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Clinical exposure to high power radiofrequency (RF) energy has been studied for its ability to both warm and destroy tissue though heat deposition.

**15. SUBJECT TERMS**
Thermal damage, RF exposure, RF bioeffects modeling

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| U | | | | | J Payne |
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# Probability of Injury from RF Exposure (PIRE)

28 June 2018


## Jeff Whitmore & Jason Payne

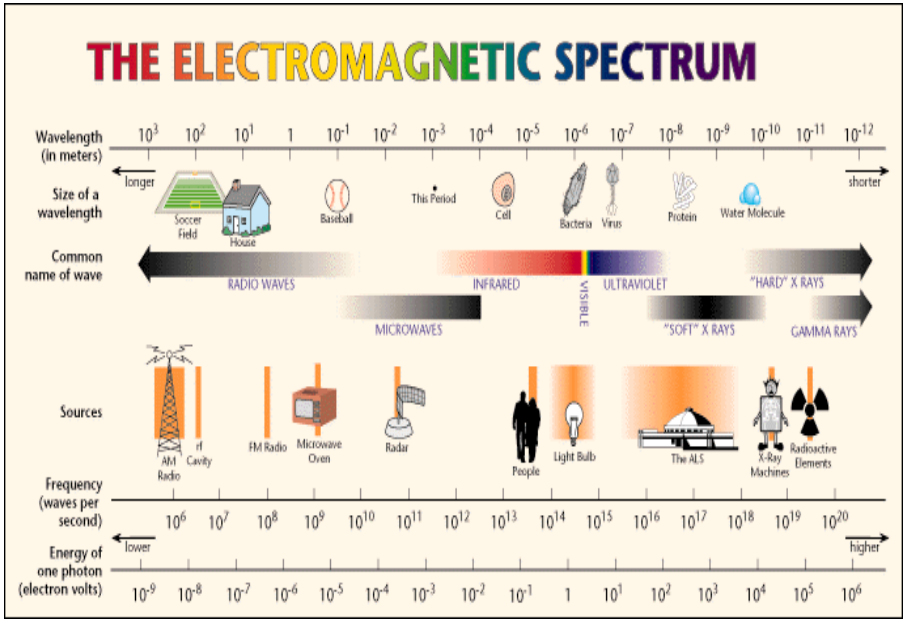
711 HPW/RHDR

Air Force Research Laboratory


*Integrity ★ Service ★ Excellence*

# Outline

- Radio Frequency Bioeffects Branch Introduction
- Radio Frequency Context
- PIRE Introduction
- Bioeffects Modeling
- Coupon Study
- Panniculus Study
- Conclusion



# Radio Frequency Bioeffects Branch

Located in San Antonio, TX -- Roots back to 1950's

Full bio-analysis from behavior to atomic level

Exploring low to high power exposures

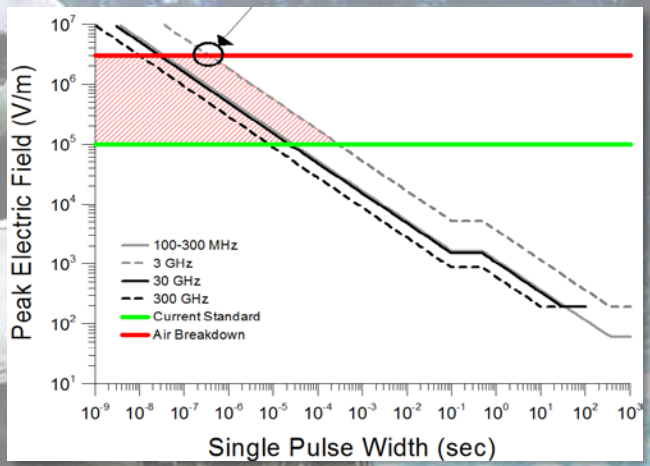
Computational analysis & simulation

RF sources (AF, Navy, & Army)

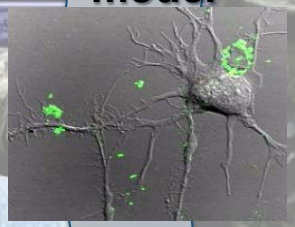
12 Chambers/labs

## GOALS

RF Bioeffects Models
RF Protection




Develop *in vitro* model



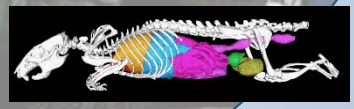
Application

**Algorithms**

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

Expand to *in vivo*



Whole Body Models

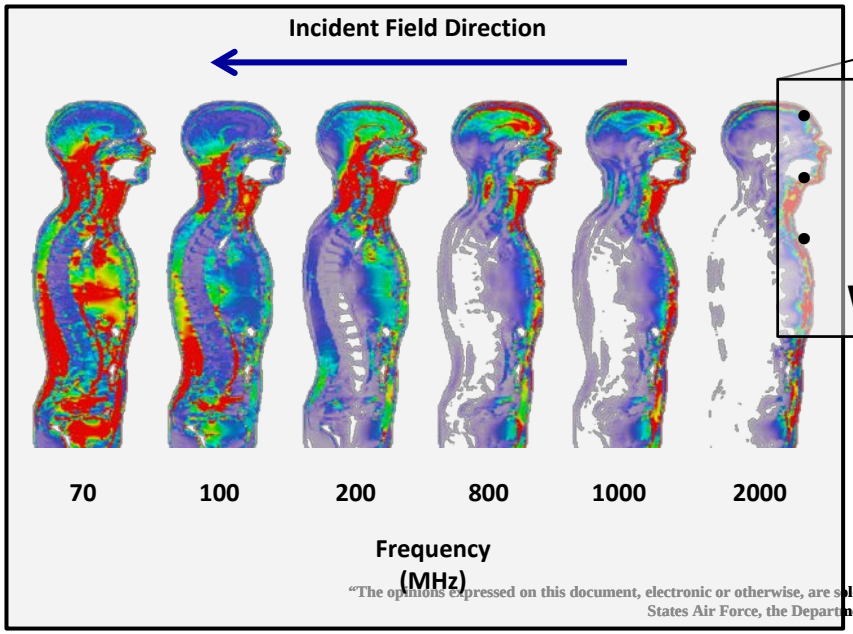
Computation

# RF Spectrum & Absorption Depth

## Radio Waves

| 3 Hz | 30 Hz | 300 Hz | 3 kHz | 30 kHz | 300 kHz | 3 MHz | 30 MHz | 300 MHz | 3 GHz | 30 GHz | 300 GHz |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ELF | SLF | ULF | VLF | LF | MF | HF | VHF | UHF | SHF | EHF | |

| Whole Body Heating | Organ Heating | **Superficial Heating** |
|---|---|---|




- **Relatively deep absorption**
- **Body resonance ~100 MHz**
- **Organ resonances up to 3 GHz**

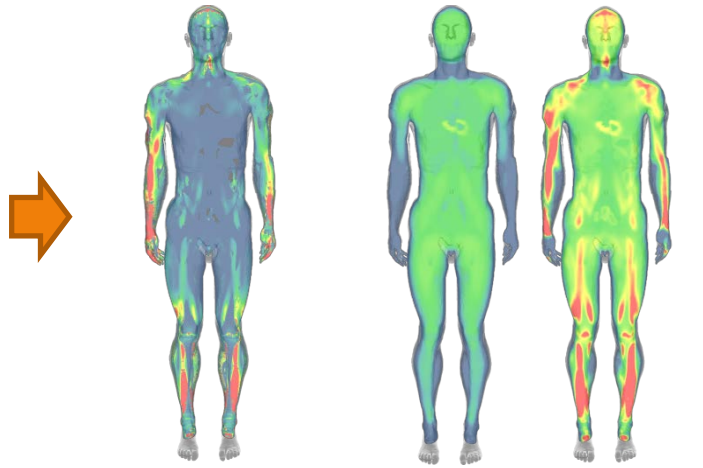
**Whole body models required**

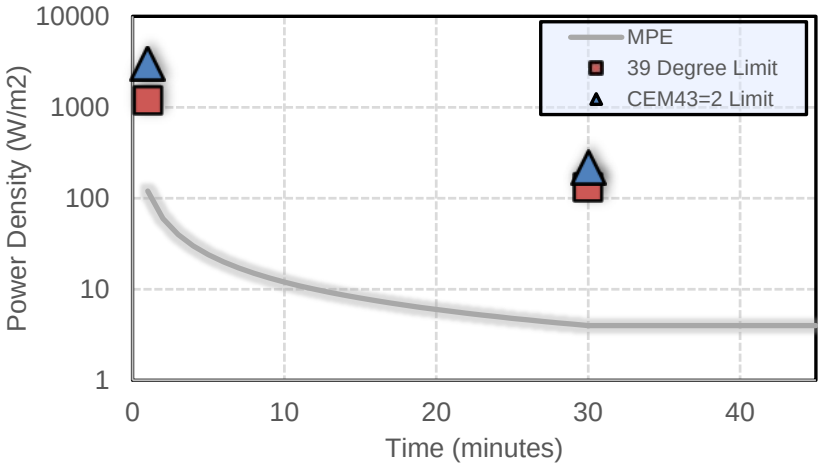
- **Shallow penetration depth**
- **Reduced modeling requirements**

# PIRE Methodology & Goals

## Methods

- Review Literature
- Develop numerical and analytical solutions to predict thermal profiles from RF exposure
- Create models relating temperature to damage (also sensation/behaviour)
- Validate models with empirical observations




## Goals

- Build real-time look-up tables
- Enable risk-based exposure standards
- Build RF injury knowledge base
- Create simulation components predicting RF exposure and damage

# Current PIRE Studies

**In vitro swine coupon – complete**

- **Validates superficial thermal model predictions**
- **Relates Arrhenius burn model to observed burns**

**Ex vivo human panniculus – data collection beginning soon**

- **Dose required to produce burns**
- **Burn morphology**

**In vivo swine – protocol approved**

- **Dose required to produce burns**
- **Burn morphology**

# Swine Coupon Experiment

**Purpose:**

- Validate thermal predictions across a range of power levels using a shallow-penetrating frequency
- Collecting empirical data to derive temperature dependent properties

**Model Details:**

- Multi-Physics approach to RF Bioeffects:
  - Electromagnetics + ThermoDynamics + Bio Response
- Parameters are temperature dependent (viz., conduction, diffusivity, specific heat)*
- Utilizes an Arrhenius damage formulation

* Analytical Solution to Nonlinear Thermal Diffusion: Kirchoff Versus Cole-Hopf Transformations; Peter Vadasz, 2010; Journal of Heat Transfer

# Swine Coupon Experiment

## Experimental Conditions

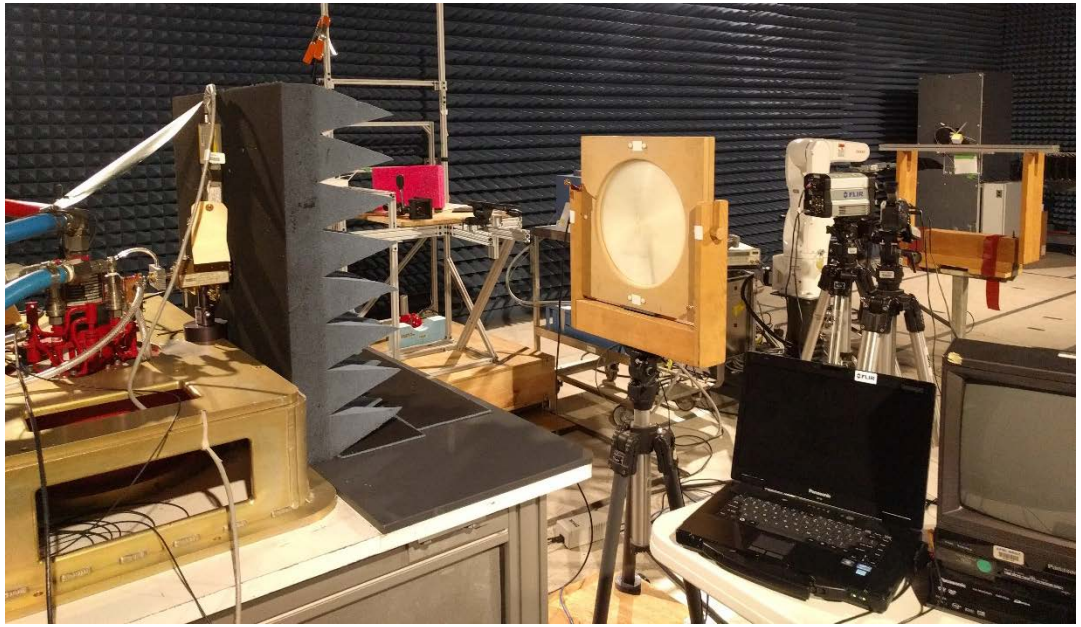
| | | Dose (J) | | | | |
|---|---|---|---|---|---|---|
| | | 6 | 10 | 15 | 20 | 30 |
| Power(W/cm2) | 3 | | | | | |
| | 10 | | | | | |
| | 30 | | | | | |

## Apparatus

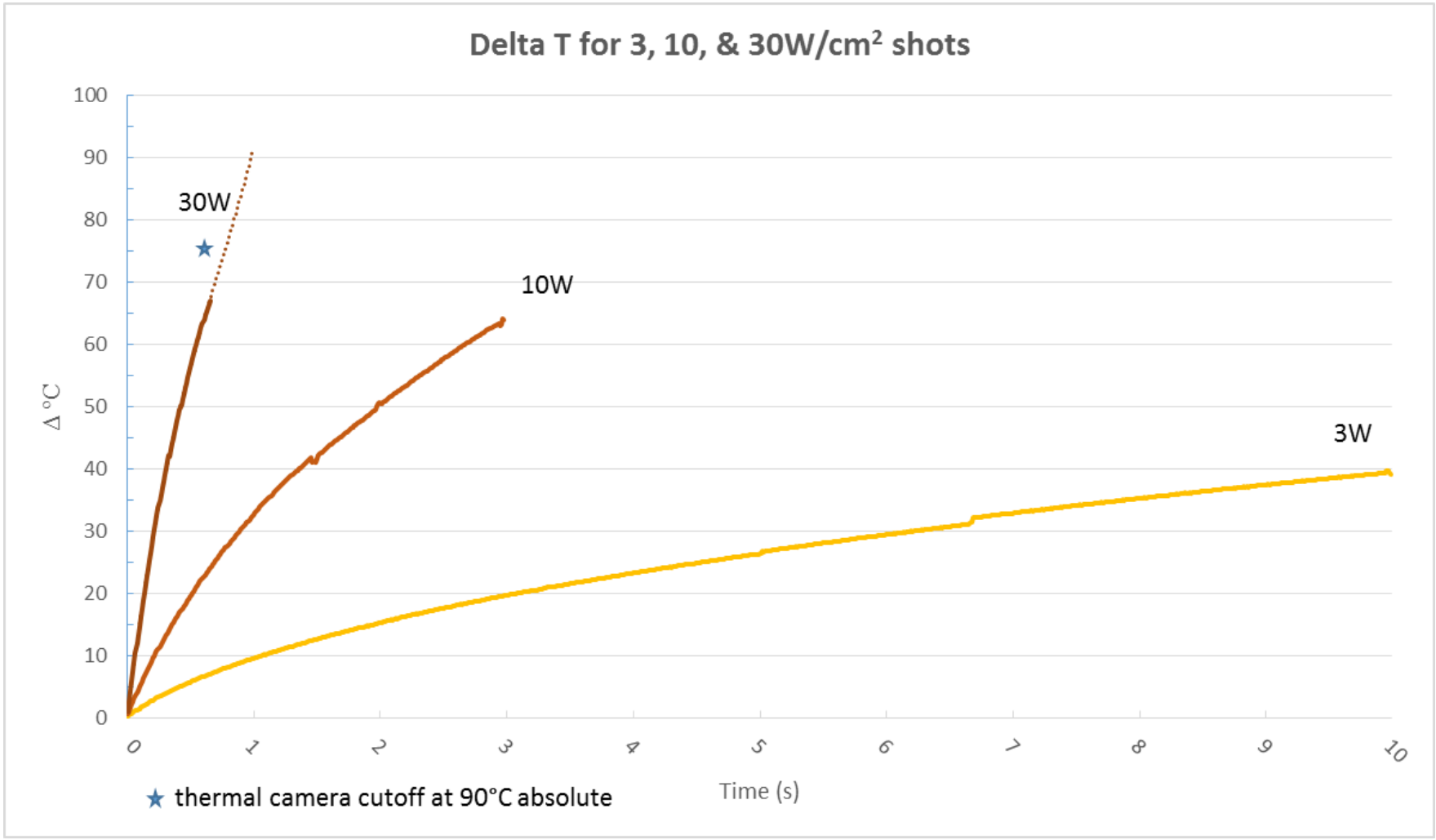
- EHF transmitter

## Experimental Procedures

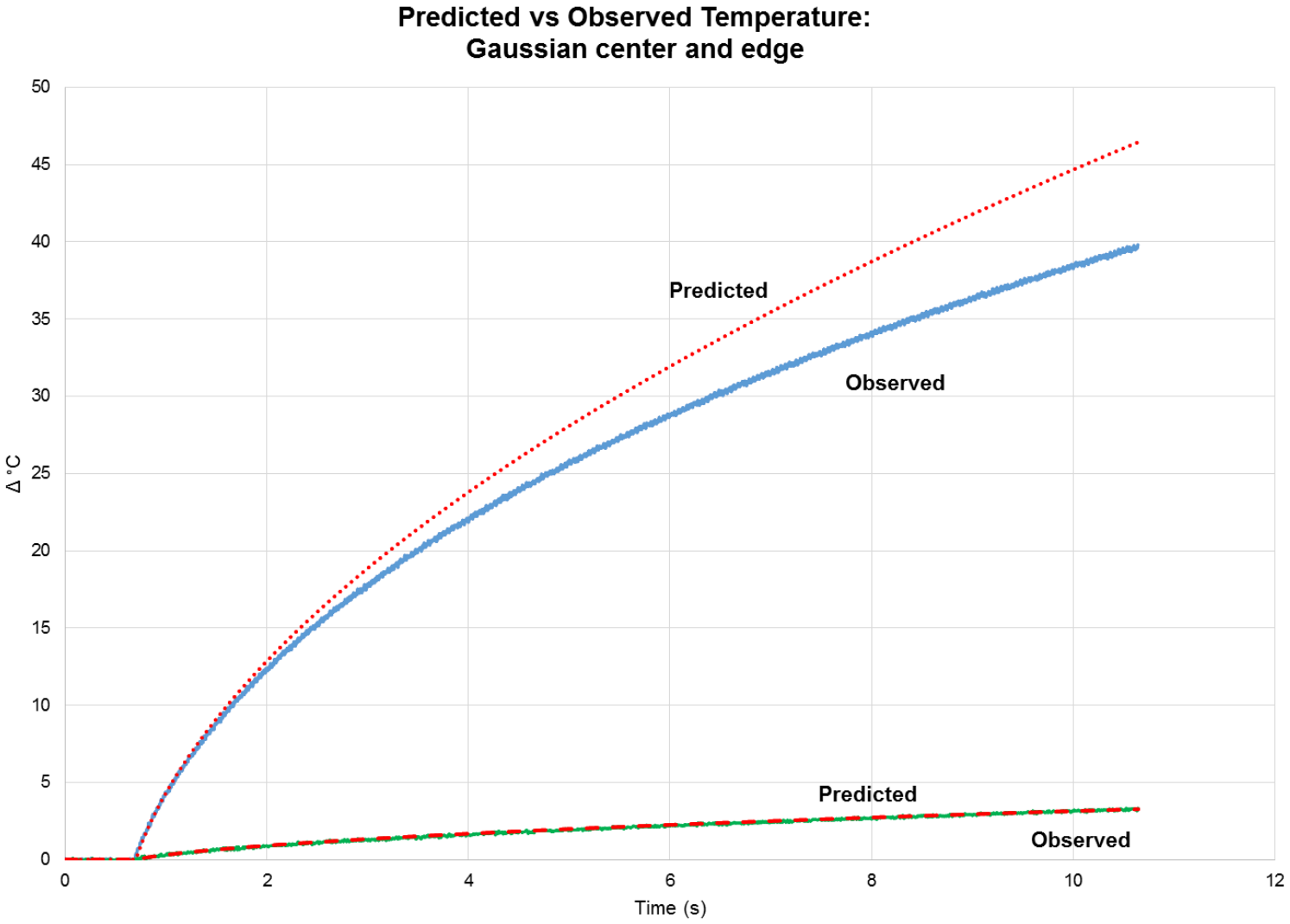
- Samples at room temperature
- Thermal imaging
- 4cm dia spot
- Histopathology



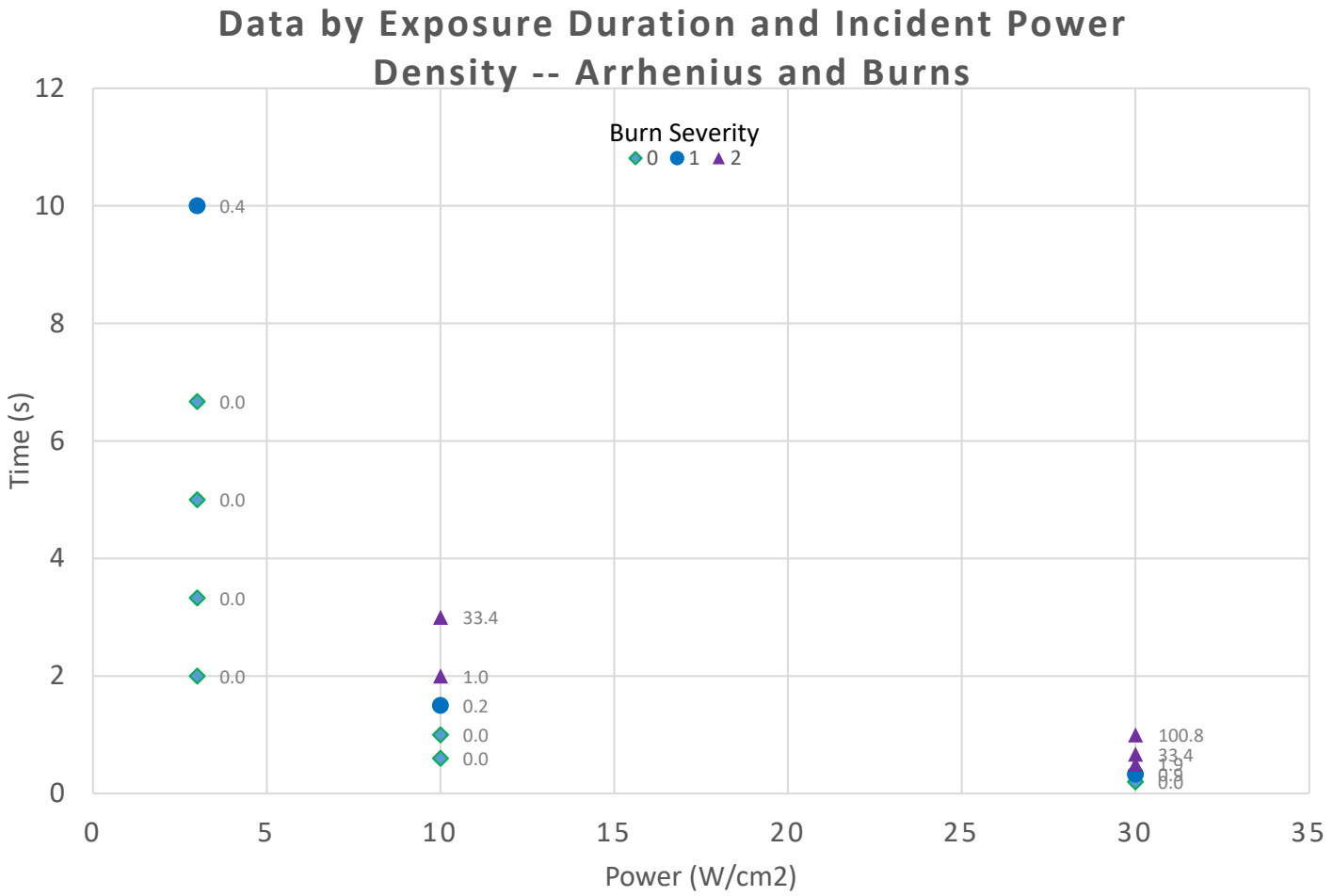
# Swine Skin Coupon Study
## Temperature Data



# Swine Skin Coupon Study
## Model Prediction (Static)



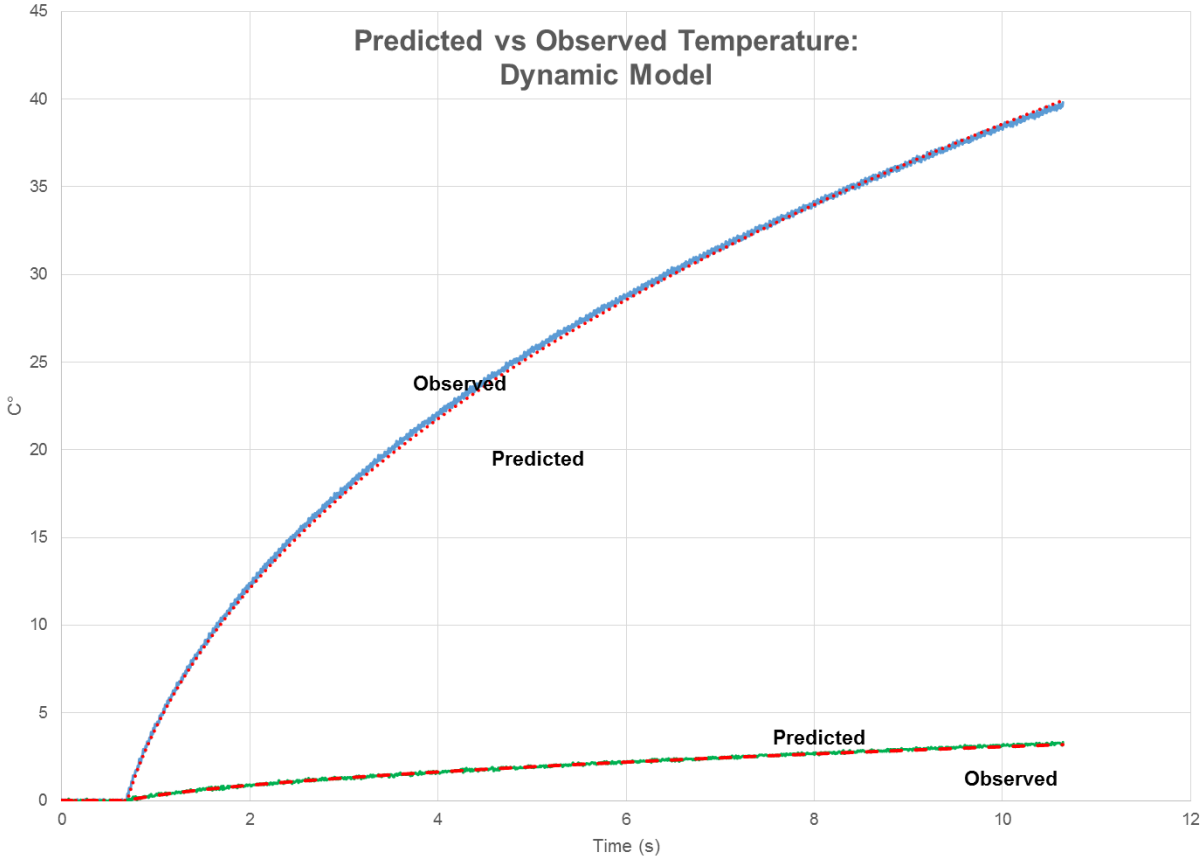
# Swine Skin Coupon Study
## Damage Metrics




- Arrhenius predictions match histopathology score
- Dose required to produce damage is a function of incident power density - Agrees with Diller and Pearce, 1999; Issues in modeling thermal alterations in tissues; Ann NY Acad Sci

# Swine Skin Coupon Study
## Results & Conclusions

- **Static tissue property model fails to predict the thermal kinetics at higher temperatures**
  - **Tissue properties/conduction coefficient change as temperature increases**
- **A dynamic model was created to include temperature dependent parameters**



# Next Steps: Panniculus Study

## Experimental Conditions

| | | EHF | | | | SHF | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Time(s) | | | | Time(s) | | | |
| | | 5 | 10 | 15 | 20 | 5 | 10 | 15 | 20 |
| Power(W/cm2) | 3 | | | | | | | | |
| | 30 | | | | | | | | |

## Apparatus

- SHF & EHF transmitters

## Procedures

- Recent abdominoplasty
- Arterially perfused with whole blood
- Samples exposed at normal body temperature

## Measures

- Histopathology
- Hydration

# QUESTIONS