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Standard Guide for Process Understanding Related to Pharmaceutical Manufacture and Control¹

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1. Scope

1.1 The purpose of this guide is to establish a framework and context for process understanding for pharmaceutical manufacturing using quality by design (QbD) (Juran, 1992;² FDA/ICH Q8). The framework is applicable to both active pharmaceutical ingredient (API) and to drug product (DP) manufacturing. High (detailed) level process understanding can be used to facilitate production of product which consistently meets required specifications. It can also play a key role in continuous process improvement efforts.

1.2 Process Analytical Technology (PAT) is one element that can be used for achieving control over those inputs determined to be critical to a process. It is important to the reader to recognize that PAT is defined as:

“...a system for designing, analyzing, and controlling manufacturing through timely measurements (i.e., during processing) of critical quality and performance attributes of raw and in process materials and processes, with the goal of ensuring final product quality. It is important to note that the term analytical in PAT is viewed broadly to include chemical, physical, microbiological, mathematical, and risk analysis conducted in an integrated manner. The goal of PAT is to enhance understanding and control the manufacturing process...” (U.S. FDA PAT)

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:³

[E456 Terminology Relating to Quality and Statistics](#)

[E2281 Practice for Process Capability and Performance Measurement](#)

¹ This guide is under the jurisdiction of ASTM Committee E55 on Manufacture of Pharmaceutical and Biopharmaceutical Products and is the direct responsibility of Subcommittee E55.11 on Process Design.

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² Juran, J., *Juran on Quality by Design: The New Steps for Planning Quality Into Goods and Services*, Free Press, New York, N.Y., 1992.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[E2474 Practice for Pharmaceutical Process Design Utilizing Process Analytical Technology \(Withdrawn 2020\)](#)⁴

[E2617 Practice for Validation of Empirically Derived Multivariate Calibrations](#)

2.2 *U.S. Government Publications:*⁵

[FDA/ICH Q8 Pharmaceutical Development](#)

[FDA/ICH Q10 Pharmaceutical Quality Systems](#)

[U.S. FDA PAT Guidance Document, Guidance for Industry PAT—A Framework for Innovative Pharmaceutical Manufacturing and Quality Assurance](#)

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *critical inputs, n*—critical process parameters and critical raw material attributes for a given process.

American Society for Quality⁶

3.1.2 *empirical, adj*—any conclusion based on experimental data and past experience, rather than on theory.

3.1.3 *expert system, n*—an expert system is a computer program that simulates the judgment and behavior of a human or an organization that has expert knowledge and experience in a particular field.

3.1.3.1 *Discussion*—Typically, such a system contains a knowledge base containing accumulated experience and a set of rules for applying the knowledge base to each particular situation that is described to the program. Sophisticated expert systems can be enhanced with additions to the knowledge base or to the set of rules.

3.1.4 *first principles, n*—a calculation is said to be from first principles, or *ab initio*, if it starts directly at the level of established laws of physics and does not make assumptions such as model and fitting parameters.

3.1.5 *mechanistic, adj*—(*I*) of, or relating to, theories that explain phenomena in purely physical or deterministic terms: a mechanistic interpretation of nature.

⁴ The last approved version of this historical standard is referenced on www.astm.org.

⁵ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁶ Available from American Society for Quality (ASQ), 600 N. Plankinton Ave., Milwaukee, WI 53203, <http://www.asq.org>.

3.1.6 *process capability*, n —statistical estimate of the outcome of a characteristic from a process that has been demonstrated to be in a state of statistical control. **E2281**

3.1.7 *process inputs*, n —the combination of all process parameters and raw material attributes for a given process.

3.1.8 *process understanding*, v —to recall and comprehend process knowledge such that product quality can be explained logically or scientifically, or both, as a function of process inputs and respond accordingly.

3.1.9 *residual error*, n —the difference between the observed result and the predicted value (estimated treatment response); Observed Result minus Predicted Value. **E456**

3.1.10 *uncertainty*, n —an indication of the variability associated with a measured value that takes into account two major components of error: (1) bias, and (2) the random error attributed to the imprecision of the measurement process. **E456**

4. Process Understanding

4.1 From physical, chemical, biological, and microbiological perspectives, a process is considered to be well understood when:

(1) All significant sources of variability in process inputs are identified and explained,

(2) The effect of these sources of variability on product quality attributes can be accurately and reliably estimated based on the inputs to the process, and

(3) Significant process parameters are continuously managed and controlled to ensure that the process must produce product which is continuously within required specifications to the user specified required degree or confidence.

4.2 A well-controlled process is a process where the risk of producing product not meeting required specifications is below the maximum acceptable level of risk as predetermined by the user. Accordingly, process understanding requires the comprehension and recall of process knowledge sufficient for the logical, statistical, or scientific understanding, or combination thereof, of how significant process parameters and raw material attributes relate to, or impact the quality attributes of, the product being produced. Sufficient process understanding should be achieved to reduce risk to an acceptable level for the patient, manufacturer, or any other stakeholder.

4.3 *A Lifecycle Commitment (Development and Commercial Manufacture):*

4.3.1 Process understanding is fundamental to QbD. It is important to realize that due to commercial realities (for example, finite resources, time, and money), a process will typically be commissioned as soon as the degree of process understanding is sufficient to permit operation of the process with an acceptably low, user specified, level of risk of producing out of specification product. While it may be appropriate to commission a process once this minimum degree of process understanding is achieved, the risk that the process may transition out of control steadily increases over time (for example, process drift), and could exceed the maximum acceptable risk without warning, unless an ongoing program to enhance process understanding is in place.

4.3.2 Accordingly, the development of process understanding should be treated as an ongoing process. Learning should continue throughout the product and process life cycle to improve the level of process understanding to include process parameters and other factors (for example, environmental, changes of scale, changes in raw materials, changes in personnel) which may have changed or which may have newly emerged since the time the process was first commissioned. Work to enhance process understanding continuously throughout the life cycle of the product and process can provide assurance that the process will continue to have an acceptably low risk of producing out of specification results.

4.3.3 Manufacturers are encouraged to continuously monitor and improve upon their operations to enhance product quality.

4.4 *Process Understanding for the Whole Process:*

4.4.1 For each product, process understanding covers the process from the initial design of the chemical or biological drug substance through manufacturing of the unit dose or device to final packaging. In addition, the critical quality attributes of the raw materials will in turn become inputs to the drug product manufacturing process, as will process parameters.

4.4.2 **Fig. 1** schematically illustrates that the performance of any process output (Y) is a function of the inputs (X), which can be classified into one of six categories (that is, operator, equipment, measurements, methods, materials, and environmental conditions).

4.4.3 Comprehensive understanding of the relationships of the process inputs and operating parameters to quality attributes of the resulting product is fundamental to developing a successful risk mitigation or control strategy, or both. Identification of critical process parameters (CPPs) and critical raw material attributes should be carried out using suitable experimental and investigative techniques. An understanding of these critical inputs (CPPs and critical raw material attributes), and their monitoring and control, is essential when designing a process that is able to consistently and reliably deliver product of the desired quality.

4.4.4 One method for achieving the desired state is through multivariate analysis and control. The acceptable operating envelope of the critical inputs defines the relationship between the design space, control strategy and operating range(s).

4.4.5 Note that for raw materials, an additional source of variability derives from the potential for adulteration. This requires that manufacturers understand their incoming supply chain and suppliers quality systems, and include methods to detect adulteration of materials in addition to confirming identity as necessary, bearing in mind that adulteration may be difficult to detect by standard methods. It also requires that manufacturers use suppliers that are aware of these concerns and are prepared to implement their own precautionary measures, and to permit transparency into their respective supply sources.

4.5 *Tools of Process Understanding:*

4.5.1 Process understanding begins with process design (Practice **E2474**) and usually a structured, small scale development program which focuses on efficiently delivering a

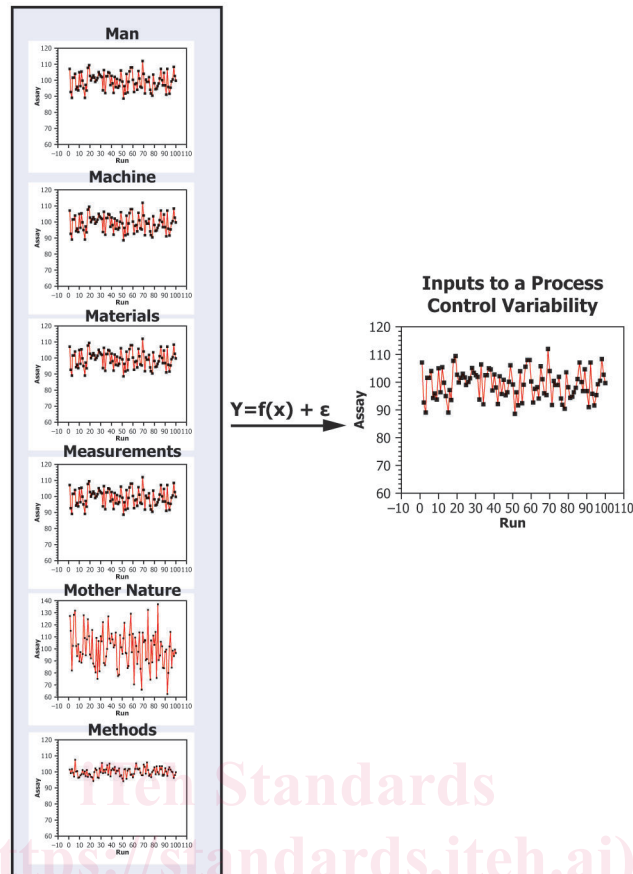


FIG. 1 Input, Process, and Output Diagram

product meeting the required specifications. Tools that may be applied during development and after commercialization include:

- (1) Scientific theory,
- (2) Prior knowledge,
- (3) Design of experiments,
- (4) Simulation of unit operations,
- (5) Selection of a suitable technology platform,
- (6) Mathematical models,
- (7) Validated empirical/statistical models,
- (8) Appropriate instrumentation, and
- (9) Appropriate analytical methods.

4.5.2 The measurement technologies include but are not limited to spectroscopic, acoustic, or other rapid sensor technologies. The development of these and other advanced techniques will continue to enable or enhance predictive control for commercial pharmaceutical processes.

4.5.3 The ability to measure process parameters and quality attributes inline, online, or atline in real time can contribute to process understanding and the ability to control the process. These technologies offer the development scientist, commercial production engineer and manufacturing personnel the opportunity for additional insight. This is achieved through the increased measurement frequency and availability of more comprehensive data.

5. Process Knowledge

5.1 Process knowledge is the cornerstone of process understanding. There are various levels of process knowledge, and these are listed from lowest to highest state of understanding:

- (1) Descriptive knowledge (what is occurring?),
- (2) Correlative knowledge (what correlations are empirically observed?),
- (3) Causal knowledge (empirical, what causes what?),
- (4) Mechanistic knowledge (explanations for observed causality), and
- (5) First principles knowledge (underlying physical, chemical, and biological phenomena of the mechanistic explanations).

5.2 Process knowledge is the accumulated facts about the process. This accumulated knowledge is generally embodied in a model of the process. Accordingly, *process model* is often used synonymously with *process knowledge*.

5.3 Process understanding is demonstrated by the extent to which process knowledge can be used to predict and control the process outcomes; a well understood process will combine knowledge from various sources to ensure a well controlled process and consistent product quality.

5.4 At any point in time for any manufacturing process, the level of understanding will likely be a combination of various