Chapter 1
Introduction

Every beginning has an end. This book covers the beginning of the end of well life. When a well reaches the end of its life, it must permanently be plugged and abandoned. Plug and abandonment can easily contribute to 25% of the total cost of drilling exploration wells offshore Norway. The cost of running a plug and abandonment operation on some offshore production wells may have a cost impact similar to the cost of the original drilling operation. Therefore, cost efficient plug and abandonment technology is a necessity without compromising the scope of the operation. The occasion that dictates the end of a well life could be integrity issues, subsidence induced well failure, depleted reservoir, water/gas coning, negative cash flow, or finished data gathering from exploration. In addition, there are other circumstances that force the wellbore(s) to be permanently plugged and abandoned. For instance, a platform in the Gulf of Suez, Egypt, was struck by a cargo vessel on December 1989. Due to the massive damage, the nine wells were forced to be plugged and abandoned and a field re-development had to be performed [1]. A question rises; what is the purpose of a plug and abandonment operation? Why are not wells left behind as they are? One answer is establishment of barriers for preventing flow of hazardous fluids to surroundings. The surroundings can be the marine environment, groundwater, ground or atmosphere. The objective of plug and abandonment operations is to restore the cap-rock functionality, securing the well-integrity permanently. In order to succeed, an appropriate permanent barrier shall be placed across a suitable formation through the utilization of relevant equipment to fulfill the local requirements.

Now a comprehensive definition of *Plug and Abandonment* (P&A) could be given as a collection of tasks and actions taken to isolate and protect the environment and all fresh water zones and surroundings from a source of potential inflow. The source of potential inflow is a formation with permeability and it may be either a water or a hydrocarbon bearing zone. The outline of a P&A operation varies a little; whether the well is offshore or onshore, or if the well is going to be abandoned permanently or temporarily, although the main goal is to secure all formations which have the potential to leak. Therefore, we begin the discussion of plug and abandonment with some basic definitions.

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1.1 Abandonment Types

Once the downhole activities or production is discontinued, the well status needs to be clarified. Generally, three different statuses may be defined; suspension, temporarily abandoned or permanently abandoned [2]. When a well is subjected to construction or intervention, the operation may need to be suspended without removing the well control equipment. In this scenario, the well status is called *suspension*. The operation could be suspended due to waiting on weather, workover on another well, waiting on equipment, rig skidded to do short-term work on another well or batch drilling (top section of hole only), or to accommodate pipe lay activities in the field.

Temporarily abandoned is a status where the well has been abandoned and the well control equipment is removed with the intention of later re-entry or permanent abandonment. Another phrase for temporarily abandoned could be *long-term suspension*. Temporary abandonment could be through a long shutdown, waiting on a workover, waiting on field development, re-development, etc. Temporarily abandoned status begins when the main reservoir has been fully isolated from the wellbore and may last from days up to several years. Different regulatory authorities have their own requirements with respect to the maximum period of temporary abandonment. A temporarily abandoned well may be with or without monitoring a system which depends upon the requirements of the regulatory authority, and well location.

Permanently abandoned is a status where the well or part of the well, has been permanently plugged and abandoned with the intention of never being re-used or re-entered.

1.2 Asset Retirement Obligation

Asset Retirement Obligation (ARO) addresses legal obligations and associated costs related to future retirement of long-lived assets. According to ARO, operators are obliged to demonstrate that sufficient assets have been allocated to cover the cost of future P&A operations [3, 4]. An ARO liability includes downhole abandonment, surface abandonment, facility site abandonment, infrastructure dismantling, and site decommissioning [5]. One of the main reasons to bring the ARO mechanism into action is the reported failure to properly abandon wells and facilities which create serious issues for environment, safety, and security. Dry wells or improperly abandoned wells or fields that are left behind require huge public funds to be allocated; however, operators were supposed to be in charge. The ARO, however, does not apply to unplanned clean-up costs such as cleaning up of an accident.

1.3 Prepared for Permanent Plug and Abandonment

When a well reaches the end of its life-cycle, it must be permanently plugged and abandoned. In addition, there are many other reasons for a well to be partially or fully plugged. A safe production operation is primarily about maintaining well integrity and sufficient barriers throughout the well life-cycle. It is common practice to perform risk assessments for all wells. Once risks are identified, wells are assigned color codes. Based on the color codes, whenever well integrity is not maintained or is compromised, the well should be economically repaired or alternatively be permanently plugged. A wellbore that has not encountered hydrocarbons of a commercially viable quantity is usually plugged. These types of wellbores are called either *dry-holes* or *dusters* even though they may contain water. Generally, most dry holes are exploratory wells. Regardless of was an exploration success or not, a common procedure for exploratory wells is to permanently plug and abandon them after data gathering is complete. This is due to their inappropriate well design for production and the costs and risks associate with modifying their design (e.g. uncertainties in the sealing capabilities of the intermediate and production casings, unknown cement tops and damaged formation nearby casing shoes).

Occasionally a sidetrack needs to be drilled to bypass an unusable section of the original wellbore or to explore a nearby geologic feature. Prior to beginning such a sidetrack the borehole below the sidetrack should be permanently plugged.

Slot recovery, re-development and well integrity issues are some other reasons that may initiate a permanent plug and abandonment operation. Slot recovery is a process of recovering an existing drilling or template slot to reach a new target. Slot recovery may be done due to limited rig skidding capacity, an irretrievable fish in a slot, not hitting the target with the original well, or a limited number of slots on a drilling platform or template.

1.3.1 Plug and Abandonment Challenges

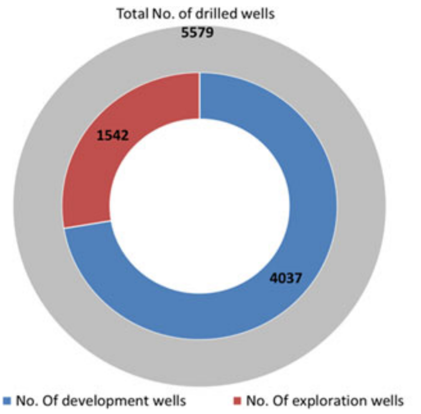
Every well is unique and the associated challenges with it as well. The main challenges which have been reported associated with the P&A of wells, can be categorized as high temperatures, unconsolidated formations, changes in formation strength as a result of depletion, uncertain ultimate reservoir pressure after abandonment, formation permeability, tectonic stresses exerted by formation (e.g. shear stress and subsidence), sustained casing pressure (SCP), lack of data from old drilled wells, deep section milling, and verifying the casing cement behind the second casing string. These are the main challenges that industry moat deal with; however, all of these may not be applicable to a specific well.

1.4 Past, Present, and Future of Plugged and Abandoned Wells on the NCS

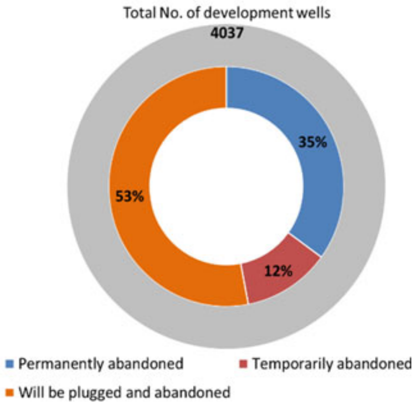
Since the first discovery in the Norwegian sector of the Norwegian Continental Shelf (NCS) in 1966 until June 2015, nearly 5600 wells have been drilled to date. Of these wells, 4037 are development wells and 1542 are exploration wells. Of the exploration wells, 1480 have been permanently plugged and abandoned. Of the development wells, approximately 1400 have been permanently abandoned and 467 have in a temporarily abandoned status. It is estimated that 2637 development wells need to be plugged and abandoned in the near future. In addition, the number of future wells that will be drilled should be added to these statistics [6]. Availability of a database for permanently plugged and abandoned wells could be beneficial for industry, government, and tax payers. This could result in knowledge sharing, optimized planning, and a better understanding of strategies and technology development related to the P&A of wells [7]. Figure 1.1 presents an overview of the status of all the wells drilled in the Norwegian sector of the NCS.

1.5 Digitalization in Plug and Abandonment

Digitalization is a process in which information and knowledge are converted into a digital format [8]. In this way, it is organized into discrete units of data, known as bits. Digitalization has already been implemented by different industries such as the automobile industry. It is not a new concept in the oil and gas industry;



(a) Total number of all drilled wells.



(b) Total number of all drilled development wells.

Fig. 1.1 A status overview of all wells drilled on the Norwegian sector of the NCS the upstream industry has been relying on digital technologies for many years. Of these, one can refer to seismic data processing from the 1980s and monitoring and optimizing critical production processes from the 1990s [9]. Digitalization has some core benefits including access to data, data management, improving accuracy in engineering by implementing the latest theories and models, optimal planning and operation, minimizing human error or human factors which contribute to failures or incidents, changing human involvement to a supervisory role and finally leading to the automation of the drilling process [10]. But digitalization creates big data volumes and it has associated challenges including data capturing, data storage, data analysis, search, sharing, transfer, visualization, querying, updating and information security [11]. These challenges need to be considered along the way of digitalization in the oil and gas industry. Digitalization of standards may also be considered in different ways; integration of standards and regulations in software programs to “police” the plans and operations or inclusion of standards as help files [12].

Applying digitalization in P&A can be differentiated for old wells and new wells. Perhaps, the most challenging part will be the digitalization of old wells; new wells can be equipped with sensors to monitor the wells and track them from the day of design and construction to abandonment. When considering digitalization of old wells, it is possible to register the well location, well status, well schematic, mechanical failures, HSE issues, previous rig footprints, and archiving the well data. One of the “low-hanging fruit” benefits of digitalization is having an updated overview of well numbers and their status. This has been implemented properly in the oil and gas sector of Norway by the Norwegian Petroleum Directorate.

1.6 The Regulatory Authorities

Regardless of abandonment type, operators must leave wellbores behind which are secured in accordance with local regulations. Figure 1.2 maps some regulatory authorities managing petroleum activities in their own territories. Different regulatory bodies have their own requirements and operators must strictly adhere to local well-abandonment regulations. Local regulations are the minimum requirements and have changed considerably over the years to facilitate P&A operations in a safe manner. Nevertheless, some operators have their own internal requirements and tend to follow them where the regulatory authorities do not provide minimum requirements.

The North Sea could be divided into four sectors; the United Kingdom, the Norwegian, the Danish and the Dutch. The Health and Safety Executive (HSE) is the appropriate department that oversee the petroleum activities in Britain. In the Danish sector, the Danish Energy Agency (DEA) is the regulatory authority. The Dutch Supervision of Mines and the Norwegian Petroleum Directorate (NPD) are the regulatory authorities for the Dutch and Norwegian sectors, respectively. The NPD is the governmental specialist directorate and administrative body for the NCS. The NPD acts as an adviser to the Ministry of Petroleum and Energy (MPE) of Norway. In the Norwegian maritime territory, there is an independent government regulator,

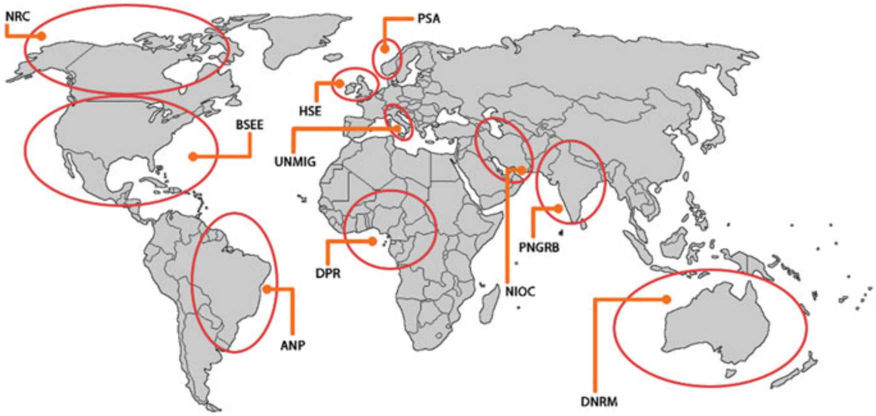


Fig. 1.2 Regulatory authorities, oversee their own petroleum activities

which is known as the Petroleum Safety Authority (PSA) Norway with responsibility for safety and emergency preparedness in the Norwegian petroleum industry. The PSA is the legislative authority for P&A activities and reviews the proposed P&A plans for the NCS. The PSA is the responsible organization for overseeing the P&A operations.

1.7 P&A Barrier Philosophy

There is a generally accepted philosophy for well barriers that the well should be equipped with sufficient well barriers to prevent uncontrolled flow from the potential sources of flow. In addition, it is generally accepted that no single failure of a well barrier component should lead to unacceptable consequences. This means that, in practical terms, the well should be equipped with two independent well barriers; a primary and a secondary barrier. This is also known as "hat-over-hat" principle whereas the secondary barrier acts as a back-up to the primary well barrier, as shown in Fig. 1.3.

The function of the barrier philosophy could be slightly different in circumstances where the P&A operation is ongoing or a well has been permanently plugged and abandonment. For a well P&A operation, some barrier elements need to be in an open position to allow access to the borehole and perform the P&A operation. It is critical that these elements close in circumstances when it is necessary to halt the operation. So the primary and secondary barrier elements may vary based on the pre- or post-abandonment status. The P&A barrier principles will be discussed thoroughly in the next chapter.

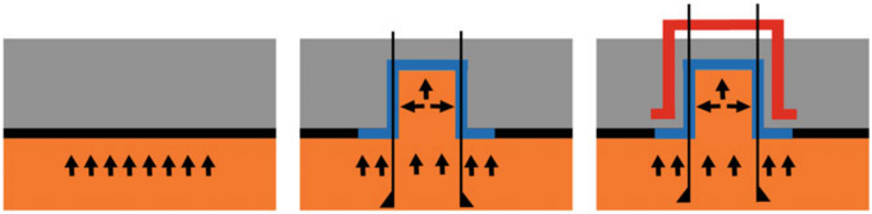


Fig. 1.3 Two-barrier philosophy shown using the "hat-over-hat" representation

1.8 The Beginning of the End—Decommissioning

All the activities conducted to shut down and remove facilities from service is defined as *decommissioning*. Decommissioning of facilities is highly complex, often even more so than the original installation. Decommissioning is a generic description and it is applicable for both offshore and onshore facilities, and it could be regarded as the beginning of the end of the facilities. Decommissioning can be challenging especially for offshore facilities and particularly in deep waters; a decommissioning process can be monumental and requires detailed considerations by specialized crews [13]. Decisions about when and how to decommission platforms involve complicated issues of environmental protection, safety, technical feasibility and associated costs.

Prior to conducting decommissioning, a *decommissioning plan* needs to be prepared and submitted to the competent authority. A decommissioning plan may consist of two main parts; a disposal plan and an impact assessment. The impact assessment provides an overview of the expected consequences of the disposal such as environmental consequences. According to the Norwegian Act 29, issued in November 1996 No. 72 relating to petroleum activities [14], the cessation of petroleum activities, Sect. 5.1; "*the decommissioning plan shall be submitted at the earliest five years, but at the latest two years prior to the time when the use of a facility is expected to be terminated permanently*".

A decommissioning plan generally includes descriptions of [15, 16]:

- Results of a documentary survey relating to facility design, fabrication, installation, commissioning, etc.;
- Possible risks during and after facility removal;
- Intended methods and strategies to be used during decommissioning, including re-floating of structures;
- Intended analyses which are planned to be carried out;
- Operations planned to be carried out in the event of a possible removal;
- Possible impacts of a removal on adjacent fields and facilities;
- Methods of waste control; and

- Possible monitoring systems which may be designed to secure the area against possible future pollution from permanently abandoned wells or polluted cuttings deposits.

The remaining issues regarding decommissioning are the associated cost and the question of who holds the liability; and according to the OSPAR Convention,[1] the ultimate responsibility of decommissioning remains with the facility owner.

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