Retired & Dangerous

Out-of-Service Equipment Hazards

By Robert Wasileski

Management of change (MOC) programs are generally well established throughout the chemical processing industry. Many of these programs have been operating for decades, while others are still relatively new and early in their maturation process. Regardless of program maturity, challenges in MOC program application and sustainability continue to provide learning opportunities for the chemical processing industry.

The application of MOC to the tail end of the process life cycle has received little attention. The typical process life cycle begins in the research and development stage, grows through the design and construction stages, and reaches a period of relatively stable operation following start-up. The hazard identification and risk assessment component of MOC is typically applied with great care and diligence during the process design phase. This high degree of professional care is largely a reflection of the facility's unfamiliarity with the process at this stage. Unfamiliarity and uncertainty will breed a strong desire to identify the hazards and understand the risk. As a result, structured analysis techniques such as guide-word hazard-and-operability analysis and failure-modes-and-effects analysis are commonly applied to new designs.

Once a facility has acquired a suitable degree of operating experience with a new process, MOC continues to be applied to operational and equipment changes. However, the rigor applied to the hazard identification and risk assessment process may wane over time, relative to that which was applied during process design. The gains in operating experience, combined with a relative abundance of process safety information that has been accumulated (e.g., during routine operation, modifications and expansions) (CCPS, 1989) will frequently result in the use of alternative techniques for evaluating in-service modifications. Techniques such as checklist analysis, what-if analysis and even plant-specific questionnaires often predominate during this phase of operation.

The latent period that follows routine operations typically receives the least amount of attention from an MOC perspective. The temperate mind-set that developed during the routine operations phase can later act as a pandemic during the retirement pe-

IN BRIEF

- **This article examines the subject of out-of-service equipment in the context of manufacturing and production facilities.**
- **Hazards associated with such equipment are reviewed and individually discussed. Case examples illustrate the risks described, and practical approaches for risk management in both new and existing facilities are offered.**
- **The scope of application of this article is quite broad in that the hazards and approaches to risk management are applicable to most manufacturing or production facilities across a range of industries.**

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Table 1
Terminology & Definitions

Term	Definition
Abandonment	A condition whereby equipment, facilities or buildings have been retired from service, either deliberately or unintentionally, and left in a state that may pose unacceptable SH&E risks.
Decommissioning	The process of physically isolating and/or disconnecting, de-energizing, and removing process material from equipment or facilities, such that no unacceptable SH&E risks remain. Decommissioning may lead to other activities, such as dismantling, mothballing or recommissioning, where deemed appropriate.
Dismantling	The physical disassembly of equipment, piping and sometimes buildings.
Mothballing	The process of maintaining decommissioned equipment or facilities in a state that preserves their fitness for use. While mothballing inherently involves decommissioning activities, mothballed equipment and facilities generally entail the use of materials and utilities that are specifically required for preservation (e.g., greases, desiccants, inert gases). Mothballing does not include shutdown or regular maintenance.
Recommissioning	The process of energizing and supplying process material to equipment or facilities that have been decommissioned or mothballed, such that no unacceptable SH&E risks are introduced.

Note. *The definitions presented here are those of the author and may differ from other organizations.*

Dispostion of out-of-service equipment should be determined during the management of change process, rather than leaving equipment abandoned or incompletely decommissioned.

riod. This mind-set can manifest itself through the culture of the organization. For example, key features of a sound safety culture such as "maintaining a sense of vulnerability" may become severely compromised during the latter stages of the process life cycle (Center for Chemical Process Safety, 2007).

Recognizing this threat, removing equipment from service should be a deliberate, planned and carefully managed process change. Further, the MOC process should clearly characterize the disposition of the equipment for decommissioning, mothballing, recommissioning or dismantling (Table 1). Too often, however, equipment is left in a state of abandonment or incomplete decommissioning. Experimental operations, unnecessarily installed spares and gradual changes in operating practices are a few reasons to blame for this precarious condition. The consequences arising from these seemingly harmless changes can be both subtle and gradual. As such, the decision to take equipment out of service may, in fact, not be intentional or conscious.

Retired equipment may contain residual inventories of hazardous materials, live electrical connections or physical connections to in-service process equipment. In the worst cases, the equipment has essentially been abandoned. Hazards associated with these situations can present imminent risks, or facilitate the gradual development of unforeseen risks over time. These conditions can lead to adverse events such as fires and explosions; undesirable chemical reactions; personnel exposures to hazardous materials; unnecessary complexity in the operation; and transfer of hazardous material from one operating area to another.

A robust out-of-service equipment (OOSE) program is strongly recommended to manage the risks associated with equipment retirement in the stages of the process life cycle that follow routine operation, modifications and expansions.

Process Hazards With Case Examples

Fire & Explosion Hazards

Flammable and combustible materials that are left to reside inside abandoned equipment may create flammable atmospheres that are subject to fires and explosions. For example, common materials such as butane or propane have flash-point temperatures of -60 and -104 °C, respectively. Under nearly all ambient conditions, these materials will be above their flash-point temperature and, thus, a flammable atmosphere has the potential to exist inside the equipment.

Furthermore, when these materials are accidentally released from containment, vapor cloud explosions, flash fires and pool fires become imminent threats. One such incident occurred in February 2007, when a large quantity of propane leaked from a cracked pipe that had been out of service for 15 years (CSB, 2008). The fire forced an evacuation and shutdown of the facility, and resulted in four injuries and losses of more than $50 million.

The risk of fire and explosion cannot be presumed to remain constant over time. Equipment and environmental conditions can and will change over time, and thereby affect the risk. In fact, the actual hazards may even change, which can be even more deceptive.

Case Example #1

An incident occurred during a plant expansion project. An atmospheric storage tank required dismantling to create space for new equipment. The tank had been out of service for 15 years and was believed to be last used for cyclopentane storage (a flammable liquid hydrocarbon). The tank was lifted out of the process area and transferred to a demolition site to be dismantled with a cutting torch. In preparation for the hot work, the tank was steamed for 2 days to remove residual hydrocarbons, then tested for the presence of flammable vapors. A negative test result was obtained, thus allowing hot work to proceed under a written permit.

During the process of removing the first nozzle with the cutting torch, a fire developed inside the tank (Photo 1). Attempts to extinguish the fire with handheld fire extinguishers were unsuccessful and a water fog was quickly introduced inside the tank to extinguish the fire. A large mass of solid foam-like material was later removed from the tank (Photo 2).

As one might suspect, the atmospheric testing that had been performed prior to hot work had not detected this combustible solid inside the tank. However, the presence of such a material was not expected, considering the tank had previously been in flammable liquid service. During the 15 years that the tank was out of service, an unanticipated hazard had materialized inside the tank and gone unnoticed. The exact mechanism(s) that led to the formation of this foam-like material were never fully understood. However, one explanation suggested that vinyl benzene monomer had been unintentionally introduced into the tank previously. A slow, uncontrolled polymerization of this monomer in the presence of cyclopentane created the amorphous foam-like combustible material discovered following the fire.

Case Example #2

An additional concern related to vapor cloud explosion hazards arises when OOSE remains installed in a plant (i.e., it is not dismantled). Equipment such as pumps, piping, vessels, tanks and buildings can add unnecessary congestion and confinement to plant layouts (Photos 3 and 4). These physical obstacles can have a significant adverse impact on vapor cloud dispersion and flame-front speeds, particularly with materials that are susceptible to deflagration-to-detonation transition behavior (e.g., hydrogen, acetylene, ethylene).

Toxicity Hazards

Most materials exhibit some degree of toxicity under the proper set of conditions (i.e., effects are dose-dependent). Hydrogen sulfide, chlorine gas and phosgene are generally regarded as highly toxic. Moreover, the toxicity hazard may exist in combination with other hazards such as flammability. One such toxic and flammable material is boron trifluoride ether complex (BF3EE).

Boron trifluoride gas (BF3) is a moderately strong Lewis acid (i.e., a chemical substance that will readily accept an electron pair from a base) and often used as a reaction catalyst in the synthesis of hydrocarbon resins. The acid-base addition reaction of BF3 gas with liquid diethyl ether yields BF3EE, which is sometimes used instead of BF3, as BF3EE is a liquid and offers some storage and handling conveniences relative to the neat gas.

However, BF3EE complex is readily reactive with water, characterized by its fuming nature when released from containment. When exposed to water (e.g., naturally occurring moisture in the air), BF3EE will rapidly dissociate and liberate both flammable ether vapors and toxic BF3 gas. Then, the BF3 gas reacts with water to form hydrates of boric acid and fluoboric acid, both of which are toxic and corrosive gases (Honeywell, 2011).

In the interest of inherent safety, less toxic alternatives are often sought for highly toxic materials in process plants. The decision to use BF3 gas rather than liquid BF3EE may not be clear and straightforward in this example case with respect to inherent safety. However, some situations are generally perceived as being less ambiguous, as in the case of gaseous chlorine. A common example of a material substitution being used to reduce process risk is the replacement of gaseous chlorine with sodium hypochlorite.

When such substitutions occur, all remaining inventories of the previous material must be either consumed in the process or disposed of safely. Residual inventories of highly toxic materials such as BF3EE and chlorine can pose significant risks and become a liability when left to reside inside retired equipment. These concerns underscore the importance of removing process material from tanks, vessels and equipment during the decommissioning process.

Case Example #3

Photo 1 (above): Atmospheric storage tank following the fire.

Photo 2: Combustible solid removed from the tank.

Photo 3 (above): Congestions and confinement created by equipment/buildings.

Photo 4: Increased obstacle density from OOSE.

Photo 5: Popcorn polymer formation.

Photo 6: Deformed condenser shell.

Anhydrous hydrogen fluoride is a colorless liquid that fumes in air and creates vapors with a sharp, pungent odor. MSDS for this material identify it as a corrosive and poisonous liquid with toxic properties that can irreversibly damage an individual's bones, joints and organs (Phillips, 2011). Further, due to its highly hazardous properties, anhydrous hydrogen fluoride is a regulated substance in the U.S. under 29 CFR 1910.119 (Process Safety Management of Highly Hazardous Chemicals) and 40 CFR Part 68 (Chemical Accident Prevention Provisions).

A loss of containment incident involving anhydrous hydrogen fluoride occurred in 1997 following a recommissioning project on a tank car. On April 2, 1997, in Memphis, TN, tank car ACAX 80010 began leaking anhydrous hydrogen fluoride during switching operations at a local rail yard. The leak forced the evacuation of about 150 people in the surrounding area for nearly 17 hours while emergency responders worked to control the situation.

National Transportation Safety Board (NTSB, 1980) published a HazMat incident brief that thoroughly describes this incident, including details of the complex metallurgical failure mechanism that gave rise to the leak. The tank car had been inspected several months prior to the incident. The inspection revealed two material defects inside the tank car, known as hydrogen blisters. The tank car was promptly decommissioned, and repairs were made to the areas in which the hydrogen blisters were located. The tank car was recommissioned following the repairs, and returned to service on March 17, 1997, where it was filled with anhydrous hydrogen fluoride in Geismar, LA. In the HazMat issue brief, NTSB describes the probable cause of the incident as:

> . . . inadequate heat treatment to reduce the hardness of the weld material used in the repair of the tank to a level that would retard or prevent hydrogen-assisted cracking and inadequate testing to determine whether the weld material hardness exceeded established limits.

This incident underscores the risks associated with recommissioning activities and emphasizes the need to carefully manage recommissioning activities with the same diligence and care as other changes in service.

Reactive Chemistry Hazards

Unintended reactive chemistry scenarios can be difficult to recognize and predict. Interactions between two or more process materials may not even be credible because of the use of check valves and other physical isolation devices. However, these isolation devices can experience failures, leading to the inadvertent mixing of process materials. For example, check valves and isolation valves can experience damage or degradation to the internal sealing surfaces through mechanical or chemical mechanisms (e.g., physical erosion effects, foreign material trapped in valve seats, chemical corrosion). In turn, leakage across the valve seat can occur, permitting the unintended transfer of process material across the isolation device.

Moreover, the mechanisms of uncommon reactions may not be widely understood by plant personnel. As such, unforeseen risks can materialize. One such example is the reaction of acids and/or water with mild steel to generate hydrogen gas. Numerous documented incidents involve explosions inside tanks constructed of mild steel that were removed from service for hot work. The investigations revealed that a flammable hydrogen/air mixture had formed inside the tanks prior to hot work activities due to the reaction of water with iron (i.e., the tank steel) to form flammable hydrogen gas (Praxair Technology, 2009).

Materials capable of polymerization are also a concern. For example, monomers such as vinyl benzene, isoprene and butadiene are generally inhibited to prevent hazardous polymerization and peroxide formation during storage. In the case of butadiene, peroxides can be created by the introduction of oxygen into the system or through insufficient inhibitor concentration. These insoluble butadiene peroxides can lead to rapid, spontaneous explosions or they may initiate undesirable polymerization reactions that can give rise to equipment damage and injuries.

Case Example #4

In 1992, an olefins facility experienced an unplanned polymerization of butadiene inside an abandoned overhead condenser. The investigation concluded that oxygen (i.e., air) had inadvertently entered the system, allowing the formation of butadiene peroxides. Over several months, so-called popcorn polymer (Photo 5) slowly formed inside the condenser until a mechanical deformation of the shell occurred due to the high internal pressures created by the polymerization reaction (Photo 6). It is common to observe ruptured piping, exchangers, valves and other equipment following these polymerization incidents due to the high pressures that are generated.

Electrical Shock & Ignition Source Hazards

Energized electrical equipment can pose risks to personnel and property. Abandoned electrical equipment will often remain electrically energized unbeknownst to plant personnel. This is problematic in aging facilities where knowledge of the equipment and details of the decommissioning process may no longer be readily available. In these cases, energized electrical equipment can lead to electrical shock and injury through inadvertent contact with a circuit. Further, this equipment can be an ignition source for flammable material releases. The integrity of abandoned electrical equipment will generally be in substandard condition since these items are no longer inspected and maintained and, thus, the likelihood of ignition will be greater.

Case Example #5

The actuator had been removed from a motor-operated control valve. The valve body and electrical leads to the actuator were left intact (Photo 7). Over several years, the flexible conduit and leads were gradually buried by the soil and gravel in the area, eventually becoming hidden from sight.

A maintenance employee drove an engine-powered scissor lift into the area to perform unrelated work. When the wheels of the scissor lift passed over the flexible conduit, the conduit and wires were severed and an electrical arc flash occurred (Photo 8). Fortunately, no injuries or property damages occurred, and the system was promptly decommissioned following the incident.

Case Example #6

While energized electrical equipment poses electrical shock and ignition risks, de-energized equipment can also be a concern. Equipment that traverses across or between process units, such as electrical conduit, can provide a route for flammable gases and vapors. These routes may join areas with differing electrical classifications, such as a motor control center and a tank farm used for flammable liquid storage.

Unsecured cover plates and open junction boxes (Photos 9 and 10, p. 38) provide an entry point into conduit for gases and vapors. Incidents have occurred where flammables traveled through long conduit runs and were ignited by energized electrical equipment.

One such incident occurred on Oct. 6, 1979, at the reception facility of the Columbia LNG Corp. in Cove Point, MD. Liquefied natural gas vapors traveled more than 200 ft through underground electrical conduit and entered a substation building. The vapors ignited inside the substation building, resulting in an explosion that destroyed

Photo 7 (top): Conduit and valve following the incident.

Photo 8: Severed flexible conduit.

Photos 9 and 10: Routes of entry for flammable vapors and gases into electrical conduit.

the substation building and led to losses of an estimated $3 million (NTSB, 1998).

HazMat Spills & Exposure Hazards

Process materials left to reside inside equipment can pose a risk to personnel and the environment. Incidents that involve personnel exposures and environmental damage underscore the importance of de-inventorying and isolating equipment that has been retired.

Case Example #7

Maintenance personnel were dismantling out-of-service piping equipment inside a utilities building. Over several weeks, they had routinely dismantled piping throughout the building, as time permitted. On the day of the incident, a section of small-bore plant air piping was scheduled to be removed using a portable electric band saw (Photo 11). A second line, which was not labeled, was loosely attached to the plant air line with steel wire for support. The second line was about 40-ft long and physically disconnected on both ends.

Prior to cutting the lines, maintenance personnel removed pipe hangers to allow the ends of both lines to slope toward the floor. There was no indication of liquid in the piping, as nothing had spilled from the ends and the lines were disconnected from other piping in the area. Shortly after making a cut into the second steel line, liquid began to spray from the pipe (Photo 12). Work stopped immediately, and an investigation was initiated.

Photo 11 (top): Plant air piping in utilities building.

Photo 12: Piping containing sulfuric acid.

The investigation concluded that the liquid was sulfuric acid from a system that had been (partially) decommissioned and out of service for nearly 25 years. Apparently, the acid had been trapped inside the piping by foreign material plugging off the pipe ends.

Other Hazards

OOSE can present hazards beyond those discussed in this article. Additional concerns that may arise from OOSE include:

- thermal expansion hazards leading to loss of process containment and/or pressure relief device discharges;
- cross-contamination with equipment that is still in service (e.g., product contamination);
- dilapidated conditions and eventual collapse of equipment, including collateral damage to surrounding equipment;
- physical barriers and restrictions to emergency firefighting access;
- impeded emergency response efforts;
- unnecessary complexity remaining in the operation, thus increasing the likelihood of human error during start-up, shutdown, routine and emergency operations;
- environmental damage arising from unintended releases;
- occupational injuries due to slips, trips, falls and similar incidents.

Risk Management

In developing an OOSE program, facilities must consider risk management strategies for both existing and future situations. While the approaches to these situations share common elements, nuances exist between the two. In addition, owners/operators of dismantled and demolished equipment must consider issues of risk transfer to third parties in their programs.

The scope of OOSE programs generally include equipment, buildings and other related facilities where there is an intent to discontinue use or operation of the facility. Activities such as routine maintenance and periodic turnarounds that require temporary equipment outages would typically be out of scope. The primary components of an OOSE program, whether applied to existing or future situations, must consist of at least the following elements:

- determination of equipment disposition;
- field equipment identification;
- hazard identification and risk evaluations;
- physical modifications, as needed, to ensure that safety requirements and/or risk criteria have been satisfied;
- inspection, testing and preventive maintenance.

Organizing an OOSE Hunt

The extent to which abandoned equipment is a concern in an existing facility will be a function of the plant's age, the operation's size and complexity, and, to some degree, past management practices. For example, abandoned equipment may be prevalent in a facility that has been in operation for 50 years or more, long before MOC practices were commonplace.

Conversely, newer plants that have been commissioned in the past decade would not be expected to contain a substantive quantity of abandoned or even decommissioned equipment. Regardless of an operation's age, size and complexity, owners/operators must take proactive steps to understand and manage the risk associated with OOSE in their facility. The following four stages have been demonstrated in practice to be both necessary and effective toward achieving this objective.

Stage 1: Field Identification

An organized, deliberate effort to identify OOSE in the field is a necessary first step toward incident prevention. Including experienced operating staff in this effort is strongly recommended, as their knowledge and history with the plant will assist in this pursuit. OOSE must be identified as such, and it is generally recommended that a unique, weather-resistant tag be securely affixed to the equipment.

The tags raise awareness of the potential risks to maintenance and contract employees who may be required to work on the equipment in the future. As such, flanges, pipe unions, manway covers and other common line-break locations are logical attachment points for tags. Furthermore, the tags should include a unique alphanumeric identification system that will allow the OOSE inventory to be catalogued in a database. Suitable examples of OOSE tags have been included for illustration purposes (Photos 13 and 14).

Stage 2: Cataloging & Categorization

An electronic database allows OOSE inventory to be catalogued, along with relevant data pertaining to the equipment's status and condition. In general, databases permit the information to be easily manipulated, thus facilitating use of the data for various purposes. The minimum recommended information that should be documented in the database is as follows:

- tag identification number;
- equipment (technical) identification number;
- equipment description;
- last service, if known;
- remarks regarding the possible presence of (process) inventory, electrical hazards and physical connections to other equipment;
- a qualitative evaluation of the equipment's condition, based on visual inspection;
- categorization of the recommended disposition (i.e., decommission, mothball, dismantle or recommission);
- recommended inspection frequency.

Stage 3: Hazard Identification & Risk Evaluation

The decision to dismantle equipment is occasionally guided by business needs, such as plant expansions and debottlenecking efforts where the retired equipment is a physical obstruction. However, the decision to dismantle is not always this straightforward. A risk evaluation is often necessary to identify and sort the unacceptable scenarios and further prioritize the scope of work.

Photos 13 and 14: Examples of out-of-service-equipment tags.

The chosen approach can be as elementary as a checklist that contains well-constructed questions designed to identify the common hazards. Although this can be an effective technique for hazard identification, it does not lend itself well to creating a risk-based inventory list and establishing budget priorities. This can be especially challenging for older facilities with a relatively large OOSE inventory and limited financial resources.

A risk screening approach has been described by Wasileski and Henselwood (2011) whereby risk-screening instruments are constructed through a retrosynthesis methodology. This approach is particularly useful in situations in which it is desirable to evaluate a large number of scenarios and prioritize those scenarios for either corrective action or further study. When the screening instruments are developed at the start of the OOSE project, it permits field staff to collect the key inputs that are later needed to make decisions regarding the risk. The author strongly recommends the use of this risk screening approach for facilities facing a relatively large inventory of OOSE.

Of course, other approaches may be used to understand and evaluate the risks, and the choice to use one method over another may be dictated by company policy. Regardless of the approach, it is paramount that unacceptable risks are identified and corrective actions are implemented.

Stage 4: Inspection, Testing & Preventive Maintenance

Equipment that has been retired from service and properly decommissioned may, in many cases, be permitted to remain in the plant. Proper decommissioning should always include the removal of process inventory, physical isolation or separation from other equipment, and de-energizing electrical equipment. Thus, the decommissioned equipment may not pose unacceptable risks in its current state.

Dismantling the equipment may be difficult to justify using traditional cost-benefit analysis under these conditions. Perhaps the best argument for dismantling lies in the concept of inherent safety (Kletz, 1978). By dismantling the retired equipment, the threat is gone, and with it the continued need to manage the related risks, thus making dismantling the best option in terms of the application of inherent safety concepts. Notwithstanding this sage advice, OOSE has been and will continue to be left installed in process plants. Therefore, it remains necessary to conduct planned, periodic inspections of decommissioned and mothballed equipment that has not been dismantled, to monitor its condition over time.

OOSE that has been tagged and catalogued must be included in the facility's inspection, testing and preventive maintenance program. Visual equipment inspections are recommended at reasonable intervals (e.g., annually) and should include:

- confirmation of the presence of OOSE tags and their condition;
- a mechanical integrity evaluation (commensurate with the type of equipment being inspected);
- safeguard verification, such as energy isolation devices and lockout/tagout equipment;
- With regard to mothballed equipment, an evaluation of the effectiveness of the methods in use and confirmation that adequate preservatives, such as greases and desiccants, are present (Twigg, 2002);
- an assessment of the current disposition and a decision to either maintain or change categories (e.g., change from mothballed to recommission);
- updates to inspection records, equipment files, and relevant process safety information, such as piping and instrumentation diagrams;
- a recommendation pursuant to the inspection, testing and preventive maintenance plan for the equipment that addresses changes to both scope and frequency of the plan for future inspection, testing and preventive maintenance activities.

Owners and operators in the chemical processing industry should implement standards and procedures to safely manage OOSE and prevent future abandonment cases.

Management of Change

MOC programs must have measures to prevent future occurrences of abandonment. MOC standards must provide guidance on what constitutes a change of service, such that operating personnel can recognize the triggers for retirement. Also, routine activities such as planned general inspections and insurance surveys can supplement these efforts by identifying questionable situations that should perhaps be subjected to an MOC review.

As with more routine equipment modifications, equipment that is entering retirement must be thoroughly evaluated in a hazard review. A hazard identification and risk assessment technique that is commensurate with the scope and complexity of the change should be selected. Corporate standards should include guidance on review method selection, safety, environmental and legal requirements, and the other aspects explained previously.

Conclusion

The scope of MOC programs must include the entire process life cycle. In comparison to new designs and in-service modifications, the life-cycle period from retirement through demolition often lacks the same types of disciplined MOC reviews (i.e., technically equivalent methodologies). Abandoned equipment creates the greatest concerns, as these items will frequently contain residual quantities of process materials, live electrical connections and physical connections to surrounding process equipment. The hazards created by these conditions can lead to process-related incidents such as fires, explosions and HazMat exposures.

Owners and operators in the chemical processing industry should implement standards and procedures to safely manage OOSE and prevent future abandonment cases. Where practical, inventories of process material should be safely consumed in the process prior to retiring the equipment. Additionally, existing facilities must be subjected to a comprehensive review to identify OOSE, evaluate the risk associated with it and take the necessary measures to ensure that the risks are being managed to an acceptable level. **PS**

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