The oxidation of 24 commercially available superalloys was measured after exposure in still air at up to 1150°C for up to 10,000 hr. The total depth affected by oxidation, which includes subscale reactions, followed the expected exponential relationship with temperature and the expected parabolic relationship with exposure time at 1000°C; oxidation of “Haynes” 25 and TD nickel chromium was not parabolic at 1150°C. The alloys could be divided into four groups according to relative resistance to oxidation at 1000°C. These differences in resistance could be explained qualitatively by the nominal compositions of the alloys.

INTRODUCTION

Because of their strength and resistance to oxidation at elevated temperatures, the nickel- and cobalt-based superalloys are candidate cladding for radioisotope heat sources that could supply power for remote marine and terrestrial locations. The superalloys are particularly suited for encapsulating irradiated cobalt metal (\(^{60}\)Co) for these heat source applications.\(^1,2\) Resistance to oxidation is required because heat source capsules may be directly exposed to a heat transfer fluid that contains oxygen or oxide compounds as impurities or to air under emergency conditions. Problems of compatibility between capsule materials and cobalt are minimized because the properties of the superalloys and cobalt are similar. Since no gas is generated inside the capsule as the \(^{60}\)Co decays, the stress in the capsule wall is low (<500 psi)
and makes feasible the desired service life of 1–5 years at temperatures near 1000°C. The service life is based on the half-life of $^{60}$Co, 5.27 yr; high temperatures are required to increase the efficiency of the power conversion systems.

This report summarizes measurements of the oxidation of 24 superalloys during exposure to still air at up to 1150°C for times as long as 10,000 hr. Published oxidation data were inadequate to predict the resistance of the superalloys to oxidation at the expected service conditions. These tests were part of a program to select suitable alloys for encapsulating $^{60}$Co, define the limiting operating conditions, and demonstrate the performance of capsules at typical heat source conditions.$^{3–5}$

**EXPOSURE CONDITIONS**

The 24 alloys that were tested are listed in Table I with their compositions and a summary of oxidation test results. Most of the alloys were selected because published oxidation data suggested that they might withstand the expected operating conditions of heat sources. Other alloys were selected because they were representative of certain classes of alloys. For example, “Tophet” A, “Tophet” C, and “Haynes” 150 are simple binary or ternary alloys based on nickel or cobalt; GE 2541 and “Haynes” 188 have minor additions of rare earth elements. Three commercial grades of pure nickel were selected as reference materials. Only a few iron-based alloys were tested because published data indicated that they would have an inadequate resistance to oxidation. None of the precipitation-hardenable alloys, such as “Udimet” 700 or IN-100, were tested because the phases responsible for the increased strengths of these alloys begin to dissolve at the expected service conditions.$^{20}$

Since the purpose of these tests was to provide data for predicting the performance of the alloys, exposure conditions were designed to measure the kinetics of oxidation. The effect of temperature was measured by exposing cylindrical samples 0.250 to 0.500 inch in diameter × 0.500 inch long to still air (ambient muffle furnace atmosphere) for 500 hr at 850, 950, 1000, and 1150°C. The effect of time at temperature was measured by exposing coupons 1.000 in. long × 0.500 in. wide × 0.060 to 0.080 in. thick at 1000°C for 1000, 5000, and 10,000 hr. All samples were heated at each temperature concurrently in the same furnace. Cylindrical samples of the more resistant alloys were exposed for 3000 hr at 1150°C in an accelerated test to confirm the kinetics observed in the other tests. The latter conditions were selected because the expected amount of oxidation would be approximately the same as that predicted for typical operating conditions of a heat source, 50,000 hr at 1000°C.