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# ENERGY EXPENDITURE AND METABOLIC HEAT PRODUCTION STORAGE ESTIMATES OF TACTICAL LAW ENFORCEMENT PERSONNEL DURING CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR (CBRN) TRAINING



United States Army
Medical Research & Materiel Command

## DISCLAIMERS

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The study's purpose was to estimate energy expended and metabolic heat produced during tactical law enforcement CBRN training operations. These values will be used to establish a work standard for when encapsulated in PPE during CBRN missions or training. Knowledge of work standards can then be used for mission planning purposes (e.g., establishing work/rest cycles) or to estimate the cooling requirements needed to allow safe operations while wearing CBRN-PPE.
Male tactical law enforcement officers (n = 48, age: 40.9 + 6.5 yrs, wt: 88.6 + 12.0 kg, ht: 179 + 6.8 cm; mean + standard deviation) participating in typical CBRN training exercises with PPE served as volunteers.
Tactical law enforcement officers expended approximately 475 + 142 kcal during their ~2 hour training exercise. Estimated 24-hour daily EE was ~2420 kcal. Average rate of heat produced over the entire exercise (1 kcal/hr = 1.163 W) was 213 + 31 W. Peak metabolic heat production for activities lasting about a minute was estimated at 668 + 124 W.

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## EXECUTIVE SUMMARY

Tactical law enforcement personnel face harsh working conditions, especially in the warmer climates of the United States. These individuals may spend several hours working in fully encapsulated personal protective equipment (PPE) where ambient temperatures can exceed 38.8°C (100°F). The resulting thermal strain (i.e., elevated skin and core temperatures) can lead to an increased potential for heat illness and injury (e.g., heat exhaustion, heat stroke). The level of thermal strain imposed upon tactical law enforcement personnel is currently unknown. In addition, it is unknown how much metabolic heat (i.e., the amount of heat the body produces due to various activities) is typically produced during chemical, biological, radiological, and nuclear (CBRN) training or actual missions. However, anecdotal evidence suggests that missions and/or the health of tactical law enforcement personnel may be compromised. Thermal strain is affected by mission requirements, environmental conditions, clothing and equipment worn, and various individual characteristics such as whether a person is heat acclimated, their health status, percent body fat, and physical fitness. Metabolic heat produced is related to energy expenditure (EE) and varies based on levels of physical activity. **Study Goal:** The study's purpose was to estimate energy expended and metabolic heat produced during tactical law enforcement CBRN training operations. These values will be used to establish a work standard for when encapsulated in PPE during CBRN missions or training. Knowledge of work standards can then be used for mission planning purposes (e.g., establishing work/rest cycles) or to estimate the cooling requirements needed to allow safe operations while wearing CBRN-PPE. **Methods:** Male tactical law enforcement officers (*n* = 48, age: 40.9 ± 6.5 yrs, wt: 88.6 ± 12.0 kg, ht: 179 ± 6.8 cm; mean ± standard deviation) participating in typical CBRN training exercises with PPE served as volunteers. Activity type and the length of time of each activity were obtained from focus group interviews. Estimates of EE and metabolic heat production were determined by the factorial method using activity type, time performing that activity, body weight, and weight carried. Standardized EE prediction equations were used. Activity EE in kilocalories (kcal) were determined for each period of activity by individual. Total training day EE was estimated from the various activities an individual performed. Metabolic heat was estimated using a mechanical efficiency of 20% for human movement. **Results:** Tactical law enforcement officers expended approximately 475 ± 142 kcal during their ~2 hour training exercise. Estimated 24-hour daily EE was ~2420 kcal. Average rate of heat produced over the entire exercise (1 kcal/hr = 1.163 W) was 213 ± 31 W. Peak metabolic heat production for activities lasting about a minute was estimated at 668 ± 124 W. Typically, climbing stairs or running with heavy equipment was the cause of these peak periods of heat production. Individual plots showed large variability in the amount and pattern of metabolic heat produced. **Conclusions:** The average metabolic heat produced over the work day was low (~213 W) because of extended periods of sitting or standing. However, bursts of high energy activities fully encapsulated in CBRN gear, potentially in a hot environment, pose a thermal risk to these law enforcement officers. The use of CBRN-PPE notably increases the potential of heat illness.

## INTRODUCTION

The tactical law enforcement community is involved in a range of missions utilizing various types of personal protective equipment (PPE). They are also exposed to a wide range of environmental conditions. The use of chemical, biological, radiological, and nuclear (CBRN) protective ensembles, either with or without body armor, can add significant thermal stress due to the increased weight and insulating properties of these garments and head gear. High ambient heat conditions, especially with high solar loads, can lead to a rapid increase in body core temperature ($T_{Core}$). When encapsulated in PPE, the rate of evaporative heat loss is substantially diminished which can lead to more rapid increases in $T_{Core}$.

The use of CBRN-PPE is typically used when investigating clandestine drug laboratories (e.g., methamphetamine labs) or during suspected terrorist attacks that include a CBRN threat (4, 27). Since the chemical attack of the Tokyo subway system in 1995, increased attention to preparedness for CBRN disasters has been emphasized (12, 17). Recommendations have included the availability of chemical-resistant PPE to include clothing ensembles with masks, gloves and boots (17). While specific research has rarely documented the thermal strain of police or law enforcement personnel performing missions or training in CBRN-PPE, there has been research documenting the increased thermal strain associated with the wearing of similar equipment by military and fire-fighter personnel (6, 19). Standards for law enforcement use of CBRN-PPE are needed. In general, standards whether they are international, national, or job specific, have been recognized as a way of increasing the safety of workers (11, 18).

Thermal strain is dependent on many factors such as ambient temperatures, clothing worn, mission requirements and metabolic rates and other individual characteristics. Knowledge of these factors allows the prediction of thermal work strain, water requirements, and nutritional requirements (7). The military has established recommended time limits based on work levels (light to heavy) and various environmental conditions (7). These time limits are shorter when working in CBRN-PPE than when working in standard military uniforms because the biophysical insulation and water vapor permeability properties associated with CBRN-PPE increase the thermal strain to the individual. While collecting information regarding weather conditions, clothing and equipment, and personal characteristics (e.g., height, weight, and body fat composition) is relatively straightforward, obtaining an estimate of metabolic rate and metabolic heat production of individuals working in the field can be more challenging. Metabolic rate and metabolic heat production can be assessed through direct or indirect calorimetry, neither of which is practical with tactical law enforcement officers engaged in training or actual missions. Direct or indirect calorimetry requires special laboratories or outfitting the individual with body-worn devices to capture and/or analyze their expired gases (16). Use of doubly labeled water, while accurate and non-invasive is expensive and provides total daily EE rather than minute-to-minute or hourly values for EE (16). Heart rate and mechanical devices (e.g., pedometers and wrist-worn actigraphs) are non-invasive but the accuracy of these assessments can be problematic. For example, heart rates have shown some day to day variation with high ambient temperatures and emotions raising heart rates with little change in EE (16). Mechanical devices need to be calibrated for the individual and usually only are reasonable estimates of EE when the activity is locomotion, running, walking, or shuffling (16) and do not capture climbing, and lifting type activities (16). A non-invasive approach to assess metabolic rates in relatively small time increments is the factorial or diary method (16). These activity values are then compared to published metabolic rates listed by physical activities (2, 3) to determine EE and metabolic heat production (16) for the various activities engaged. A variant of this factorial method was used in this study as has been done previously in assessing the metabolic heat production of Border Patrol agents (9). This modified factorial method uses focus groups, whereby participants verbally recreate the activities they performed during a particular day of training or undergoing a mission. Use of focus groups have the advantage of having individuals that performed the same activities or were in the same vicinity as others hear what others say and then confirm, contrast, or correct what was said. This likely increased the accuracy of these post hoc self-reported activities.

The research objective was to estimate EE and metabolic heat produced during tactical law enforcement CBRN training or operations. These values will be used in establishing a work standard for tactical law enforcement personnel encapsulated in PPE during CBRN missions or training. Mission tactics might be altered to ensure the safety of the officers while encapsulated in CBRN-PPE. The publishing of standards would be the first step in allowing the entire tactical law enforcement community to use the best equipment and procedures during CBRN operations, reducing the risk of heat injury or illness to law enforcement officers.

## METHODS

Tactical law enforcement personnel participating in a typical CBRN training mission were studied. Upon completion of their mission(s) they were interviewed in a focus group to determine the various activities they performed during their training. From these activities a modified factorial method (16) of estimating EE was applied. Detailed methodology regarding the factorial method of estimating EE and metabolic heat production is described below.

### VOLUNTEERS

Forty-eight male volunteers were recruited from the Cincinnati Ohio ($n$ = 12), Orange County (Orlando) Florida ($n$ = 12), Phoenix Arizona ($n$ = 14), and the Massachusetts State Police ($n$ = 10) departments. Training occurred in the above cities with the Massachusetts training taking place at a Massachusetts State Police training facility in New Braintree, MA. Participants consisted of police officers or state troopers ($n$ = 28), police sergeants ($n$ = 8), master deputies ($n$ = 5), detectives ($n$ = 3), police deputies first class ($n$ = 2), and police specialists ($n$ = 2). Volunteers were briefed on the purpose, risks, and benefits of the study and gave their written informed consent prior to study participation. This study was approved by the Scientific and Human Use Review Committees at the U.S. Army Research Institute of Environmental Medicine.

Volunteers averaged 40.9 ± 6.5 (mean ± standard deviation) years of age and had 15.5 ± 7.3 years of tactical law enforcement experience. On average, they spent 8.0 ± 0.6 years at their present duty station. They weighed 89 ± 12 kg and were 179 ± 7 cm tall. They typically engaged in physical training, briefings, and other routine police tasks on a daily basis. Routine patrolling and responding to calls that did not result in the use of CBRN-PPE wear was not considered being engaged in an actual tactical law enforcement mission for the purpose of this study. Most volunteers that served on the tactical law enforcement team also completed non-tactical law enforcement missions. Only 14 participants reported taking part in an actual CBRN mission that required CBRN-PPE. In addition, most volunteers reported a CBRN training mission within the last six months ($n$ = 35). However, the remaining volunteers likely participated in CBRN training but did not respond to that question on the questionnaire (i.e., missing data).

Volunteers had run either a 2-mile run (16:03 ± 2:05 [minutes:seconds]) ($n$ = 25) or an alternative distance run of 2.4 ± 0.9 miles (18:18 ± 7:19) ($n$ = 8) for time within the last 6 months. The average per mile pace was 8:01 min/mile for those completing the 2-mile run and 7:38 per mile pace for other running distances. The longer run completed at a faster pace might be explained by these volunteers' time recorded in a local competitive road race, while the 2-mile run was a qualified physical training run. Estimated $VO_2\,max = 46.1\,ml \bullet kg^{-1} \bullet min^{-1}$ was based on the previously established relationship between two mile run for time and maximal oxygen uptake (15).

## EXPERIMENTAL PROCEDURE

Training in each location consisted of a morning and an afternoon session. Volunteers typically changed CBRN-PPE between sessions. Volunteers in the Cincinnati, Orange County and Phoenix training sessions wore either National Fire Protection Association (NFPA) Class 2 or Class 3 PPE. There were two types of Class 2 ensembles, the Lion MT94 (Lion Apparel, Dayton, OH) garment (Appendix A) and the Blauer (Blauer, Boston, MA) HS9420 garment (Appendix B). Both were navy blue in color. These garments weighed 2.1 kg. The lighter (0.9 kg) Class 3 Lion ERS (Lion Apparel, Dayton, OH) clothing ensemble (silver in color) was also worn. The Class 2 garment also has a higher insulating value compared to the Class 3 garment (10). The Class 2 systems provide more protection (equivalent to the Occupational Safety and Health Administration's (OSHA) Level B protection) (26), while the Class 3 is equivalent to OSHA's Level C protection (26). For the Cincinnati, Orange County, and Phoenix training, a total of 35 individuals wore the Class 2 PPE and 37 wore the Class 3 PPE. Of the 37 participants wearing the Class 3, three of them only wore the Class 3 PPE. Missing data reflect differences in participant numbers. Massachusetts personnel ($n$ = 10) wore their standard unclassified Rampart PPE (GENTEX, Simpson, PA) (Appendix D) for their two training exercises.

The training exercises consisted of riding in a vehicle to approach the scene of a simulated incident, short runs, breaching doors, checking multiple story buildings for potential threats, arresting suspected criminals, and dealing with health emergencies.

Slight differences existed between the scenarios and across training venues. Training was set by the leadership of each unit, but verified to represent the nature and duration of training done by these police departments. The shortest scenario (15 min) took place in Phoenix, AZ where the conditions were the most thermally stressful, while the longest scenario took place in New Braintree, MA (59 min) where the ambient temperature was cooler (Table 1).

Upon completion of the training exercises, volunteers filled out a brief background questionnaire. All information was obtained without the use of names, that is, only an assigned volunteer identification number. Data was gathered anonymously to enhance candor. Questions included demographic questions (e.g., age, height, and weight) and job experience questions (e.g., time served in tactical law enforcement, job position, and rank). Volunteers then participated in focus groups to reconstruct the various activities. Eight focus group sessions (two per city), with groups of five to seven individuals were held. These sessions were video-taped. The use of focus groups allowed individuals to describe the day's activities in detail, including time spent doing each activity and what they were wearing and carrying. The moderator(s) followed recommended guidelines for focus groups such as not using jargon, making sure all volunteers contributed their ideas and/or experiences, did not allow one participant to dominate the conversation, and validated each idea as important (1). Topics besides the re-constructing of a day's activities proceeded from general to more specific as has been recommended (14). The videos from the focus group sessions were transcribed to a written narrative. From these narratives, data files were constructed that included activity, time engaged in each activity, body weight, weight carried, and environment the activity took place in (e.g., sitting in a car, walking upstairs).

During the focus group sessions, volunteers were asked to provide a subjective rating of the maximum level of heat stress they experienced during the day's activities. The heat stress scale was presented verbally on a one to ten scale. A "1" was defined as no heat stress such as being in an air conditioned office and a "10" was defined as the heat stress imposed that would push a person to the point of heat exhaustion where they felt they might pass out. Other questions asked included what were the most strenuous missions they had participated in, number and nature of previous heat injuries, issues associated with proper fluid requirements, and amount of sleep obtained the night before the day's activities.

The local weather during the experiments varied greatly among the four different locations. There were also slight variants during the course of the experiments because of the length of the exercises. For example the Orange County, FL exercise took approximately 40 min from the time all volunteers had their equipment on and began moving to their objective until they returned to the safe area and began removing their CBRN-PPE. The Phoenix, AZ in contrast only took approximately 15 min. Table 1 shows the weather during the trials, which all took place over the course of approximately four hours. Weather data was obtained from http://www.wunderground.com (accessed on 11 August 2011).

**Table 1.** Local weather data by training city for the duration of the exercise.

| City | Temperature (°C) | Wind Speed (km/h) | Humidity (%) |
|---|---|---|---|
| Cincinnati, Ohio | 8.9 – 17.8 | 0.0 | 35 – 80 |
| Orlando, Florida | 26.1 – 30.0 | 16.7 – 24.1 | 51 – 72 |
| Phoenix, Arizona | 33.3 – 42.8 | 0.0 – 16.7 | 4 – 20 |
| New Braintree, Massachusetts | 2.9 – 4.4 | 11.1 – 22.2 | 86 – 100 |

## CALCULATIONS

A MET level was assigned to each physical activity by matching the activity to the closest activity in Ainsworth et al.'s (2, 3) compendia of physical activities. Activities in the compendia are expressed in terms of MET levels of EE. A MET is defined as the ratio of metabolic work rate to a standard resting metabolic rate (16). Therefore, 1 MET = 1.0 kilocalorie (kcal) x body weight in kg per hour. For example, for an 80 kg person, sitting in a chair for an hour expending 1 MET, would equate to them expending 80 kcal for that hour. To calculate metabolic heat production, a mechanical efficiency of muscular work of 20% was assumed (21, 23). Therefore, total kcal expended was multiplied by 0.8 to represent that 80% of the kcal were expended as heat, while 20% of the kcal were expended in useful mechanical work. Energy expenditure values are expressed as kcal. Metabolic heat production was converted to watts (W) of heat produced. The standard conversion equation of 1 kcal/hr equals 1.163 W was used.

## DATA ANALYSIS

Data are presented as average W of heat produced over the course of the work day, and absolute peak W of heat produced regardless of the length of time of a particular activity. Descriptive statistics are presented as means ± standard deviations (S.D.) and minimums (Min) and maximums (Max). A one-way analysis of variance (ANOVA) with Tukey's post hoc test was used to identify significant differences in the maximum thermal discomfort felt during the day between training locations.

# RESULTS

The CBRN events were estimated to have an average duration of 2.0 ± 0.5 hr. The average active EE among participants was 475 ± 142 kcal during the exercise. Active EE was the energy spent doing the various CBRN activities including preparing for and concluding the activity. That is, retrieving the CBRN-PPE and putting it on prior to the exercise and taking it off at the conclusion of the exercise. Resting EE was the time not involved in the exercise. A rough estimate of total daily EE would be about 2420 kcal calculated by adding estimated active EE to estimated resting EE (~ 1920 kcal). Resting EE was calculated as resting EE (1 MET) multiplied by body weight and number of hours of non-active EE. Volunteers reported sleeping 6.8 $\pm$ 1.3 hours prior to the assessment day and this estimate was used in the calculations of total daily EE.

## METABOLIC RATES

Metabolic heat production unlike EE cannot be summed because watts are associated with time. Therefore, a specific time period of interest needs to be established. There are three time periods where calculations have been determined, 1) average for the whole training time period including the time spent putting on the CBRN-PPE, 2) peak metabolic heat production where the duration of activity was ten minutes or greater, and 3) peak metabolic heat production. Table 2 is a summary of all exercises while Table 3 is a breakdown by training location. The longest activity was generally getting dressed while standing. In Cincinnati, officers were directed exactly how and when to put their boots on, pull up the suit, put on the mask, etc., so the overall time was the same for all individuals but the longest in duration. In the other locations all officers started at approximately the same time but there was some small variability in the time it took to dress and that is reflected in the SD for each location. The training exercises were the same for all officers within each location with small variations, as officers worked in tactical teams. The teams executed the mission with coordinated tactics as they would do an operational mission. As noted above, the shortest duration exercises were in Phoenix with each exercise lasting between 15 and 20 minutes. Therefore, for the 1 hour and 22 minutes of training in the CBRN-PPE recorded, about 37 minutes consisted of the actual exercise and 45 minutes was donning the CBRN-PPE. However, in calculating metabolic heat production for the whole exercise, it was determined that keeping track of the time it took to put the equipment on was important as putting on and standing and even moving slowly with the weight of body armor and breathing apparatus air tanks could generate significant metabolic heat. During the exercise some of the activities required assuming a defensive posture position of standing or lying prone. These activities generated low levels of metabolic heat. Extended activities such as walking/checking the perimeter of a location were often broken up by repeated security checks involving kneeling or standing still for short periods of time.

**Table 2.** Estimated average rates of metabolic heat production during the work day, and peak rates of metabolic heat production for all volunteers for all locations.

| | Work Day Average | | | Peak $\geq$ 10 Minutes | | | Peak | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\pm$ S.D. | Min | Max | $\pm$ S.D. | Min | Max | $\pm$ S.D. | Min | Max |
| **Heat Produced (W)** | 213 $\pm$ 31 | 159 | 299 | 210 $\pm$ 31 | 154 | 306 | 668 $\pm$ 124 | 260 | 980 |
| **Total Time (h:min)** | 2:04 $\pm$ 0:29 | 1:20 | 2:29 | 0:26 $\pm$ 0:06 | 0:11 | 0:34 | 0:02 $\pm$ 0:01 | 0:01 | 0:06 |

**Table 3.** Estimated average rate of metabolic heat production during the work day, and peak rates of metabolic heat production by training city.

| City | | Metabolic Heat Average | | | Peak ≥ 10 Minutes | | | Peak | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ± S.D. | Min | Max | ± S.D. | Min | Max | ± S.D. | Min | Max |
| Cincinnati, Ohio | Heat Produced (W) | 209 ± 35 | 162 | 299 | 212 ± 36 | 166 | 306 | 694 ± 127 | 530 | 980 |
| | Total Time(h:min) | 2:29 ± 0:00 | 2:29 | 2:29 | 0:50 ± 0:10 | 0:40 | 1:00 | 0:01± 0:00 | 0:01 | 0:02 |
| Orlando, Florida | Heat Produced (W) | 217 ± 28 | 169 | 260 | 238 ± 42 | 169 | 304 | 650 ± 151 | 260 | 810 |
| | Total Time(h:min) | 2:14 ± 0:07 | 2:07 | 2:20 | 0:23 ± 0:12 | 0:11 | 0:34 | 0:02± 0:01 | 0:02 | 0:06 |
| Phoenix, Arizona | Heat Produced (W) | 196 ± 24 | 159 | 244 | 192 ± 23 | 154 | 237 | 617 ± 79 | 493 | 760 |
| | Total Time(h:min) | 1:22 ± 0:02 | 1:20 | 1:24 | 0:26 ± 0:00 | 0:26 | 0:26 | 0:01± 0:00 | 0:01 | 0:01 |
| New Braintree, Massachusetts | Heat Produced (W) | 233 ± 29 | 197 | 291 | 210 ± 21 | 188 | 254 | 733 ± 119 | 602 | 913 |
| | Total Time(h:min) | 2:22 ± 0:03 | 2:17 | 2:28 | 0:31 ± 0:00 | 0:31 | 0:31 | 0:02 ± 0:01 | 0:01 | 0:03 |

Individual charts of the volunteers' estimated metabolic heat outputs over time are provided as Appendix E. These charts show large differences in activity patterns over time for each individual. Additionally, there are large differences among individuals in the patterns of metabolic heat production. Because individuals were engaged in similar activities, the source of differences in EE and metabolic heat production was primarily associated with differences in body weight on the size of the individual and the amount of weight carried. For example, individual body weight ranged between 66.4 kg and 131.8 kg.

When volunteers subjectively rated the maximum thermal discomfort they experienced during the day's activities on a ten point scale (1 = no thermal discomfort to 10 = maximum thermal discomfort you could experience before passing out) officers reported a mean rating of 5.5 ± 2.0 when wearing the Class 2 PPE and a mean rating of 4.4 ± 1.2 when wearing the Class 3 PPE. All individuals reported an increase in heat strain as the external temperature increased, regardless of the type of PPE they were wearing. Subjective ratings of the heat stress were significantly greater for Cincinnati (7.0 ± 1.6), Orange County (6.6 ± 0.7), and Phoenix (5.8 ± 0.9) compared to Massachusetts (2.6 ± 0.7) ($p < 0.01$). While Phoenix had the hottest environmental temperatures, the training exercise was the shortest. Orange County had a longer training exercise than Cincinnati but volunteers were encapsulated the longest in Cincinnati waiting for the actual exercise to begin. One individual was treated for symptoms of heat exhaustion during the Orange County training exercise. Very few individuals ($n = 4$; 8%) had experienced heat illness or injury prior to this exercise either during actual police training or non-police training (e.g., playing sports, military, other work or personal activities).

## MOST STREUNOUS ACTIVITIES REPORTED

Volunteers were asked how typical the activities were during the period of observation compared to their other tactical training events. Participants noted that often they carried significantly more weight than what they carried during this evaluation which was 31.6 $\pm$ 1.7 kg. They estimated they typically carried 4.5 to 6.8 kg (10 to 15 lbs) more weight than during this exercise. In the focus group session they were asked: “What is the most strenuous activity that you have done on this job in the last year?” to assess what might be the highest levels of metabolic heat produced during CBRN activities. Activities varied depending on the location of the volunteers, but some officers reported being in CBRN-PPE for two to three hours searching a property for chemical or biological hazards. One officer also reported clearing out a marijuana growing facility fully encapsulated for 2.5 hours, carrying up to 13.6 kg.

## OTHER COMMENTS

Participants in this study were aware of the importance of hydration to prevent heat illness and injury. Officers made an effort to stay hydrated during the exercise, drinking water when possible and when they felt it was necessary. During the assessment period the test volunteers consumed 5.4 $\pm$ 7.3 liters of water but this included water consumed before and after the actual training exercise when they were donning and doffing the CBRN-PPE (i.e., in-between the morning and the afternoon sessions). Often officers reported that they were unable to consume water during the actual exercise because of the impediment caused by the breathing apparatus they were wearing. Yet, they reported they would have liked to have been able to drink during the exercise if it was possible. All officers reported consuming liquids after the exercise concluded. Table 4 is a list of open-ended comments made by tactical law enforcement officers during the focus group. Most comments focused on the inability to drink with the breathing apparatus employed.

**Table 4.** Open-ended comments made by tactical law enforcement personnel.

| Response | *n* |
|---|---|
| I was unable to drink water with my breathing system but would have liked to. | 16 |
| The only personal protective equipment we have is outdated and the new ones are inappropriate for actual missions. We are actively looking for new personal protective equipment but have been unable to find ones that we like. | 3 |
| We normally carry much more weight. The movements were similar to a typical mission but not the equipment. | 3 |
| The biggest factor in heat strain was not the activity but the type of suit worn. | 3 |
| I sweat so much in the blue suit it literally poured out of the suit when I took it off. | 1 |

## DISCUSSION AND CONCLUSIONS

This study provided reasonable estimates of the metabolic heat produced during tactical law enforcement officers' training in CBRN-PPE. The total daily EE of approximately 2420 kcal/day was less than most military exercises (25) and Border Patrol missions (9). These exercises of tactical law enforcement activities are short compared to most of the previously studied military field training scenarios. However, their day did involve sporadic bursts of high EE in CBRN-PPE. When examining the metabolic heat production of these officers, it should be noted that the average heat production over the course of a day is rather low because of extended periods of time sitting or standing. However, during peak activities, metabolic heat production was elevated. For example, volunteer #307 who weighed 108 kg during an approach run to a building had a burst of metabolic heat produced that exceeded 900 W (see individual chart on Page 29 in Appendix E). Bursts of activity of less than 10 minutes may not pose a significant problem with regard to the thermal strain experienced by these officers under normal conditions. However, when dressed in CBRN-PPE and combined with hot environmental conditions, the risk of heat illness or injury is a real possibility.

While thermal strain can increase the risk of heat illnesses or injuries, it can also decrease mental and physical performance. Performance of operational tasks is already degraded because of the encumbrance of the CBRN-PPE, especially the use of protective gloves and masks (8,20). Physical performance in fire-fighters wearing similar CBRN-PPE as used on this study was shown to be compromised (22, 24). The addition of thermal strain increases the degradation in tasks requiring physical (21) and cognitive abilities (13). These effects could have devastating consequences to law enforcement personnel who are investigating, disarming criminals or coming to the aid of victims in a contaminated environment, whether a clandestine drug lab or an area that has been affected by a chemical or other threatening agent attack.

Heat dissipation of tactical law enforcement personnel is compromised by the clothing and equipment they wear. On the one hand heavy equipment, such as weapons and ammunition and body armor, reduces the risk of injury or death from altercations with suspected drug dealers or suspected terrorists, but on the other hand increases the risk of thermal injuries because of the weight, encumbrance and insulation factors associated with its use or wear. The equipment and CBRN-PPE worn by these tactical law enforcement officers inhibits air circulation, trapping moist warm air close to the body decreasing evaporative cooling. Sweat rates may reach up to two liters per hour (7), but the sweat must evaporate to result in heat dissipation and body cooling.

Elevated core temperatures because evaporative cooling is compromised has been documented in Marines on patrol in Iraq wearing properly secured body armor (5). When Marines knew the risk of attack was low, they opened the front of their body armor, increasing air flow next to the body. This resulted in lower core body temperatures (5). The body armor worn by tactical law enforcement personnel could not be opened up or taken off because it is often worn under the CBRN-PPE. One solution to reduce the heat strain would be to design body armor that is worn on the outside of the CBRN-PPE. This would allow it to be easily removed when the threat of gunfire or other ballistics projectiles has been removed, but with a CBRN threat still present necessitating the use of the CBRN-PPE. If body armor could easily be removed, lowering the weight carried and its associated cost in metabolic heat production, it would lower the risk to thermal injury. Furthermore, by having the armor on the outside of the CBRN-PPE, critical time could be conserved from surveying a contaminated area by not having to retreat from that area to go through the whole decontamination process, just to remove the body armor.

Other studies have been conducted with firefighters in PPE (22, 24). In a study where firefighters were assigned to a 16 minute task in standard firefighting PPE in either a neutral or hot condition; those in the hot condition showed a significantly slower recovery (22). It may be deduced that tactical law enforcement officers working in hot conditions face similar challenges in trying to recover physiologically from the demands of their mission. The thermal strain of working in encapsulating gear continues after the exercise is completed, especially when coupled with dehydration. Fluids lost by sweating must be fully replaced or else dehydration will occur. Individuals performing moderate physical activity should consume 6-8 quarts of water a day and those engaged in extreme physical activity require 9-12 quarts of water in a temperate climate (7). During the exercise there was great variability in the amount of fluid consumed. Law enforcement personnel consumed only 5.4 $\pm$ 7.2 liters (approximately 6 quarts) of water throughout. Several officers used on-the-move hydration systems such as a Camelbak system (Camelbak Products LLC, Petaluma, CA) and several others reported carrying water bottles. Water bottles are not a feasible means of hydration if the officers are required to be in CBRN-PPE for an extended period of time. Many officers reported that their masks did not allow them to use a hydration system compromising hydration levels. The inability to hydrate increases these officers risk of dehydration and heat complications. A possible fix is to incorporate a breathing apparatus that could allow for the drinking tube of a hydration tube to be passed through the mask.

This study focused on heat production values obtained from officers from several tactical law enforcement locations. Weather differences in various locations and/or the various types of emergencies may lead to different estimates of metabolic heat produced. It should be noted that the actual training conducted in this study while in the hotter environmental conditions was very short. However, there were periods of high metabolic work and some law enforcement personnel did exhibit signs of heat strain during the training with one officer having to be removed from training in the Orange County exercise due to this thermal strain. The standards developed for the level of activity likely to be performed, and the ability to perform safely should be related to the environmental conditions. This report does not set forth any standards. Rather, it provides the estimates of metabolic rates and associated heat production from which standards can be developed. In turn, these estimates will allow for mission management or guidelines towards developing cooling systems.

Metabolic heat production was determined for tactical law enforcement personnel in four different training events wearing unclassified CBRN-PPE as well as NFP Class 2 and Class 3 CBRN-PPE. Environments and missions differed substantially, most notably between the Massachusetts State Police and Phoenix, AZ Police training exercises.  Differences, in metabolic heat produced, weather conditions, length of mission, and CBRN-PPE worn all lead to differences in the thermal strain experienced by tactical law enforcement personnel.  This report provides estimates of metabolic heat produced.  It addresses some of the factors that influence metabolic heat produced such as the type of activities engaged in, weight of the individuals, and weight of equipment worn or carried.  However, it does not address the thermal strain experienced by tactical law enforcement personnel.  To get a more accurate prediction of thermal strain and the ramifications associated with the environment or equipment worn, thermoregulatory predictive models should be used to predict core temperature changes that might be experienced by these personnel for a given set of parameters.

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## APPENDIX A

## NFPA Class 2 Lion MT94 CBRN Garment

The LION CBRN MT94 provides vapor, liquid, and FR protection for chem/bio incidents and is certified to meet NFPA 1994/Class 2 and NFPA 1992. The MT94 guards against exposure to hazardous waste, drug labs, biological threats, and domestic terrorism agents.

- Rugged GORE™ CHEMPAK® Ultra Barrier fabric features thin, lightweight, and high-strength PTFE film sandwiched within tough DuPont™ Nomex® outer and inner layers.
- Streamlined design and light weight deliver optimum comfort and natural freedom of movement.
- Rugged construction allows you to perform in the most challenging of circumstances.
- Re-usable for multiple wears and washings, if not exposed or contaminated.
- Certified for use with Gore G9492 gloves and OnGuard HAZMAX® 87012 Boots.
- Navy or tan color.
- Hook and loop belt loops to hold equipment belt securely.
- ID patches on chest and shoulders for hook and loop mounted badges.
- Roomy thigh pockets.
- Hook and loop wrist and leg cuff adjustments for secure fit.
- National Tactical Officer's Association (NTOA) Member Tested and Recommended



Information from obtained from company (Lion Apparel, Dayton, OH); Website at: http://www.lionprotects.com/ (Accessed 15 September 2011).

# APPENDIX B

## NFPA Class 2 Blauer HZ9420 CBRN Garment

**HZ9420 Multi-Threat Ensemble**
Blauer's HZ9420 Multi-Threat ensemble offers the highest level of protection in the Homeland Defender® line from liquid, vapor, and particulate forms of CBRN challenge agents. The HZ9420 is made of GORE® CHEMPAK® Ultra-barrier fabric and is certified to NFPA 1994 (2007 Ed.) Class 2 for protection against chemical warfare agents (CWA's) and toxic industrial chemicals (TIC's) at concentrations at or above IDLH when worn with approved SCBA systems and footwear. For added protection, this revolutionary non-permeable membrane is laminated to a 4.5 ounce NOMEX IIIA outer shell, which provides excellent static dissipative performance and resists melting, dripping, and burning when exposed to high heat and flame.

**Superior Heat Stress Management**
First responders and HAZMAT teams typically must deal with heat stress and elevated core body temperatures caused in large part by their PPE ensembles, which trap body heat and interfere with the body's sweat response. The HZ9420 Multi-Threat suit effectively alleviates this problem through a unique "evaporative cooling" capability. The NOMEX® IIIA outer shell has been engineered to absorb water without affecting the integrity or protective performance of the underlying GORE® CHEMPAK® barrier. By wetting the suit down with water before or during use, the wearer benefits from a natural cooling effect similar to sweating as the water evaporates from the outer shell.

Information obtained from company (Blauer Protection) website: http://www.blauer.com/ (Accessed 15 September 2011).

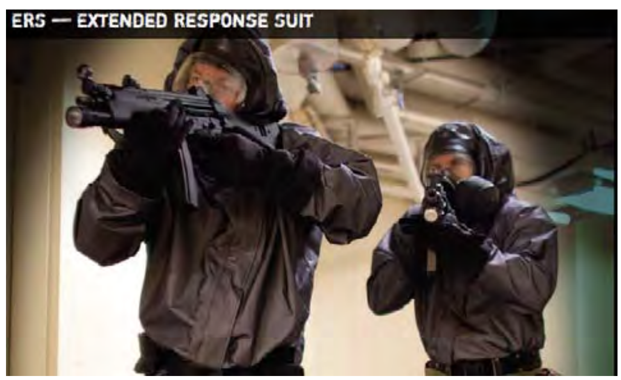
# APPENDIX C

## NFPA Class 3 Lion ERS CBRN Garment

The LION ERS is a rapid response certified CBRN ensemble with a Selectively Permeable Fabric (SPF) that is liquid proof, air permeable and breathable — keeping you protected and comfortable. Because it's a one-piece coverall with attached Gore® glove liners and booties no taping is required, so you're ready for a quick deployment.

ERS Features:

- Protection against NFPA 1994, Class 3 TICs, TIMs & CWAs
- Added mission time due to breathable membrane
- High strength W.L. Gore® fabric and seams
- Long shelf life, non-carbon based technology
- Certified to NFPA 1994, Class 3 standard (2007 Edition)
- Premium glove system with Nomex® outer glove for optimal dexterity and durability
- Air-tight zipper keeps both liquid and vapors out




The ERS (Extended Response Suit) is designed with maximum comfort and protection in mind. The one-piece, front-entry suit is easily stowed in a vehicle to facilitate the most immediate deployment possible and can be worn for an extended period of time.

The ERS is made with lightweight GORE® CHEMPAK® Selectively Permeable Fabric and is certified for "warm zone" operations where hazardous chemical and biological agents are anticipated or identified. The ERS protects against lower levels of vapor and liquid concentrations that may be encountered in the "warm zone" when deployed with the proper ensemble elements. Certified to NFPA 1994, Class 3.

- **Value-added features deliver maximum dexterity and highest protection factor for Class 3 ensembles**
- **One-piece, lightweight design easily compacts for storage**
- **Certified to NFPA 1994, Class 3 for warm zone operations**

## FEATURES

- GORE™ G9492 glove system with Nomex® outer glover resists tearing and allows for added dexterity
- Air-tight zipper provides premium vapor and liquid protection
- Durable GORE® CHEMPAK® Selectively Permeable Fabric provides protection below IDLH concentration levels against TICs and CWAs while performing tactical operations
- Sleek, one-piece, lightweight design
- Front-entry design for ease of donning
- Fully sealed seams eliminates need for taping
- 8-hour wear life if not damaged, exposed or contaminated

## APPLICATIONS

- Perimeter security and crowd control
- Extended decontamination
- Patient processing

## ERS SPECIFICATIONS

| | |
|---|---|
| Certification: | NFPA 1994, Class 3 |
| Zone: | Warm |
| Systemic Physiological Protective Dosage Factor ($PPDF_{sys}$): | 6346 $PPDF_{sys}$ (average) |
| Garment design: | 1-piece, front-entry |
| Respiratory system: | Contact Lion at CBRN@lionapparel.com for options |
| Hand protection system: | GORE™ G9492 glove system with GORE® CHEMPAK® Ultra Barrier Fabric worn under Nomex® outer glove |
| Foot protection system: | Integrated bootie with GORE® CHEMPAK® Selectively Permeable fabric; OnGuard HAZMAX® boot |
| Barrier technology: | GORE® CHEMPAK® Selectively Permeable Fabric |
| Storage life: | Up to 10 years |
| Multi-use: | Yes, 8-hour wear life if not damaged, exposed or contaminated |
| Training suit available: | Yes |

## BARRIER CHEMICAL PERMEATION PERFORMANCE

GORE® CHEMPAK® Selectively Permeable Fabrics as used in ERS Suit

| Challenge Chemical | Challenge Level | Endpoint µg/cm² | 8 Hour Cumulative Results |
|---|---|---|---|
| Acrolein | 40 ppm | 6 | < .01 µg/cm² |
| Acrylonitrile | 40 ppm | 6 | non-detect |
| Ammonia | 40 ppm | 6 | non-detect |
| Chlorine | 40 ppm | 6 | < .02 µg/cm² |
| Cyanogen Chloride | 40 ppm | 6 | non-detect |
| Dimethyl Sulfate | 10 g/m² | 6 | non-detect |
| Hydrogen Cyanide | 40 ppm | 6 | non-detect |
| Mustard (HD) | 10 g/m² | 4 | < 0.2 µg/cm² |
| Phosgene | 40 ppm | 6 | non-detect |
| Sarin (GB) | 10 g/m² | 1.25 | < .02 µg/cm² |
| Soman (GD) | 10 g/m² | 1.25 | < .01 µg/cm² |
| Tabun (GA) | 10 g/m² | 1.25 | < .01 µg/cm² |
| VX | 10 g/m² | 1.25 | < 0.3 µg/cm² |



WARNING: Never wear the garment without the correct respirator, footwear, gloves, hood or belt; never wear the Garment without all elements in place. The garment alone does not provide protection against all chemical and biological hazards. CBRN ensembles provide no protection against flame. CBRN ensembles provide limited protection against, abrasion, puncture, bodily fluids, other liquids and gases. No products, including garments, footwear or handwear, can offer absolute protection, even when new, and their protective performance will decline with wear, tear, abrasion, and other damage associated with use. W. L. Gore & Associates, Inc. and Lion Apparel, Inc. make no guarantee of how the product will perform in actual use.



GORE Chempak. FABRIC

DuPont™ NOMEX®

LION APPAREL

6450 Poe Ave. / Suite 300 / Dayton, OH, 45414
Main: 937/898-1949 / Fax: 937/415-2936
Toll Free: 800/548-6614
CBRN@lionapparel.com
www.lionapparel.com

Information from obtained from company (Lion Apparel, Dayton, OH) Website at: http://www.lionprotects.com/ (Accessed 15 September 2011).

# APPENDIX D

## Unclassified Rampart Chemical Biological Garment

### Product Overview

The Rampart® Chemical Biological Defense Overgarment is a two-piece system comprised of a coat and trousers designed to be worn as a duty uniform by tactical users, including Special Weapons Assault Teams (SWAT) and First Responders.

Originally designed for the U.S. Department of Energy SWAT, the coat and trousers are more form-fitting than the U.S. Department of Defense JSLIST garment.

The overgarment system has been member tested and member approved by tactical users, such as the National Tactical Officers Organization (NTOA). The system also meets performance requirements similar to those required in the JSLIST program. Overall, wearers are offered protection against chemical and biological agents in a system that is lightweight, launderable and permeable to provide the lowest possible level of heat stress for a system of its type.

The coat features a functional hood which interfaces with several respirators, including the MSA-Millennium, M40, M50, M53 and MCU-2P. The coat is also specially tailored shorter than other tactical garments, preventing interference with the wearer's utility belt. The waistband and wrists feature Velcro® tabs for further fitting adjustments. Zippered pockets on the front chest area offer access and storage of essential tactical gear and accessories. The coat is first secured closed with a nylon zipper and then a Velcro® overflap.

The trousers feature a high bib-style waist, extra-wide, adjustable suspenders and zipper closures at the leg bottoms. Flapped pockets are featured at both hips for additional tactical gear and accessories.

The coat and trousers both feature additional fabric layers at the greater wear areas - elbows and ankles.

The standard color is solid navy. U.S. Woodland and Desert Camouflage, as well as other colors are available for the outer shell fabric. The Rampart Overgarment coat and trousers are packaged and sold separately. Sizes may be mixed and matched for each individual wearer.

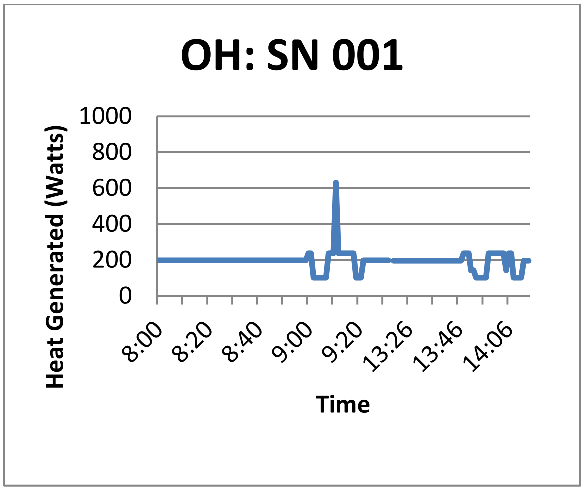
Information obtained from company (GENTEX, Simpson, PA) Website at: http://www.gentexcorp.com/default.aspx?pageid=358 (Accessed 15 September 2011).

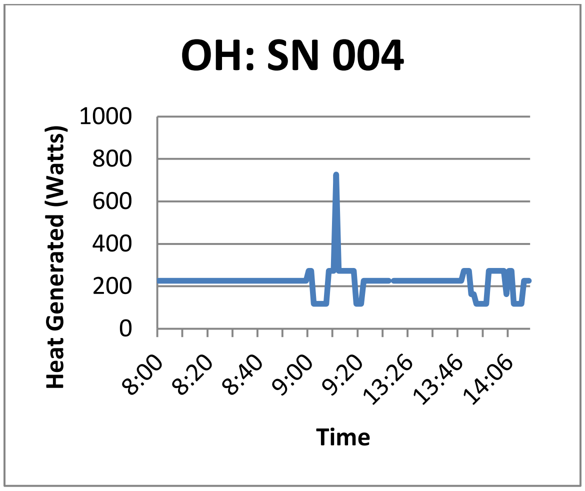
# APPENDIX E

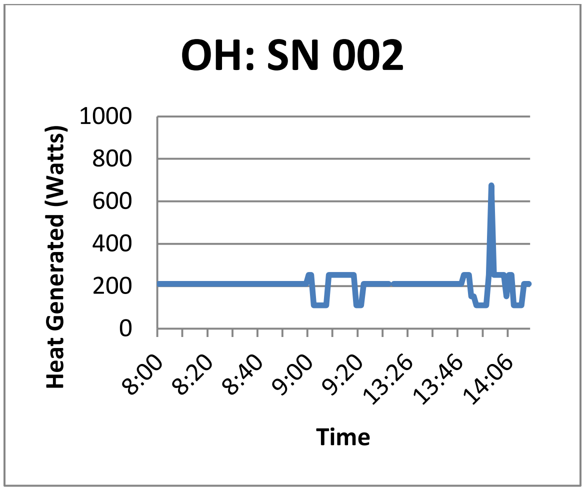
## INDIVIDUAL PARTICIPANTS' METABOLIC HEAT GENERATED FROM WORK ACTIVITIES OVER THEIR ENTIRE WORK DAY

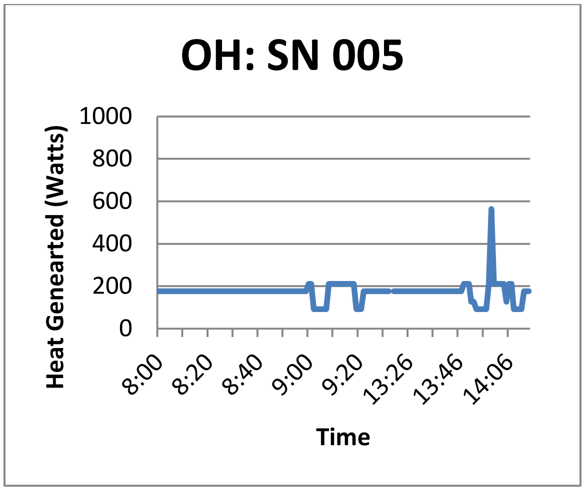
Note: There are small differences in timelines because groups of individuals worked in teams. The team missions while coordinated with other teams may have been off by 1 to 5 minutes from another team's mission.

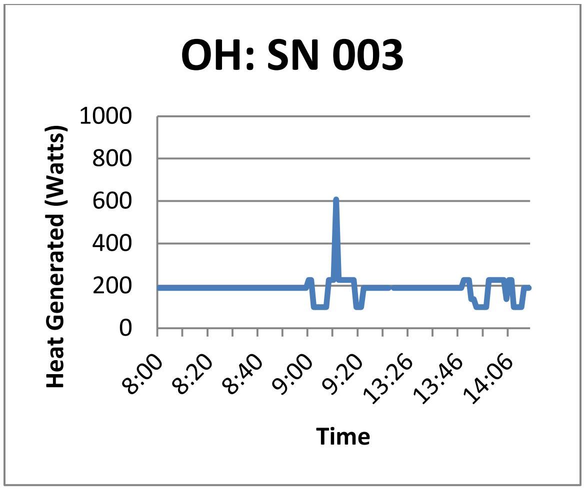
**Cincinnati, OH**

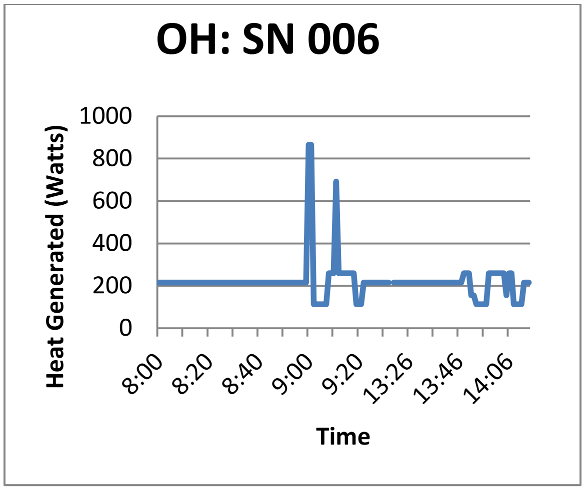


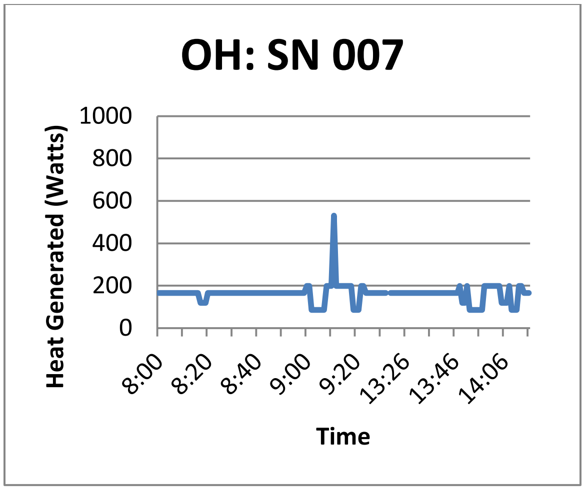

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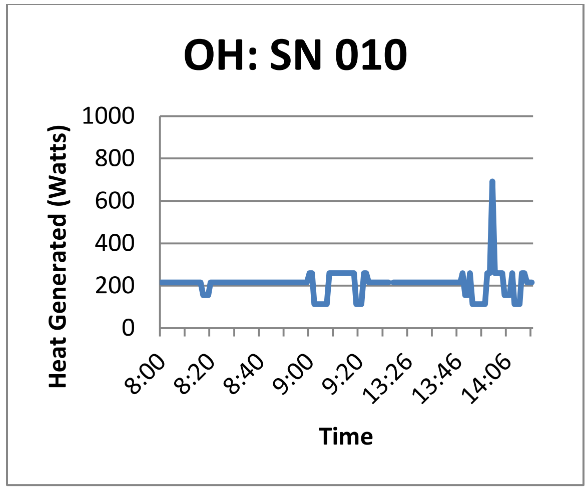
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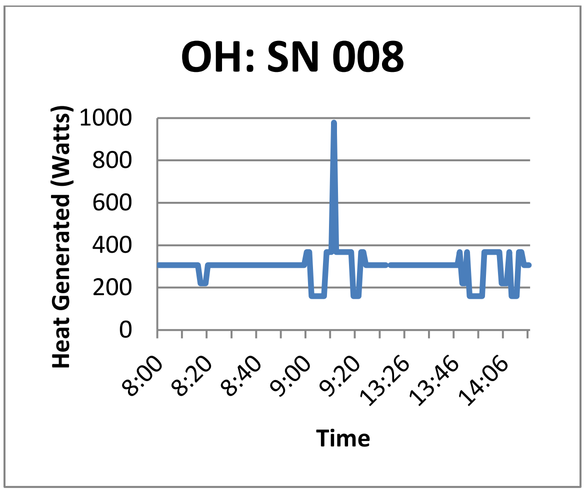
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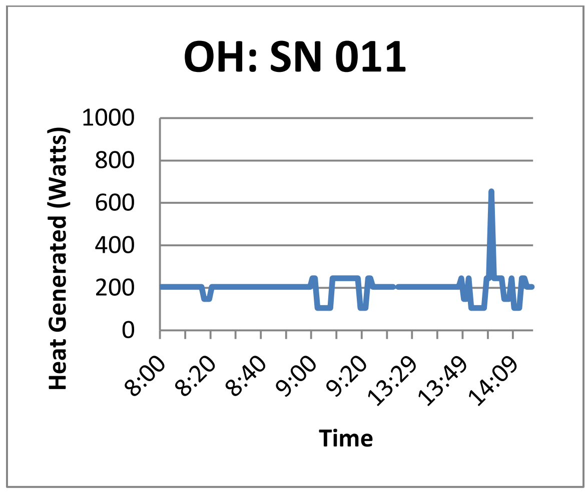
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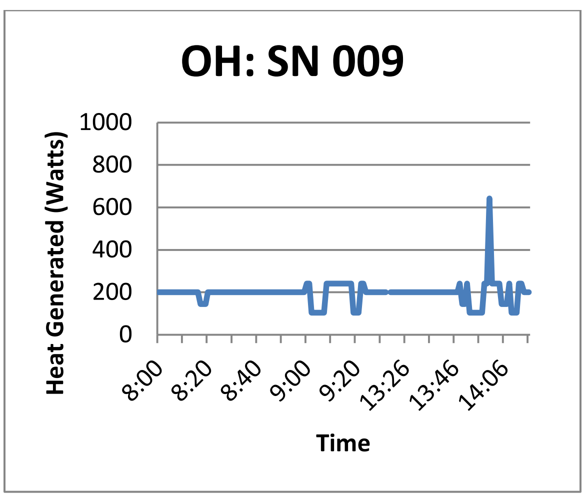
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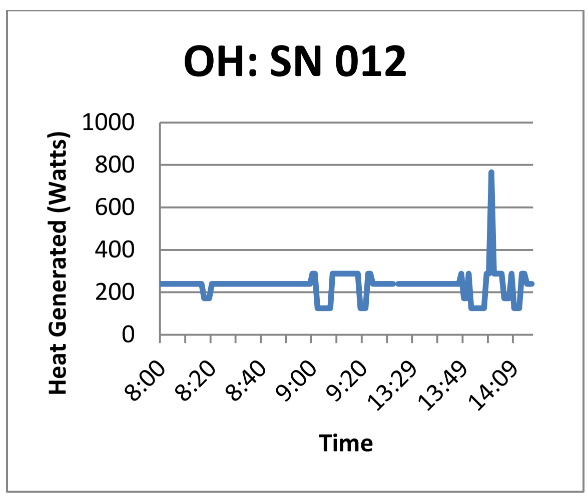
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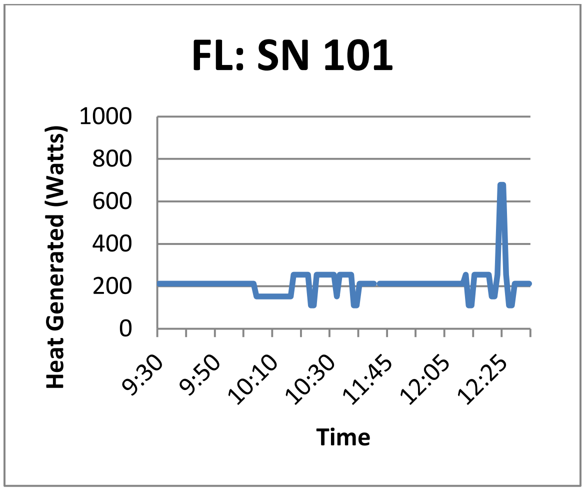
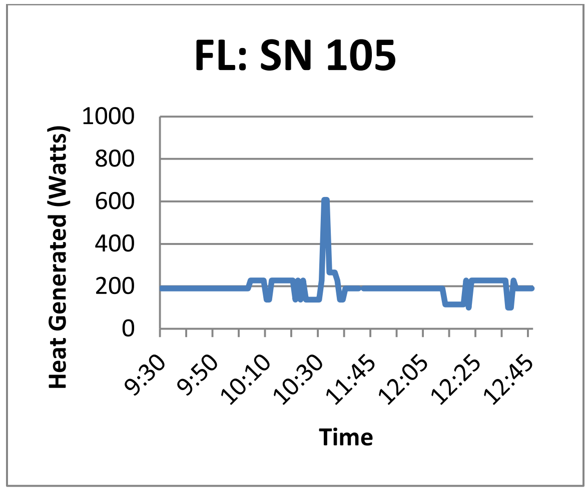
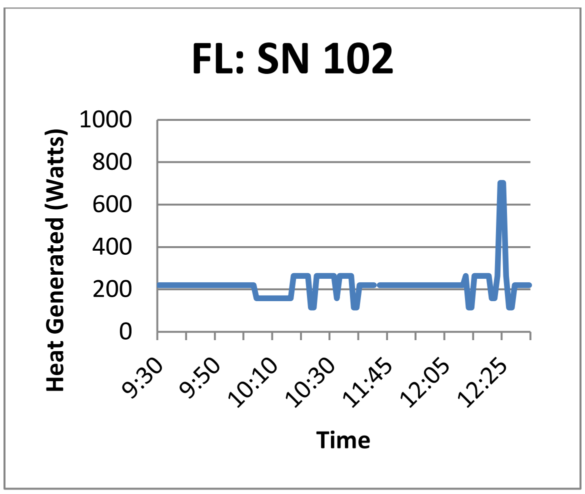
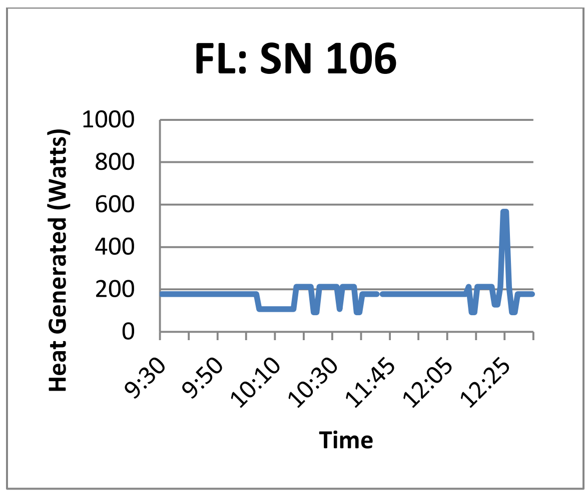
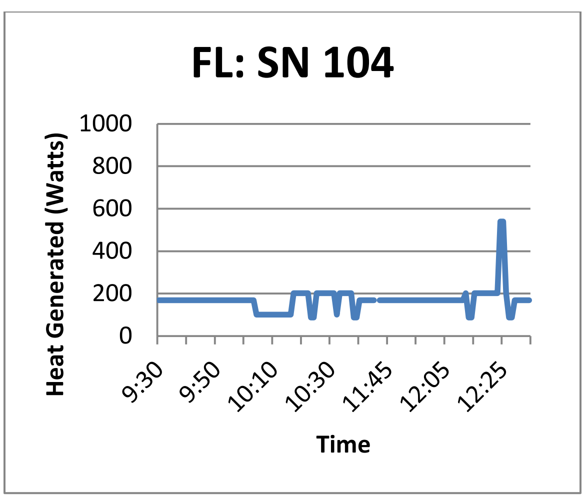
**Orange County, FL**

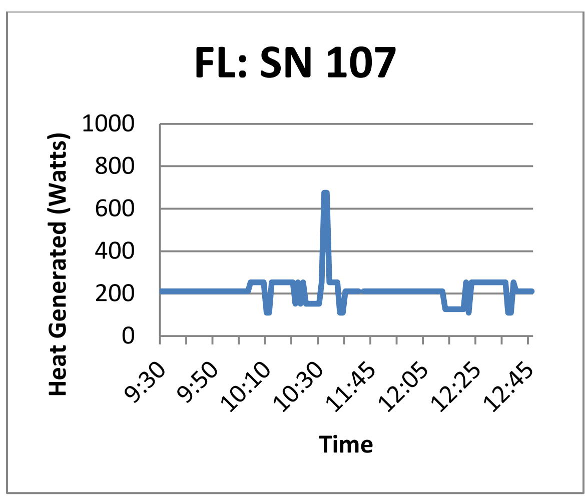


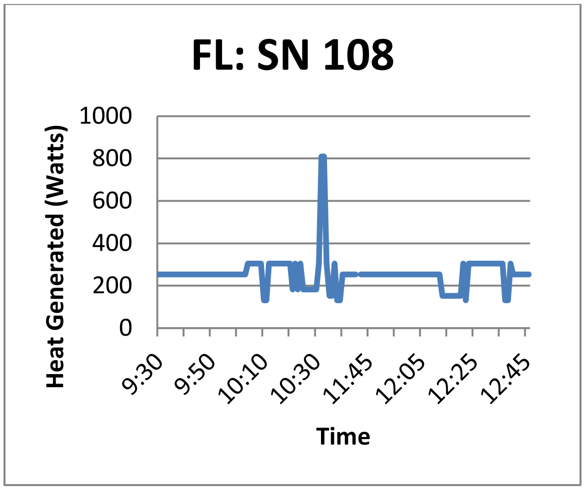

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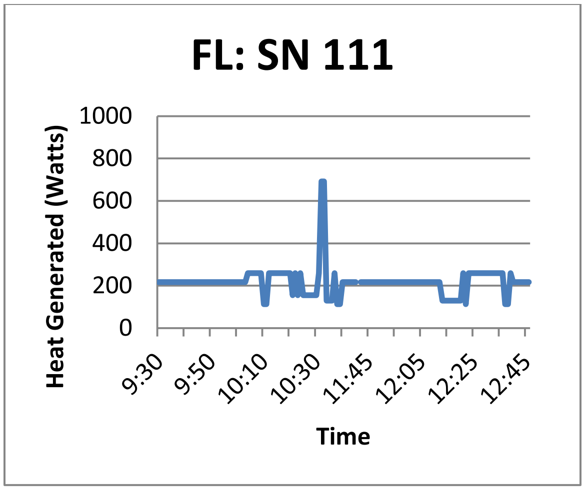
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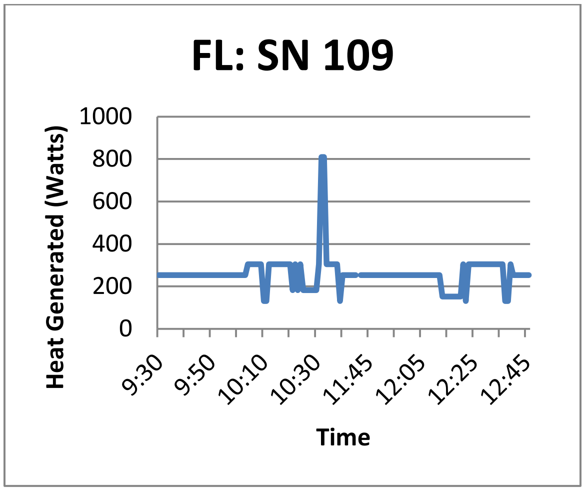
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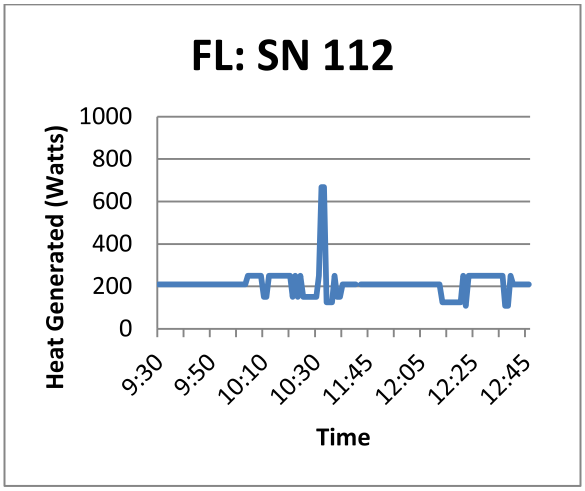
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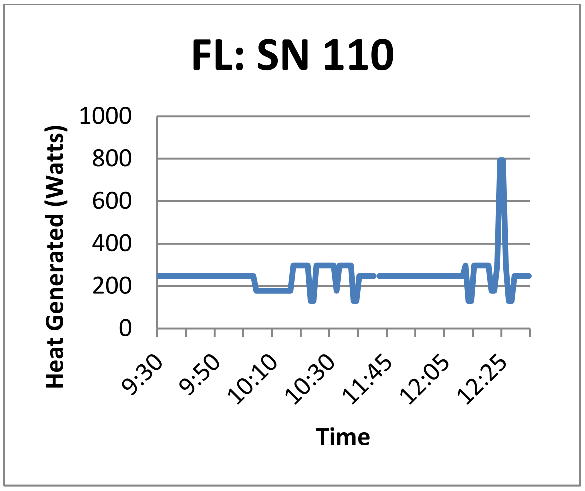
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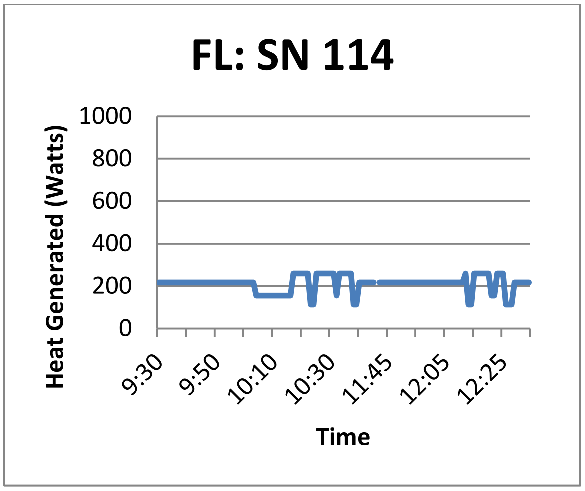
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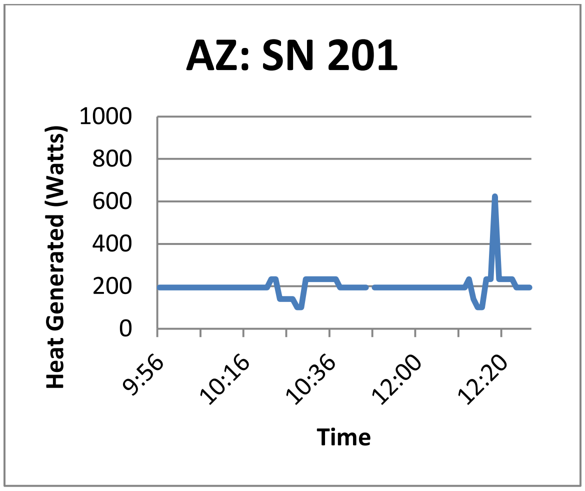
**Phoenix, AZ**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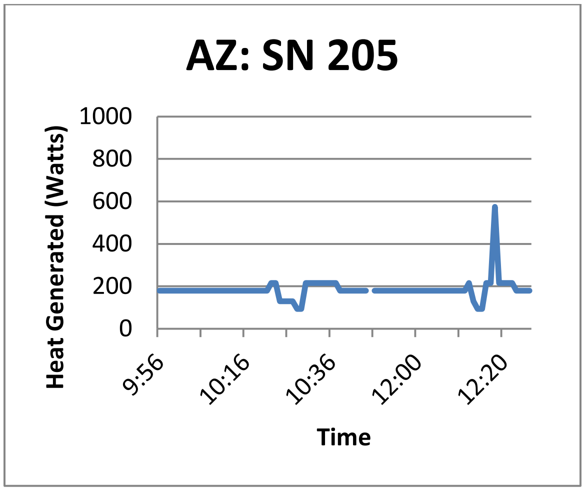
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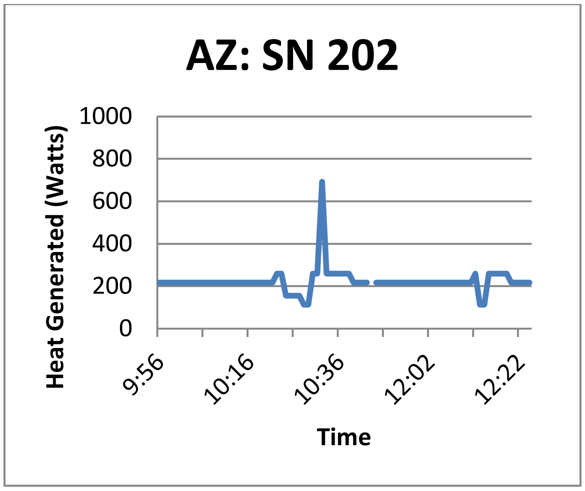
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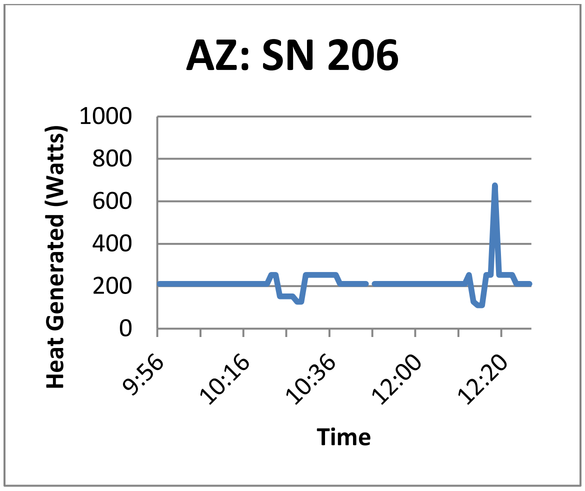
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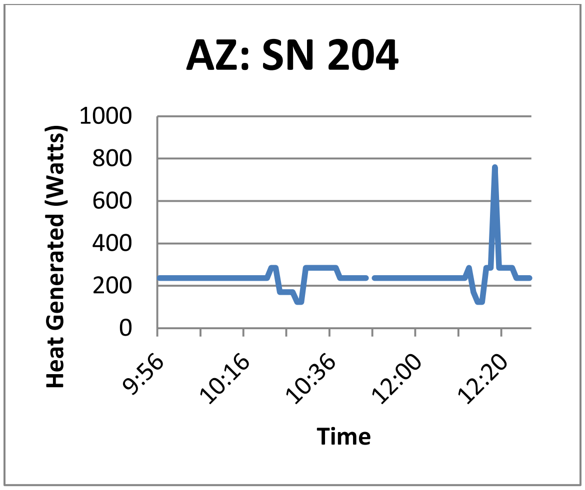
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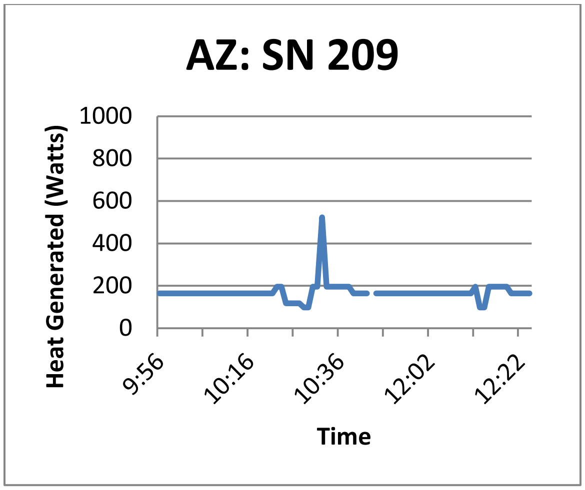
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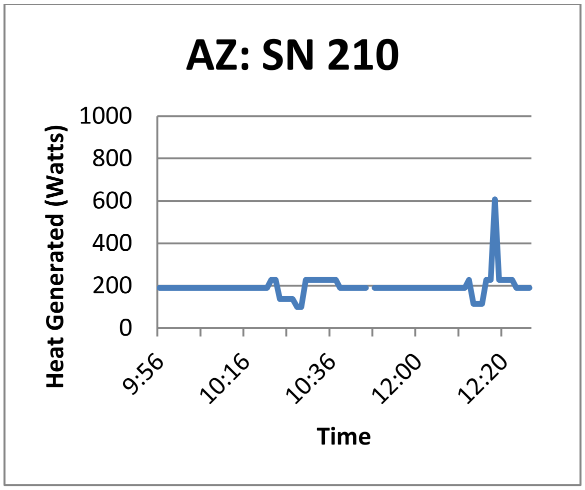
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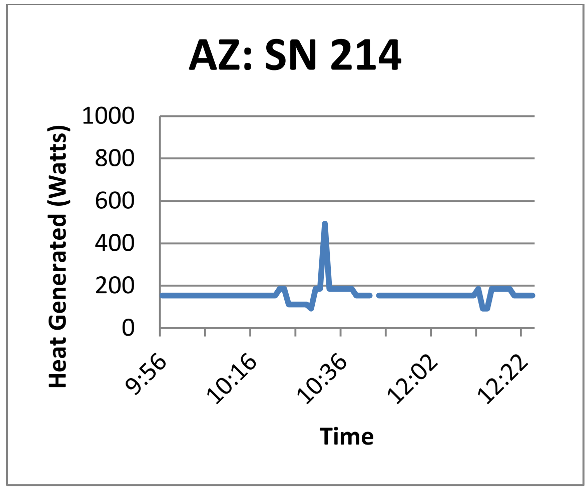
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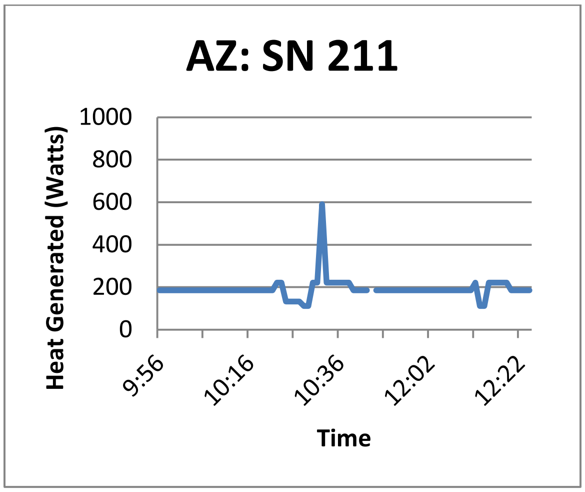
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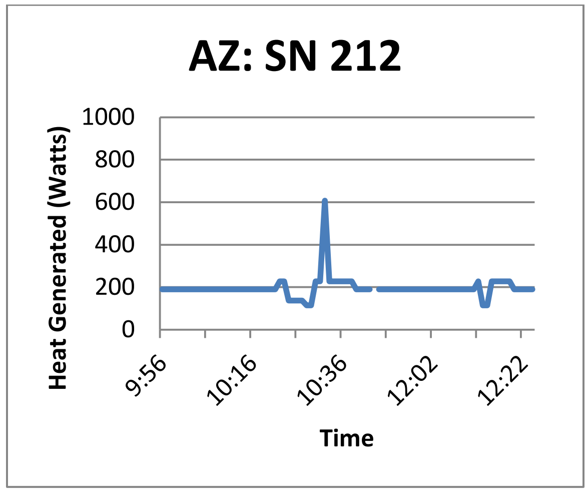
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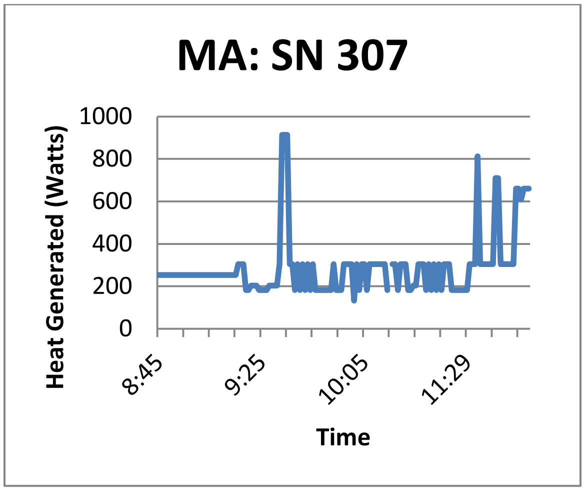
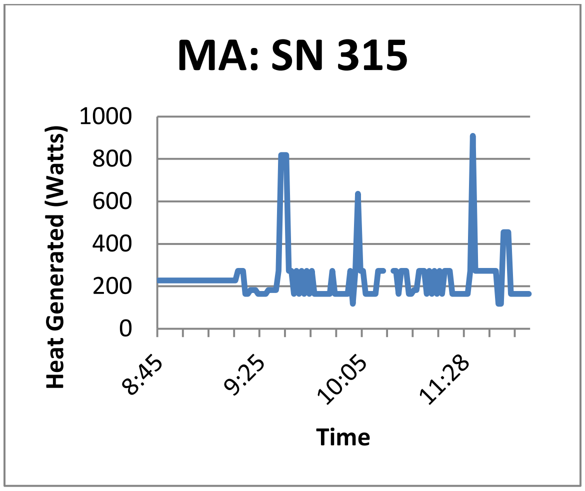
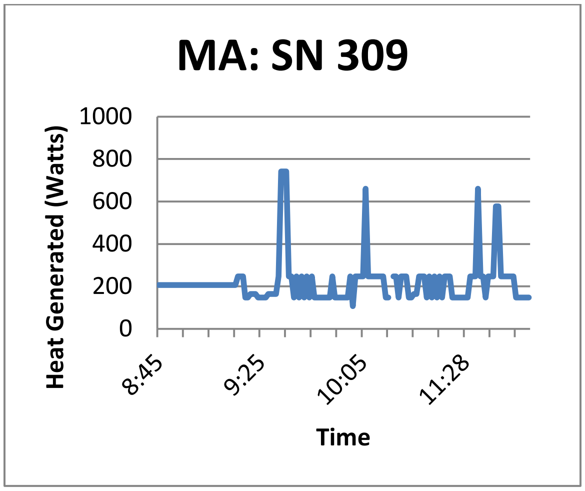
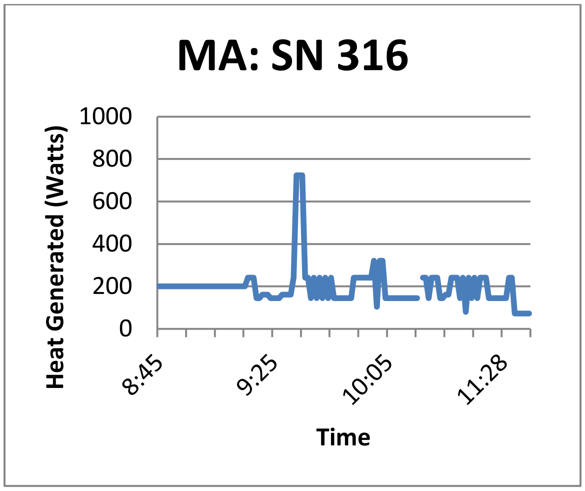
Time

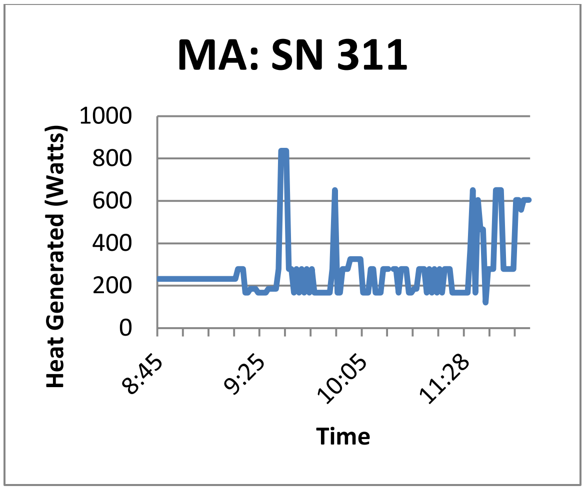
**Massachusetts State Police, MA**

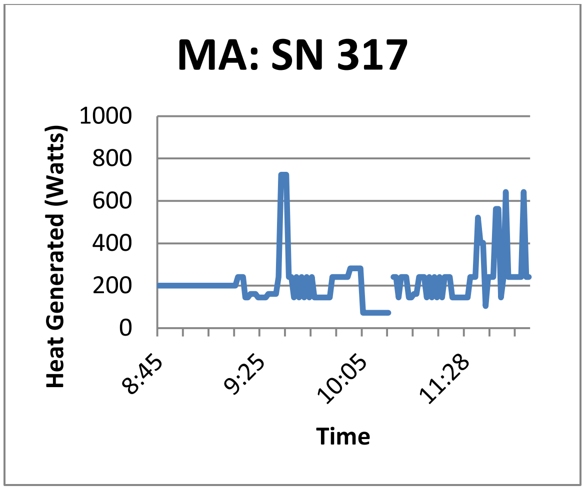


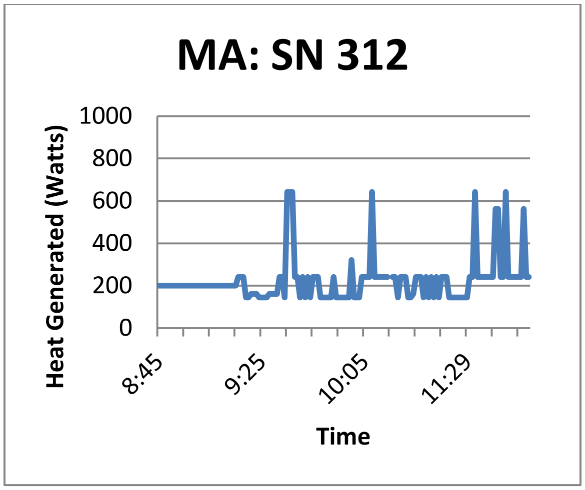

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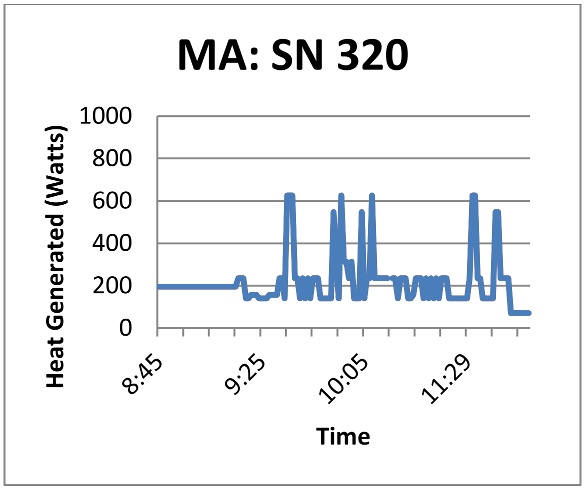
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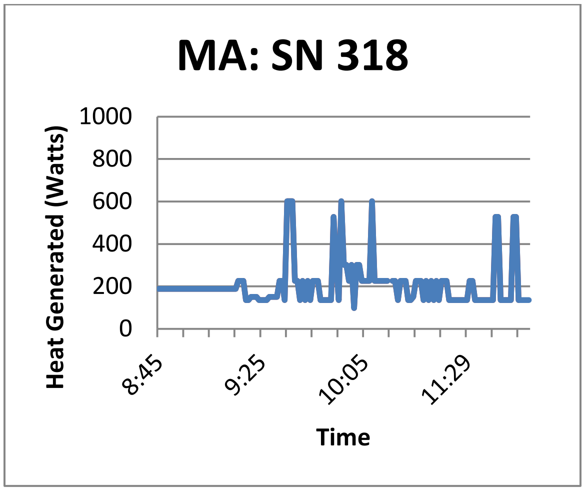
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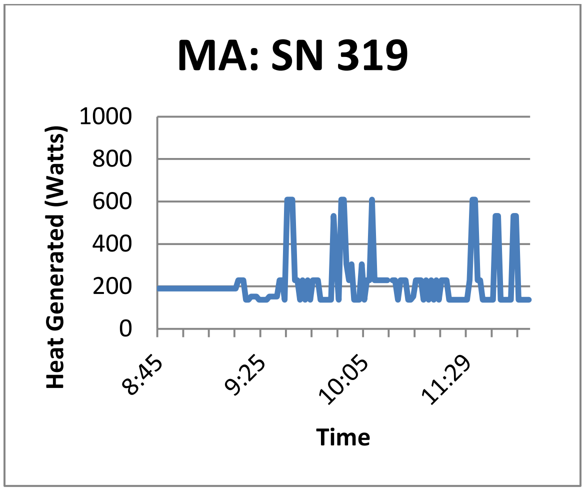
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