ENERGY COMPUTATIONS

The approach described in this guide is based upon a recent study that demonstrated, from an analysis of over 500 injuries, that the magnitude of energy (estimated in Joules) is a strong predictor of injury severity. To arrive at this conclusion, the researchers reviewed the circumstances surrounding each injury, estimated the energy severity while blind to the outcome, and determined the distribution of energy magnitude by injury severity level. The salient conclusions were as follows:

- Hazards involving 500 ft-lbs or less energy are most likely to cause a less-than-serious injury (low energy)
- Injuries involving over 500 ft-lbs of energy are most likely to cause a serious injury or fatality (high energy)

These conclusions serve as the basis for the forthcoming energy assessments and thresholds. It should be noted that the original study did not involve all energy sources. In this guide, it is assumed that the energy thresholds apply to all hazards that are physical in nature.

In the examples provided below, case examples are provided in imperial units, but all computations are made using the metric system. The conclusions are converted back to imperial units for interpretation.

Gravity

Gravitational energy represents the potential energy inherent in an object owing to its elevation relative to a lower reference point. This form of energy is intrinsically linked to the gravitational force and is contingent upon two fundamental factors: the mass of the object or individual and the separation distance between said entity and the chosen reference point. In the context of occupational safety, incidents resulting in injuries stem from the release of gravitational energy, which subsequently undergoes conversion into kinetic energy. Such injuries manifest either when an object in descent imparts its kinetic energy onto a worker or when the worker descends to a lower position, experiencing the consequential effects of gravitational energy.

Gravitational Energy (E) exhibits a direct proportionality to the mass of an object or individual, their height above a reference point, and the gravitational constant denoted as G. In the International System of Units (SI), mass is quantified in kilograms (kg), height in meters (m), and the gravitational constant (G) is standardized at 9.8 m/s^2.

_E_ = mass x height x gravitational constant

<u>Examples:</u>

- 200 lb (90 kg) falls 15 feet (4.6 m)

E = 90 kg x 4.6 m x 9.8 m/s^2 = 4057 Joules
E = 4,057 Joules x 0.74 ≈ 3,000 foot-pounds
Conclusion: High energy

- 1 lb (0.45 kg) tape measure falls on a worker from 10 ft (3 m)

E = 0.45 kg x 3 m x 9.8 m/s^2 = 15 Joules
E = 15 Joules x 0.74 ≈ 10 foot-pounds
Conclusion: Low energy

Motion

Motion energy, also known as kinetic energy, pertains to the translational movement of an object through space. It encompasses all forms of motion except those induced by gravitational forces, mechanical rotation, tension, or compression. The magnitude of motion energy hinges on the object's mass and exhibits exponential dependence on its velocity.

Motion Energy (E) is contingent upon the mass of the object and experiences exponential growth with respect to the object's velocity. In the International System of Units (SI), mass is quantified in kilograms (kg), and velocity is measured in meters per second (m/s). In Imperial units, mass is represented in pounds (lbs), and velocity is expressed in miles per hour (mph). As a point of reference, 1 m/s is equivalent to 3.6 kilometers per hour (kph) or 2.2 miles per hour (mph).

$$E = 0.5 \text{ x mass x velocity}^2$$

Examples:

- 2646 lbs (1200 kg) vehicle strikes worker at 25 mph (11 meters per second or 40 kph)

$E = 0.5 \text{ x } 1200 \text{ kg x } (11 \text{ m/s})^2 = 72{,}600$ Joules

E = 72,600 Joules x 0.74 ≈ 53,000 foot-pounds

Conclusion: High energy

- Workers carrying a 220 lb (100 kg) pipe strike the torso of another worker at 3 mph (5 kph or 1.34 m/s)

$E = 0.5 \text{ x } 100 \text{ kg x } (1.34 \text{ m/s})^2 = 90$ Joules

E = 90 Joules x 0.74 ≈ 66 foot-pounds

Conclusion: Low energy

Electrical

Electrical energy, also referred to as electrostatic potential energy, poses risks primarily when charged particles are introduced into the body as an electric current. This current undergoes conversion into thermal energy as it traverses through the human body, perturbing its internal equilibrium. To facilitate the utilization of this tool for estimating electrical current, we consider the resistance of the human body as 1500 ohms and assume that all electrical energy dissipates as heat. The magnitude of injury is directly proportional to the exposure time and exhibits exponential dependence on the voltage. The estimation of electrical energy can be approached in two ways: by considering the current (amperage) or by examining the voltage, and contact time.

Electrical energy relies on time measured in seconds (s), voltage (V), amperage (A), the assumed resistance of the human body (1500 ohms), and the assumption that all electrical energy transforms into heat. These computations remain consistent regardless of whether SI or imperial units are employed.

$$E = \text{time} \times \text{voltage}^2 / \text{resistance} \qquad \text{OR} \qquad E = \text{time} \times \text{current}^2 \times \text{resistance}$$

<u>Examples:</u>

- Worker touches a 220V wire for 2 seconds

$E = 2s \times 220\ V^2 / 1500\ ohm = 64.6$ Joules
$E = 64.6$ Joules $\times\ 0.74 \approx 48$ foot-pounds
Conclusion: Low energy

- Arc flash for 0.05 seconds inside a 10kV circuit breaker

$E = 0.05s * 10{,}000\ V^2 / 1500\ ohm = 3333$ Joules
$E = 3{,}333$ Joules $\times\ 0.74 \approx 2{,}500$ foot-pounds
Conclusion: High energy

Pressure

Pressure energy is typically stored within containers, such as vessels, cylinders, and tanks, in the form of compressed gases or liquids. The accumulation of pressure energy exhibits a linear relationship with both the pressure residing within the container and the volume of said container. It is essential to acknowledge the equal significance of both these variables in the context of pressure energy analysis.

Pressure energy hinges on the pressure contained within the vessel and is typically measured in pounds per square inch (psi), with 1 psi equivalent to 7,000 Pascals (Pa). To estimate the volume of a vessel, we employ the metric system, where 1 liter corresponds to approximately 0.264 gallons. Furthermore, for cylindrical vessels, which are prevalent in such scenarios, the volume can be approximated as 3.14 times the square of half the vessel's diameter multiplied by the vessel's length, all measured in meters. In the case of linear vessels such as pipes, the energy estimation is conducted on a per meter basis by estimating the pressure within the pipeline (psi) and the diameter of the pipe (m). 1 joule equals to 1 Pascal*m^3.

For Vessels: $E\ (Pa * m^3) = 7000 \times \text{pressure (in psi)} \times 0.001 \times \text{volume (in L)}$

For Pipes: $E = 7000 \times \text{pressure (in psi)} \times \pi\ (0.5 \times \text{diameter (in m)})^2$

<u>Examples:</u>

- Welding with a 2.5 Gallon (10-liter) acetylene cylinder at 250 psi (1,724 kPa)

E = 7000 x 250 psi x 0.001 x 10 L = 17,500 Joules[1]
E = 17,500 Joules x 0.74 ≈ 12,950 foot-pounds
Interpretation: High energy

- Working near a 2-inch (5 cm) natural gas line at 40 psi (275 kPa)

E = 7000 x 40 psi x 3.14 x $(0.5 \times 0.05)^2$ = 550 J
E = 550 Joules x 0.74 ≈ 400 foot-pounds
Interpretation: Low energy

[1] *Note that in these equations and in the associated energy severity assessment tool, pressure is estimated for SI units in pounds per square inch (psi) rather than kilopascals (KPa). This convention has been used because psi is the typical convention used in most industrial applications. Pounds per square inch may be converted to kPa at 1 psi = 6.89 kPa.*

Mechanical

Mechanical energy is typically stored within stationary systems in two primary forms: rotational energy (E_r) and elastic energy (E_e). Rotational energy involves spinning components such as grinders, turbines, gears, or pulleys, while elastic energy resides in objects exhibiting spring-like properties, particularly those experiencing tension or compression such as a cable in tension.

Rotational energy (E_r) hinges on two key parameters: the object's rotational inertia (I), influenced by both its mass and shape, and the angular velocity. Rotational inertia (I) is measured as I = 0.33 x weight x length^2 for a rod or I = 0.5 x weight x radius^2 for a cylinder. For a rod, this assumes rotation about one end. For a cylinder, this assumes rotation along the z axis. Angular velocity is measured in radians per second where 1 rotation per minute (rpm) equates to approximately 0.104 radians per second.

In contrast, elastic energy (E_e) depends on the stiffness of the object (k) measured in Newtons per meter. For example, a spring that extends by 10 cm when supporting 85 kg (830 Newtons) has a stiffness of k = 8300 N/m. The distance in meters is the difference between the rest length and the current length.

For rotation: $E_r = 0.5 \text{ x } I \text{ x angular velocity}^2$

For tension or compression: $E_e = 0.5 \text{ x } k \text{ x distance}^2$

Examples:

- A grinder wheel with a 4.5-inch (0.114 m) diameter weighing 300 grams is rotating at a speed of 11,000 RPM (1144 rad/s).

I (kg x m2) = 0.5 x 0.3 kg x (0.114m / 2)^2 = 0.00049 kg x m2

E_r = 0.5 x 0.00049 kg x m2 x (0.104 x 11000 rpm)^2 = 320 J

E_r = 320 * 0.74 ≈ 237 foot-pounds

Conclusion: Low energy

- Cable extends by 10 inches (0.25 m) while supporting 1,000 lbs (453 kg or 453 x 9.8 = 4448 N).

k = 4448 N/0.25 m = 17,792 N/m
E_e = 0.5 * 17,792 N/m * (0.25 m)^2 = 556 Joules
E_e = 556 Joules x 0.74 ≈ 411 foot-pounds
Conclusion: Low energy