposure Racks are ordered, shipment to sites set for March

CA Topographic Map

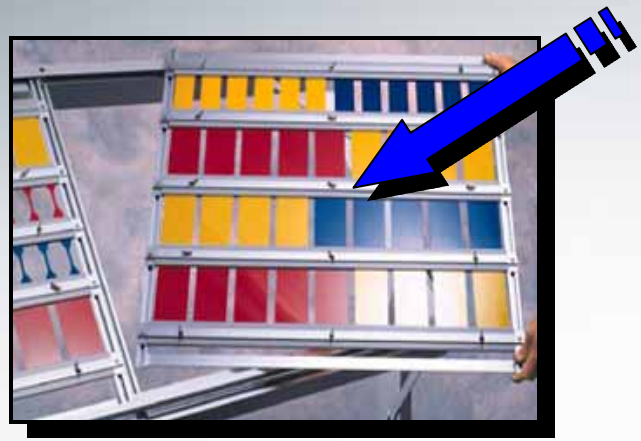


Sites	Company	City	County	Climate Zone
1	Custom-Bilt	**Sacramento**	Sacramento	**12**
2	Steelscape	**Richmond**	Contra Costa	**3**
3	BASF	**Colton**	San Bernadino	**10**
4	Maruhachi Ceramics of America	**Corona**	Riverside	**10**
5	ELK Corporation	**Shafter**	Kern	**13**
6	Department of Water Resources	**McArthur**	Shasta	**16**
7	Department of Water Resources	**Meloland**	Imperial	**15**

Field Exposure Sites

Shuttle Radar Topography Mission (SRTM)
Space Shuttle Endeavor
National Imagery and Mapping Agency (NIMA)

Field samples contained in “sure grip” sub-assembly modules



Two “sure grip” sub-assemblies per main frame

- 3½” by 3½” sample size
- 5 rows of samples
- 10 samples per row (max)

	Colors	Row 1 Concrete Tile	Row 2 Clay Tile	Row 3 PVDF Metal	Row 4 Asphalt Shingle	Row 5 Cedar Shake
1	Charcoal Gray	1	1	1	0	0
2	Hartford Green	1	1	1	0	0
3	Rawhide	1	1	1	0	0
4	Brick Red	1	1	1	0	0
5	Regal White	1	1	1	0	0
6	Slate Bronze	1	1	1	0	0
7	Slate Blue	1	1	1	0	0

Sacramento exposure site Climate Zone 12

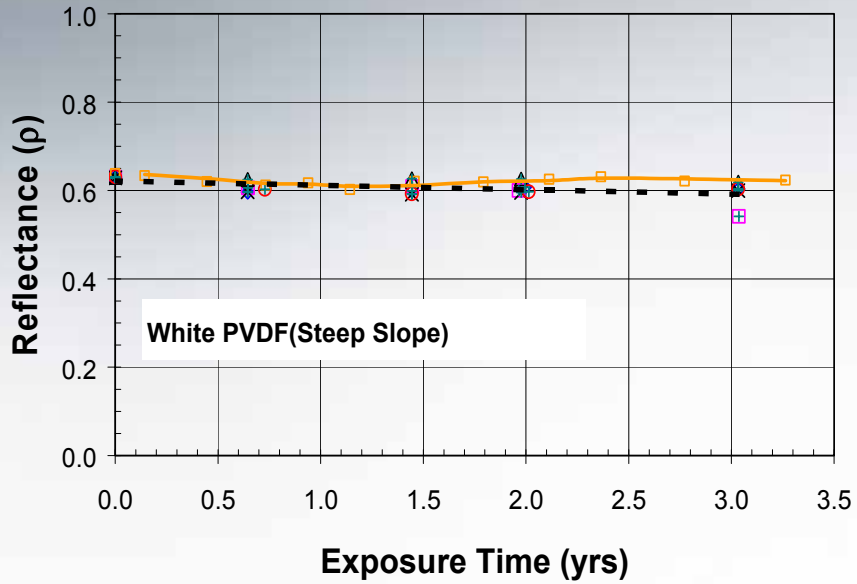
- Central Valley population is expanding

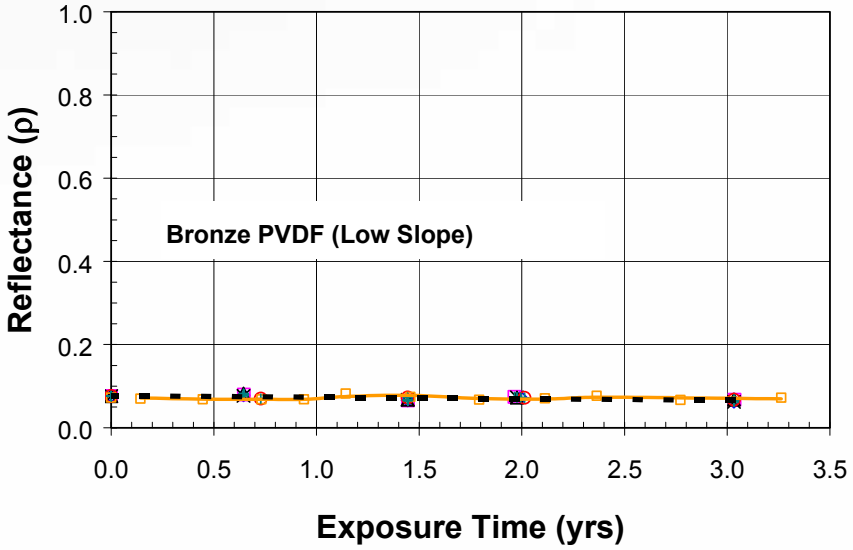
Dry Bulb High 91.6, Low 37.7°F

Average RH 65%

Space Shuttle Endeavor
Shuttle Radar Topography Mission (SRTM)

Loss of Reflectance is less than 5% for Painted Metal



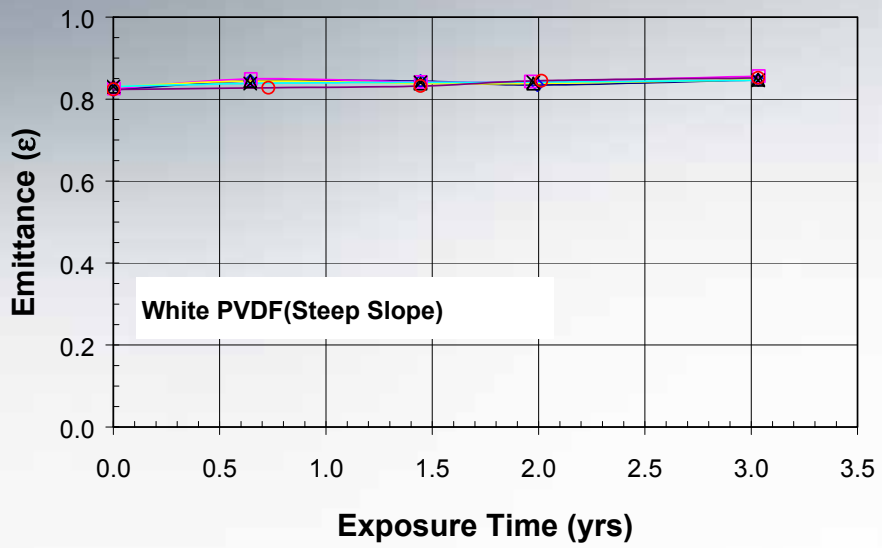


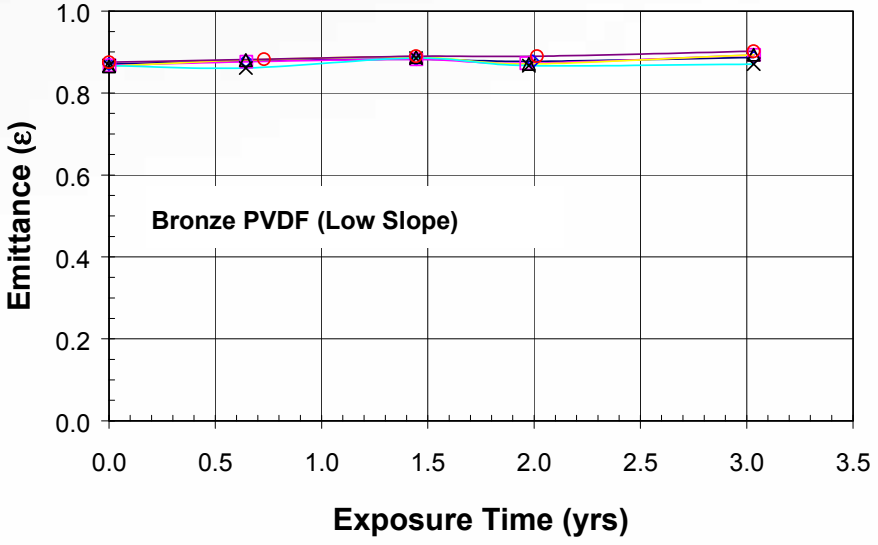
CMRC Findings Jan, 03

- Reflectance Loss ≤ 5.0%
- Loss in reflectance similar across all climates in USA

Monroeville, PA
Nova Scotia, Canada
OAK RIDGE, TN
Ft Lauderdale, FL
Bethlehem, PA

Emittance of Painted Metal increases with exposure time





CMRC Findings Jan, 03

- No Loss in ε
- Emittance trends similar across all climates in USA

Implementation Stage for 2.6.2 OUR Next Steps

- **BASF manufacturing painted metal field samples**
  - "Cool" color chips sent Hanson, MCA, FERRO & Shepherd Color Co.
- **Monier Lifetile making concrete tile samples**
  - Shepherd Color Co. blending "cool" colors into Monier's concrete mix
- **Maruhachi Ceramics of America making clay tile samples**
  - MCA matching similar clay colors to "cool" color chips
- **BASF, MCA and Monier ship samples to ORNL**
  - Reflectance and emittance catalogued by ORNL
  - Samples placed in "sure-grip" sub-assemblies
  - LBNL measures duplicates in spectrophotometer

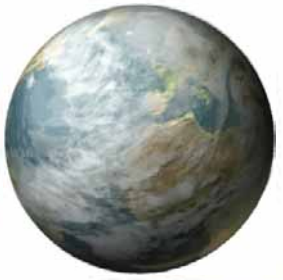
2.6.3 Steep-slope Assembly Testing at ORNL

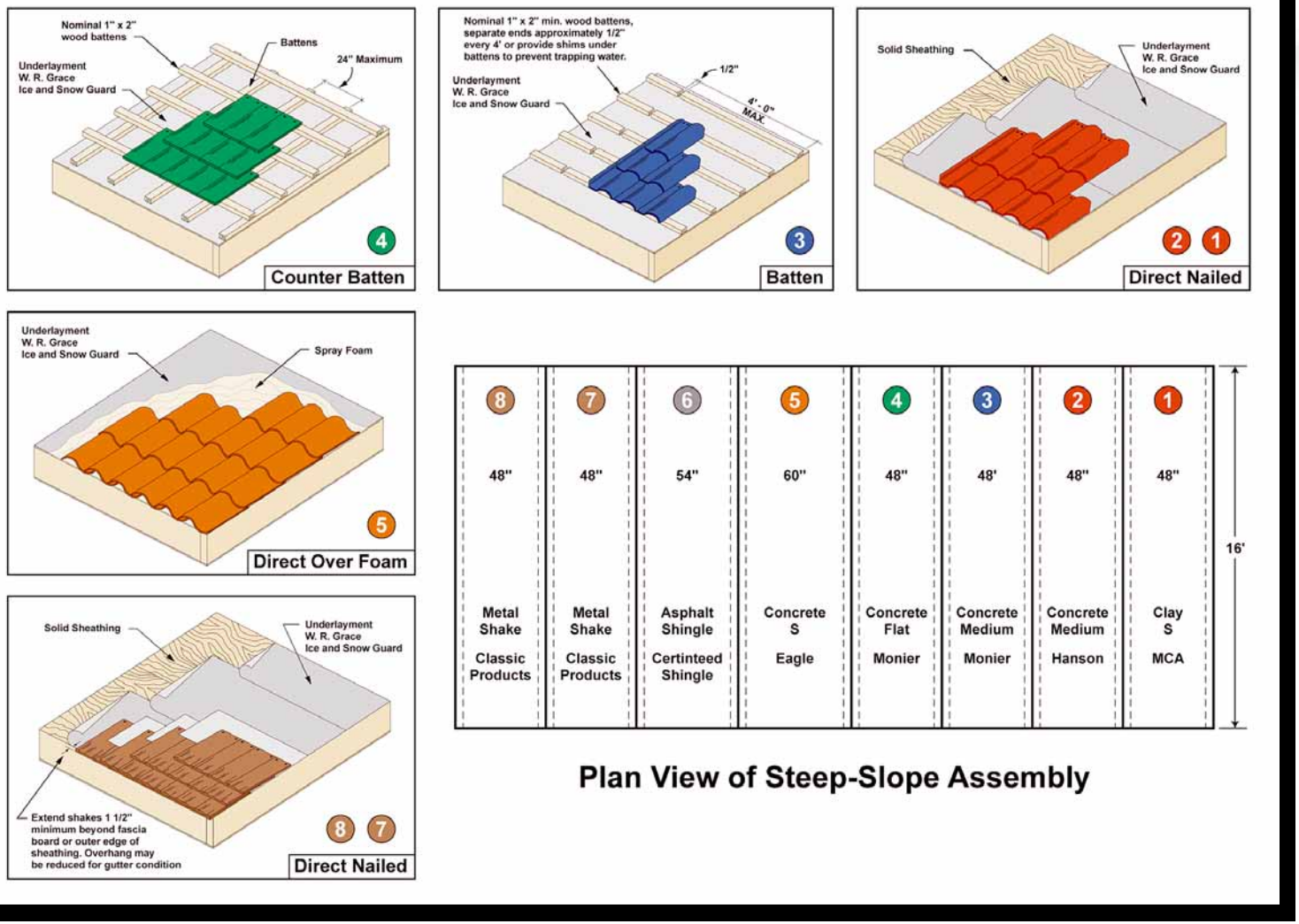
- Objective: Field test cool color pigmented roof products on the Envelope Systems Research Apparatus (ESRA) to document the effect of reflectance and emittance weathering on the thermal performance of the cool pigmented roof systems
- Deliverables:
  - Whole-Building Energy Model Validation
  - Presentation at the Pacific Coast Builders Conference
  - Steep Slope Assembly Test Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 10 %

Envelope Systems Research Apparatus (ESRA)

- Some Sixty Roofs Under Evaluation
- Residential & Commercial Markets
- AISI, MCA, NamZAC, NCCA, MBMA, SPRI and RCMA

Roof Tile Institute to install five different tile assemblies on ESRA



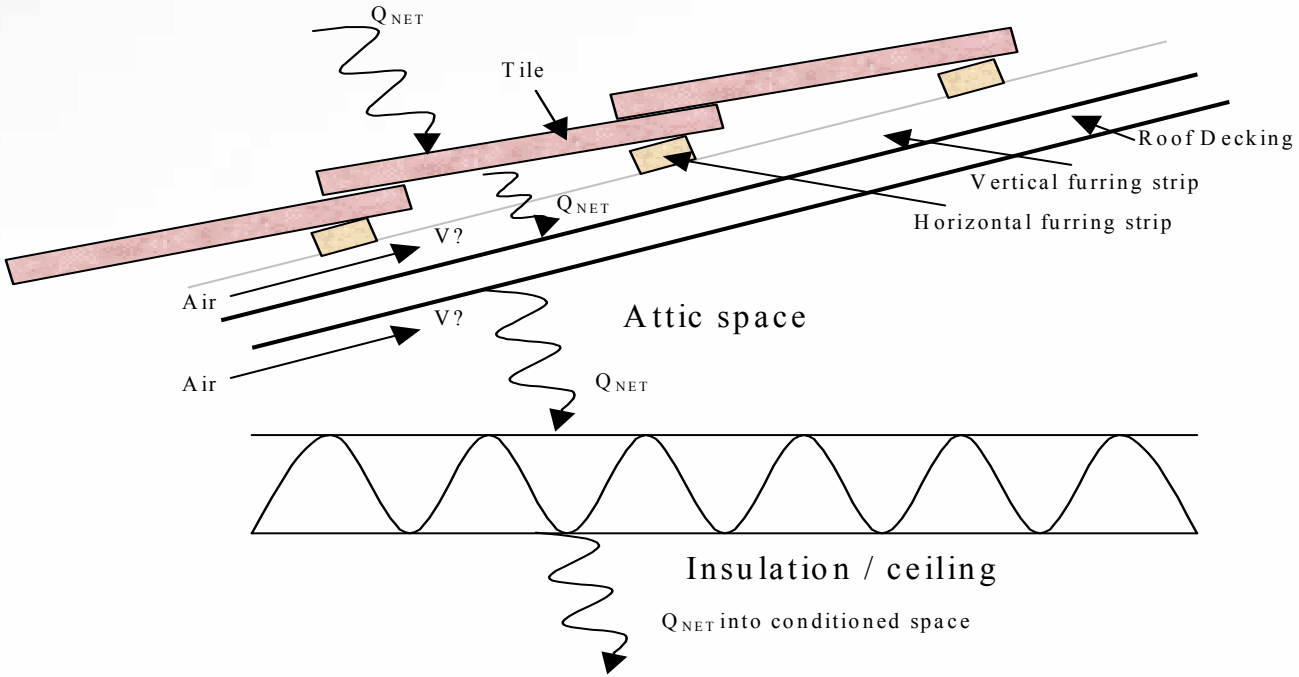


Formulation and Validation of Heat Transfer Correlations

UTK Research Team

- **Professor Majid Keyhani**
- **Dr. William (Bill) Miller**
- **Ph.D. Student Ron Domitrovic**
- **Undergraduate Student**

Venting between Roof Deck and Exterior Tile Roof



Implementation Stage for 2.6.3 OUR Next Steps

- **ORNL subcontracts Tennessee Roofing**
  - Remove existing steep-slope metal roofs from ESRA
- **Calibration of steep-slope assembly instrumentation**
  - Remove existing transducers and recalibrate
- **Roof Tile Institute installs concrete tile systems**
  1. MCA “S-Mission” Clay tile (Terra Cotta Glaze “cool” color)
  2. Hanson “Regal” Concrete Medium “cool” color same as at Cavalli Hills
  3. Monier Lifetile “Villa 2000” Concrete Medium (Slurry Terra Cotta color)
  4. Monier Lifetile “Sentry Slate” Concrete Flat (Brown)
  5. Eagle “Capistrano” Low Profile Concrete (Slurry Terra Cotta color)
- **Custom-Bilt Metals/Classic Products of Cool Metal Roofing Coalition**
  7. Painted metal shake “cool” color same as at Cavalli Hills
  8. Painted metal shake “standard” color same as at Cavalli Hills

Schedule of PAC meetings

	Meeting	Date
1.	Project Kick-off Meeting (completed)	May 16, 2002
2.	Project Advisory Committee Meeting 1 (PAC1)	September 12, 2002
3.	Project Advisory Committee Meeting 2 (PAC2)	March 11, 2003
4.	Project Advisory Committee Meeting 3 (PAC3)	September 11, 2003
5.	Critical Path Review Meeting 1 (CPR1)	October 3, 2003 (or September 12, 2003)
6.	Project Advisory Committee Meeting 4 (PAC4)	March 4, 2004
7.	Project Advisory Committee Meeting 5 (PAC5)	September 10, 2004
8.	Critical Path Review Meeting 2 (CPR2)	October 7, 2004 (or September 11, 2004)
9.	Project Advisory Committee Meeting 6 (PAC6)	March 3, 2005
10.	Project Final Meeting	October 6, 2005

September 2003 Meeting

- September 11, 2003 (Is this OK?)
- At Berkeley (LBNL)

Cool Colors Project Website

- Project information (including copies of this presentation) available online at

http://CoolColors.LBL.gov