Useful Life of the Trans-Alaska Pipeline

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Abstract

Useful life is defined as a combination of *design life, physical life,* and *economic life.* The useful life of TAPS can be described as the period during which the pipeline provides a safe, environmentally sound, economically viable transportation link to get Alaska North Slope crude oil to market. Useful life is also one of the three primary elements for establishing the duration of the federal and state rights-of-way for TAPS, the others being serving a public purpose or benefit, and the ongoing facility costs.

This paper addresses the following issues with special emphasis on facility aging and life-cycle issues associated with operating a warm crude oil pipeline in cold regions:

- TAPS design life is based on the incorporation of robust components coupled with system monitoring programs designed to detect and counteract aging and facility use factors.
- TAPS physical life can be virtually unlimited given the execution of appropriate maintenance, repair and replacement programs.
- TAPS economic life is governed by the extent of recoverable North Slope crude oil reserves. Predictions show these reserves being produced in quantities sufficient to support the continued operation of the pipeline well into the 21st century.

Introduction

The Trans Alaska Pipeline System (TAPS) has transported over 13 billion barrels of Alaska North Slope crude oil since start-up in 1977. The pipeline currently carries nearly 20 percent of all crude oil produced in the U.S., and it can continue for decades to provide a critical link in the supply of a significant share of the nation's crude oil.

In its 800-mile (1288 km) length from the North Slope oil fields to the port of Valdez, the pipeline crosses hundreds of miles of state and federal land. Before constructing and operating the pipeline on those lands, the TAPS Owner companies were required to obtain long-term, renewable rights-of-way from the government land

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management agencies. These rights-of-way, issued in 1974 for 30-year terms, expire in 2004. The TAPS Owners' application for renewal of these federal and state rights-of-way seeks the maximum terms for the renewals.

In considering the length of a renewal term, federal and state right-of-way laws invoke several criteria — the useful life of the pipeline, its public purpose, and its cost. The focus of this paper is the useful life of the pipeline, which comprises both physical and economic utility. The physical life span of a pipeline is determined primarily by both the quality of its original design and its upkeep. The economic life of a crude oil pipeline is determined by how long it can provide its owners with a reasonable economic return and attract shippers.

Useful Life

While the term "useful life" is not defined in the applicable laws or regulations, the useful life of TAPS seems clearly meant to describe the remaining life of the pipeline, which is a function both of its physical life span and its economic utility. The physical life of the pipeline is determined principally by the nature of its original design and subsequent maintenance, repair, and replacement activities. The economic life of the pipeline is determined by how long it provides reasonable economic return, considering original investment and operating costs.

For purposes of this document, *useful life* is defined as a combination of *design life, physical life,* and *economic life.* The useful life of TAPS can be described as the period during which the pipeline provides a safe, environmentally sound, economically viable transportation link for Alaska North Slope crude oil.

TAPS useful life can continue well beyond the maximum allowable 30-year right-of-way renewal because:

- TAPS design life is based on the incorporation of robust components coupled with system monitoring programs designed to detect and counteract aging and facility use factors.
- TAPS physical life is considered virtually unlimited given the execution of appropriate maintenance, repair, and replacement programs.
- TAPS economic life is governed by the extent of recoverable North Slope crude oil reserves. Predictions show these reserves being produced in quantities sufficient to support the continued operation of the pipeline, with tariff rates that attract shippers, well into the 21st century.

The succeeding sections discuss, in turn, design life, economic life and physical life in more detail.

Design Life

Engineers developed design criteria for TAPS based on assumptions that protection of the Alaska environment was paramount and that, as the only oil transportation link to Alaska's North Slope, the pipeline had to function reliably and safely, with sufficient structural integrity to resist arctic conditions over an indeterminate period. These significant technical challenges resulted in a design that incorporates many redundancies and safety factors to account for known and unpredictable future conditions. The pipeline design was intentionally robust, and 25 years of operation have provided the opportunity for a critical evaluation of the design assumptions and features (TAPS Owners, 2001b). That evaluation has confirmed that the design decisions were correct.

Key TAPS design features addressed technical challenges such as support of a warm-oil pipeline in permafrost and seismic risks to pipeline integrity.

Design elements included assumptions and features that anticipated the effects of aging, such as:

- Estimates of thaw settlement allowances for buried pipeline segments,
- Pipe movement allowances in the above-ground design to provide for crude-oil temperature changes over time, and
- Analysis of soil creep or frost jacking at aboveground pipe supports.

TAPS performance is evidence that the design tolerances and protective features have been more than adequate to meet the challenges. Pipeline integrity has been stable, and age-dependent issues have been manageable over time. Buttressing the design features are surveillance and monitoring programs that continually assess the viability and functioning of the system and gauge the status of the pipeline system against the original design standards. Maintenance and repair programs keep TAPS in a safe, reliable state that protects the surrounding environment from adverse impacts from TAPS operations.

The design life of TAPS is a concept used by engineers to provide a basis for time-dependent economic analysis of alternative materials and techniques for the original pipeline design. For continued operations, the performance of design features that mitigate the effect of cold region operation or seismic risk is continually evaluated and upgrades and modifications are made whenever appropriate.

While some early statements regarding the intended service life of the pipeline estimated 30 years, in fact the pipeline design was not based on retirement or cessation of operations 30 years from the start of operations in 1977. These statements are derived from original estimates of the life of the proven Prudhoe Bay field reserves (Norman, 1971), which were used to justify the field owners' decision to proceed with TAPS construction. However, given the size of the Prudhoe Bay field, the possibility of further North Slope discoveries, and the consequences of a design failure, the pipeline was designed and built so that it could be physically operated indefinitely while meeting all safety and environmental criteria. Of course, Prudhoe Bay has produced far more reserves and has a far longer life span than originally predicted. Moreover, other significant North Slope fields have been, and still are, being developed. The original design goal — to incorporate features which would facilitate a virtually unlimited useful life of the system — was well selected.

In fact, the initial duration of the Federal Grant and State Lease was set at 30 years because that was the maximum period allowed by law, not because of any concern that the pipeline system would not last longer than 30 years.

Economic Life

The economic life of TAPS is essentially determined by whether there is sufficient North Slope crude oil economically available to justify continued operation of TAPS.

U.S. government and State of Alaska predictions of North Slope oil production show that, although production from current fields will continue to decline, by 2020 production will level off in the range of 500,000 barrels per day until the end of the period in 2034. These conservative estimates are based principally on well-established decline curves for existing fields and on a small increment in future production to be supplied by increased production from existing fields and by production from very modest discoveries. The estimates do not include the assumption that any oil will be produced from new major discoveries or from areas that are currently closed to exploration and production. More than sufficient economically recoverable oil is available to support the operation of the pipeline.

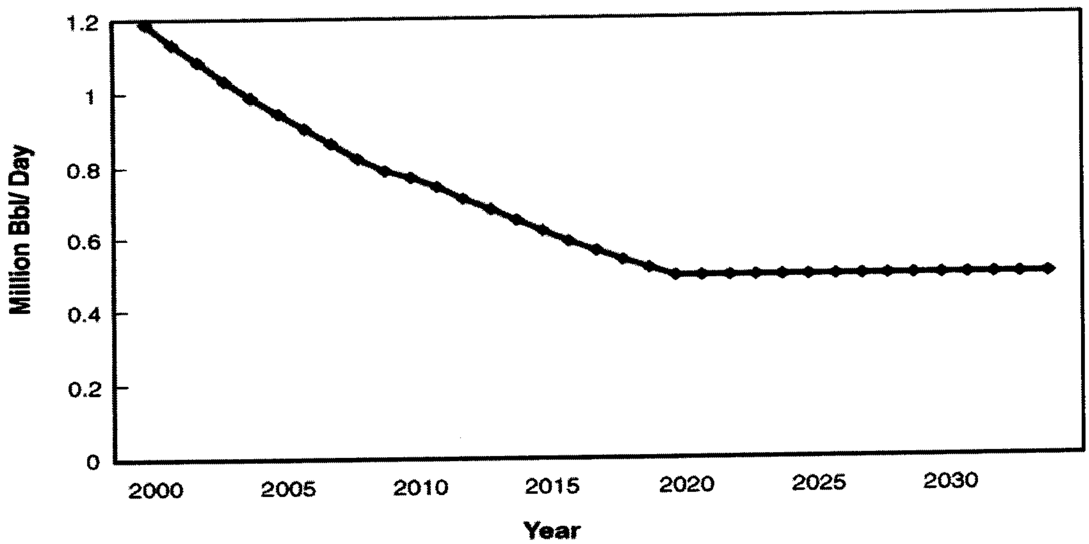

Figure 1 - Projected Throughput to 2034 (Source: TAPS Owners 2001a)

Currently, TAPS throughput is about 1 million barrels per day (bbl/day). Throughput projections indicate that throughput will continue to decline and then stabilize at about 500,000 bbl/day (TAPS Owners, 2001a) (Figure 1). At pipeline startup in 1977, throughput was about 300,000 bbl/day, and at peak operation in 1988, throughput was over 2 million bbl/day (Figure 2). Two conclusions can be drawn from this operating experience:

1) TAPS has already operated in the throughput ranges expected to occur in the next 30 years, and
2) Since throughput has decreased by over one million bbl/day in 12 years, dealing with an additional decline of 500,000 bbl/day in the next 30 years is well within technical and operating abilities.

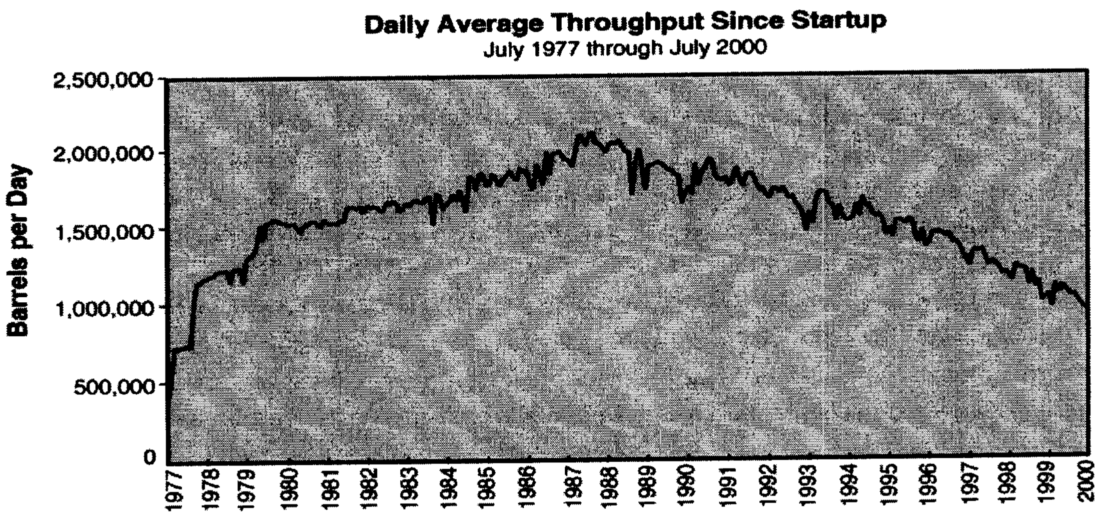

Figure 2 - Daily Throughput

Physical Life

TAPS physical life will last as long as the integrity of the pipeline and facilities is maintained adequately to allow continued safe and environmentally sound transport of crude oil. Alyeska possesses one of the industry's most rigorous maintenance programs, key aspects of which are continual monitoring and replacement of TAPS components, where advisable, either to ensure system integrity or to take advantage of technological improvements and efficiencies. Just one indication of the massive nature of that program is the approximate $25 million to $50 million spent each year to detect and control corrosion.

TAPS is proven to be reliable — from July 28, 1977, through December 31, 2000, the pipeline operated for over 204,000 hours and was shut down for a total of only 852 hours, giving it a reliability rate of 99.6 percent. The pipeline also has an excellent performance record with respect to leaks. Since startup, over 13 billion barrels of crude have been transported, with only 6 major leaks (i.e., greater than 1,000 barrels) on the mainline pipeline totaling approximately 31,600 barrels, one-half of which occurred through a sabotage incident at Steele Creek. The expectation is that these results will be improved on in the future, given diligent upkeep and further developments in such areas as in-line inspection and leak detection technology which Alyeska has pioneered in past years.

Since startup of TAPS in 1977, Alyeska has continued to improve and expand its initially comprehensive programs to detect and repair potential problems that might threaten the integrity of the pipeline system. Alyeska has developed innovative, state-of-the-art methods to monitor the condition of the pipeline and associated facilities. Where corrosion, settling, or other problems have been detected, prompt repairs — including the replacement of several sections of mainline pipe — have been made. These programs verify that the initial design specifications and construction methods were robust and lasting even in harsh arctic conditions.

Pipeline Longevity/Performance Studies

In addressing TAPS longevity, it is useful to compare the TAPS operating period with that of other pipelines. Some pipelines have been in good operating condition for more than 50 years (Muhlbauer, 1996).

A study of Cook Inlet, Alaska, oil pipeline performance performed by Alaska Department of Environmental Conservation (ADEC) noted:

> "The fact that the pipelines have reached their original design life does not imply that the lines have become inadequate or unsafe. The integrity of an older pipeline is a function of how well the line has been maintained, the type of throughput, and how the current operating conditions compare with the original design conditions. With proper maintenance the remaining life of a pipeline can be several multiples of the original design life." (Visser et al., 1993)

Several studies have examined the effect of aging on pipelines. In one recent study, a European pipeline consortium collected data over a 25-year period on the performance of cross-country oil pipelines in Western Europe (Lyons, 1998). The data were analyzed to record the pipeline system development over time, quantify environmental performances, and reveal trends in causes of spills. The following summarizes the findings of the study:

- In 1971, 70 percent of the pipelines inventoried were 10 years old or less, but by 1995 only 8 percent were 10 years old or less and 30 percent were over 35 years old.
- Pipeline spills averaged fewer than 14 per year and most were very small. Less than 5 percent of the spills were responsible for 50 percent of the gross volume spilled.
- Over the 25 years, the frequency of spills improved from 1.2 spills per 1,000 kilometers (620 miles) of pipeline to 0.4 spills per 1,000 kilometers.
- The two most important causes of spills are third-party accidents and mechanical failure, with corrosion in third place, and operational and natural hazards making minor contributions.

The study concluded that there is no evidence that the aging of a pipeline system increases risk. The development and implementation of new techniques, such as internal inspection using smart pigs, hold out the prospect that pipelines can continue reliable operations for the foreseeable future.

In assessing TAPS longevity versus performance, it is useful to review oil spill statistics over time. If aging of TAPS increased risk, an upward trend in oil spills would be noted. Such an analysis was done for the draft *Environmental Report for Trans-Alaska Pipeline System Right-of-Way Renewal* (TAPS Owners, 2001) (Figure 3) presents volumetric spill rates by year for the pipeline. There is substantial variability, but also evidence of a downward trend in volumetric spill rates in later years. Except for a sabotage incident near Livengood, all large pipeline spills occurred during the first five years of operation of TAPS.

A linear regression line (the dashed line in Figure 3) has a negative slope, indicating decreasing volumes spilled. Nonetheless, the predictive power of the linear trend model is not high, indicating that year-to-year variability is large relative to any time trend. For this reason, it is conservatively assumed that the volumetric spill rate is constant over time. Consequently, oil spill statistics do not indicate a pipeline nearing the end of its useful life.

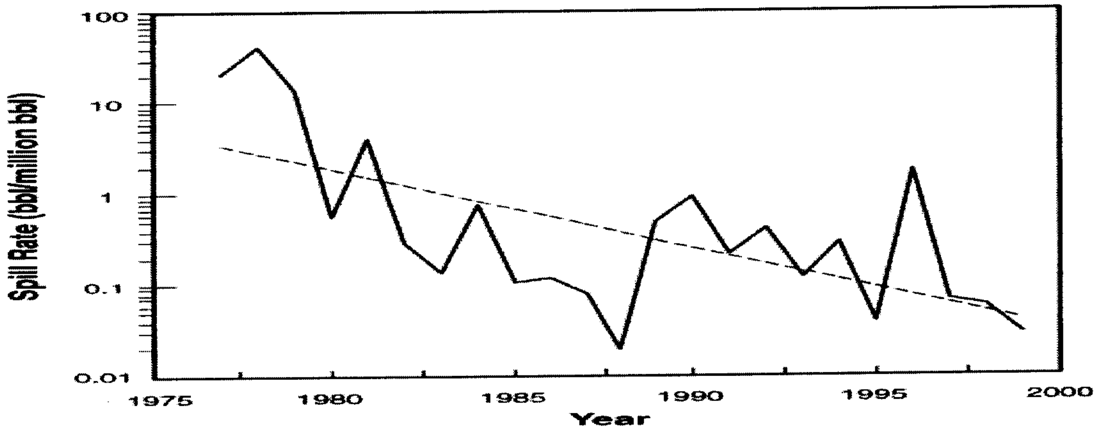

Figure 3 - Volumetric Spill Rates by Year

Age-Related Effects on Pipelines

Pipeline age itself has no metallurgical effect on the microcrystalline structure of steel that would cause the strength and ductility of the pipe to degrade over time. However, there are several ways that the age of a pipeline can influence the potential for failures, including corrosion, fatigue, and manufacturing and construction methods (Muhlbauer, 1996; Crocket and Maguire, 1999). An indirect effect of age is the increased time when a pipeline is exposed to the threat of "outside-force damage" (damage caused by accidental impact from an external force such as a vehicle or heavy equipment).

The following discussion highlights these effects on pipelines in general. Following this discussion is a section describing techniques and programs used specifically on TAPS to mitigate the threat of these age-related effects.

- **Corrosion** is related to the environmental conditions surrounding the pipe. It is reasonable to assume that with the passage of time, the opportunity for undetected (and hence, uncontrolled) corrosion and/or fatigue effects increases. Pipe-coating systems are susceptible to deterioration over time from mechanical abrasion and chemical reactions from absorbing gases and liquids in the surrounding environment. Pipeline operators use corrosion-control programs to counter the threat from corrosion.
- **Fatigue stresses** that result in cracks are a potential effect of age in metal pipelines. Fatigue cracks, if unchecked over time, can lead to pipe failure. Pressure fluctuations during pipeline operation over long periods can lead to fatigue. Common practices used to detect fatigue are fatigue monitoring, hydrostatic testing, and in-line inspection with crack detection tools.
- **Manufacturing and construction methods** can affect physical life. Poor field welds, incomplete fusion of longitudinal pipe seams, and defects in the steel manufacturing process could contribute to pipe failure over time. Although most defects of these types are detected before initial pipeline operation, some defects could manifest themselves over time as pressure cycles, fatigue stresses, and external impacts affect pipeline performance. Radiographic examinations of

welds, construction and manufacturing inspections, hydrostatic testing, and in-line inspections are methods by which this threat to pipeline integrity is detected.

- **Outside-force damage** is an indirect age-related effect on physical life simply by the increased time of exposure to potential incidents. Damage caused by outside forces is usually localized and is minimized by information dissemination (e.g., posted notices, public awareness campaigns), surveillance, and monitoring.

Mitigating the Effects of Age on TAPS

Potential effects of age discussed above are countered on TAPS through surveillance and maintenance programs to identify flaws in coatings, provide adequate cathodic protection and monitor pipe condition through in-line inspection. Pumps, turbines and other components of the pipeline are repaired and replaced as required. If the potential age-related effects are properly controlled, the physical life of the steel pipe is considered essentially unlimited. On TAPS, potential age-related threats are mitigated as described below.

Corrosion. Monitoring of corrosion protection is accomplished in several ways. Cathodic protection monitoring of mainline pipeline takes place annually. Data are gathered from test stations, buried corrosion coupons, cased road crossings, and the fuel gas pipeline. Cathodic protection data also are gathered at buried propane tanks, pump stations, and the Valdez Marine Terminal. Rectifiers are checked six times a year.

Inhibitors are used to control corrosion in isolated and low-flow or seldom-flow piping in pump stations and in road-crossing casings. Internal coupons, which verify the effectiveness of the inhibitors, are removed and analyzed twice yearly. In-line inspection tools ("smart pigs") are used to monitor corrosion and curvature on the mainline pipeline. Data are collected, stored, evaluated, and trended.

Fatigue. Cracks from fatigue stresses can affect the physical life of metal pipelines. On TAPS, two potential fatigue-stress scenarios exist: structural resonance of the piping and pipeline pressure-cycling.

Structural resonance of piping occurs in the piping manifolds of mainline pumps when the pump impeller spins at a rate that can excite the piping or its appurtenances at their natural structural frequency, resulting in high vibration and stress levels. Structural resonance manifests itself only in piping and appurtenances adjacent to the mainline pumps. To mitigate the effects, operators routinely check for fatigue damage to piping near the mainline pumps and implement corrective measures as required to maintain system reliability.

Pressure-cycling is a concern only in areas on the mainline pipe where dents, sleeves, or similar anomalies can result in localized pipe-wall bending stresses as the pipe goes through changes of pressure. The degree of potential fatigue damage depends on the number of cycles and the stress magnitude for each cycle. For dents, sleeves, and other pipeline anomalies, the potential fatigue stresses can be high during shutdowns and restarts, but the number of cycles is low. In areas where the cycles may be high, such as at the base of slackline areas, the pressure deviations and resultant stresses are low. These slackline and dent areas, such as Thompson Pass, have been studied, and either fatigue life has been determined to be unlimited or corrective actions have been implemented. (Baskurt et al., 1998; Hart et al, 1998; Norton et al., 1998; Stevick et al, 1998; Tart and Hughes, 1998; Tonkins et al., 1998)

Manufacturing and Construction Methods. Manufacturing defects or poor construction methods could have a deleterious effect on the longevity of a pipeline. However, TAPS was built under the most stringent criteria available and was closely inspected, tested, and monitored. The following examples of pipe materials, welding, and valves indicate the level of mitigating measures employed.

Mainline Pipe. TAPS pipe is carbon steel (API 5LX and 5LS) with five different pressure capabilities. There are two wall thickness 0.462-inch (11.7 mm) and 0.562-inch (14.3 mm) and three specified minimum yield strengths 60,000; 65,000; and 70,000 psi (413,400; 447,850; and 482,300 kPa).

The design basis criteria for allowable curvature were based on pre-construction mainline pipe testing at the University of California at Berkeley (Bouwkamp and Stephen, 1974). In order to study the potential behavior of the pipeline prior to construction, test specimens were subjected to a number of different load conditions. The basic parameters in these studies were the internal pressure and the temperature differential between tie-in or installation temperature and operating temperature. To evaluate these phenomena under increasing lateral loads, a total of seven specimens under different pressure and simulated temperature conditions were investigated. These tests continued until the pipe wall buckled. For five specimens, tests continued until the pipe wall ruptured. Furthermore, one test specimen was used to study the effect of a pressure drop on pipe-wall stability.

Recent advances in analytical techniques have led Alyeska to develop tools to evaluate the below-ground pipe at specific locations on the basis of the demand on the pipe and the pipe's particular capacity to resist bending. These studies and tools allow Alyeska to confirm that, in light of current technical knowledge, TAPS pipe continues to retain original throughput performance capabilities.

Welding. Welding on the pipeline, whether during construction or repair, must:

- Be performed by qualified welders in accordance with approved procedures;
- Be protected from weather conditions such as precipitation;
- Be performed in a manner to prevent, repair, or remove defects; and
- Undergo nondestructive testing (radiography and hydrotesting).

All mainline pipe was hydrotested and all welds inspected by radiography before TAPS was commissioned. In the event that pipeline repairs require relocation or replacement, all replacement components undergo hydrostatic testing, and all mainline welds are inspected to ensure the integrity of the relocated or replacement pipe. Alyeska does not use any replacement pipe or component that has not been hydrostatically tested in conformance with Department of Transportation standards or that fails to meet hydrostatic testing standards.

Valves. Alyeska specifications for the design of mainline valves require conformance to American Petroleum Institute standard API 6D, as well as several other requirements. Department of Transportation regulations under 49 CFR 195 also require that new valves meet the test requirements of API 6D, which covers valves of 2-inch nominal pipe diameter and larger.

The Department of Transportation regulations also require pipeline operators to maintain those valves "required for safe operation" in good working order. Alyeska maintains its valves in good working order and demonstrates the functionality of the valves through partial closure of the valves twice a year. In addition to the regulatory requirements, Alyeska implemented the TAPS Valve Program in 1997 to validate the condition of these valves and to perform testing to determine if the valves performed in accordance with sealing criteria developed by Alyeska. Valves that do not meet performance criteria are repaired or replaced. (Aus et al., 2000; Jackson and White, 2000; Pomeroy and Norton, 2000; Weber and Malvick, 2000)

Outside-Force Damage. Approximately half of the 800-mile (1288 km) pipeline is above ground and, therefore, potentially subject to damage caused by accidental impact from an external force such as a vehicle or heavy equipment. Access to most of the right-of-way is determined by the federal (Bureau of Land Management) and state (Alaska Department of Natural Resources) landowners. In addition, Alyeska limits access to the pipeline through signs and with locked gates on access roads to the right-of-way. For locations where access roads pass under the pipeline, "headache" bars have been installed to ensure that vehicles have enough clearance under the pipe.

For below-ground pipe, all excavation within the right-of-way must be authorized by Alyeska. Warning signs along the pipeline contain a 24-hour telephone number to contact the Controllers at the Operations Control Center (OCC). Callers with excavation requests are connected with the appropriate personnel to coordinate excavation requirements. In addition, Alyeska conducts an educational program to help the public, government organizations, and people engaged in excavation-related activities to recognize a crude-oil pipeline emergency and to report it to Alyeska and/or other emergency response organizations.

Alyeska's pigging program monitors the pipeline for external damage using state of the art ultrasonic technology to detect pipe-wall thinning from gouges and scrapes. Other curvature pigs detect dents and ovalities. Leak detection systems monitor for leak loss from any source, including outside-force damage.

Conclusion

The useful life of TAPS is the period during which an economic benefit is derived from continuing operations and during which the pipeline can be operated safely and without harm to the environment. The useful life of TAPS will continue well beyond 30 years for at least three key reasons.

1) The physical life of TAPS is virtually unlimited assuming continued appropriate maintenance and surveillance. In-line inspection tools (smart pigs) for pipeline corrosion, deformation and settlement are run on rolling three-year

cycles. If corrosion or other damage is found that would reduce the capacity or pressure capability of TAPS, repairs are made. Pumps, turbines and other components of the pipeline are repaired and replaced as required.

2) The economic life of TAPS will continue for the foreseeable future based on pipeline throughput estimates from a variety of public sources.
3) The design life of TAPS is a concept used by engineers to provide a basis for time-dependent economic analysis of alternative materials and techniques for the original pipeline design. For continued operations, the performance of design features that mitigate the effect of cold region operation or seismic risk is continually evaluated and upgrades and modifications are made whenever appropriate.

Acknowledgements

The authors wish to acknowledge Alyeska Pipeline Service Company for providing support for this paper. The authors especially wish to acknowledge James F. Johnson, James Lukin, Bill Christian, Dan Maxim, and Rebecca McAllister.

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